The main results and summary of Drive Beam activities

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for the CTF3 operations team

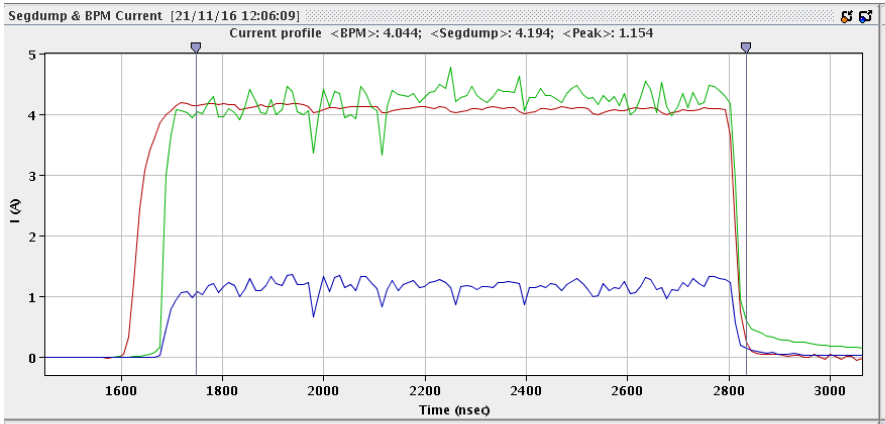
Caveat

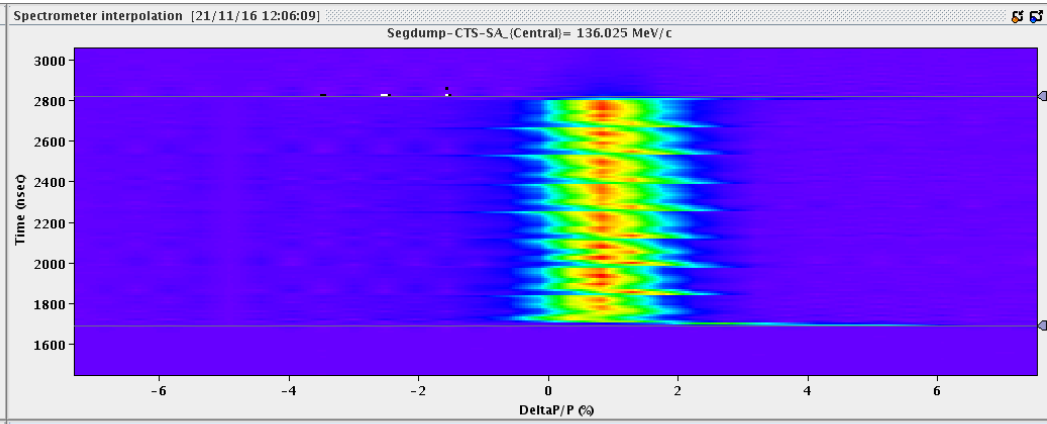
All the presented results for
emittance measurements are ***preliminary***

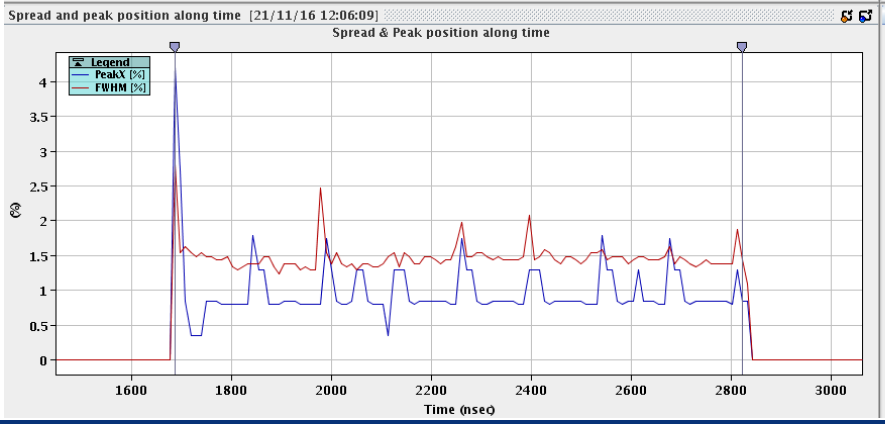
End of the Linac

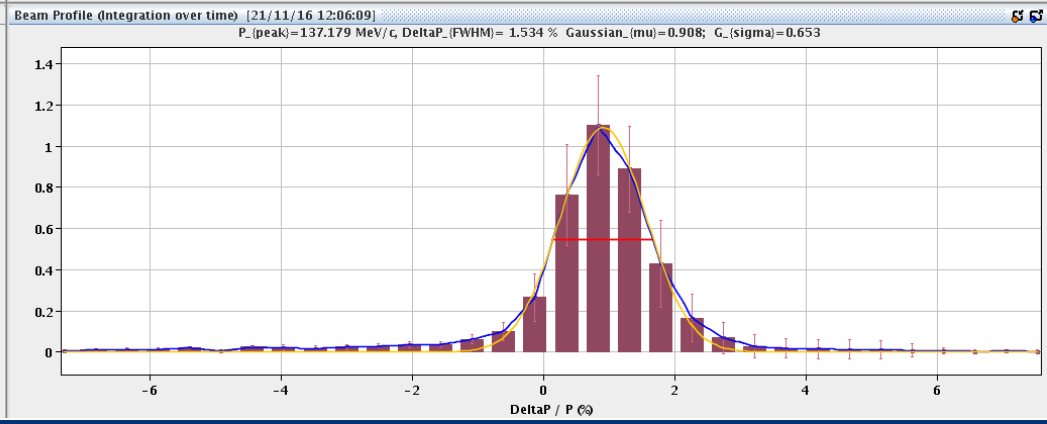
- Injector and Linac optimization gave
  - dp/p 0.7%
  - Bunch length 1.7 mm r.m.s
  - Emittance 60/40 mm mrad (H/V)

- ***Solenoids tuning***
- ***RF setup***
- ***Optics correction based on Quad Scan and re-matching***
- ***DFS***



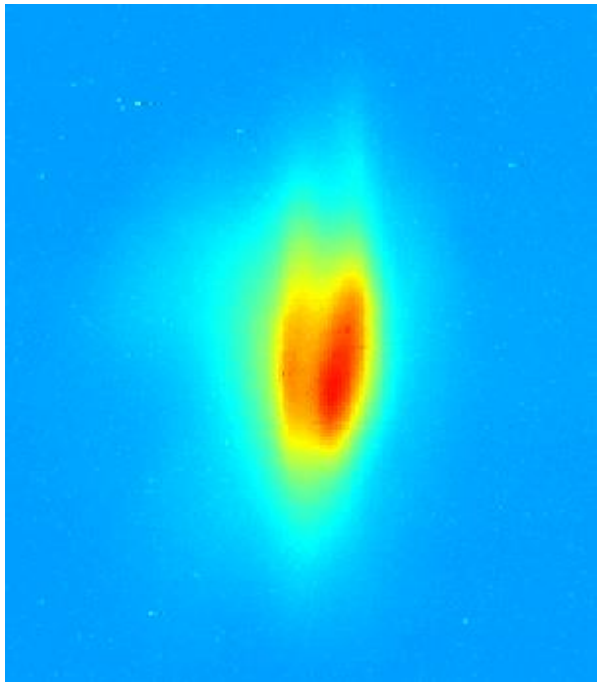




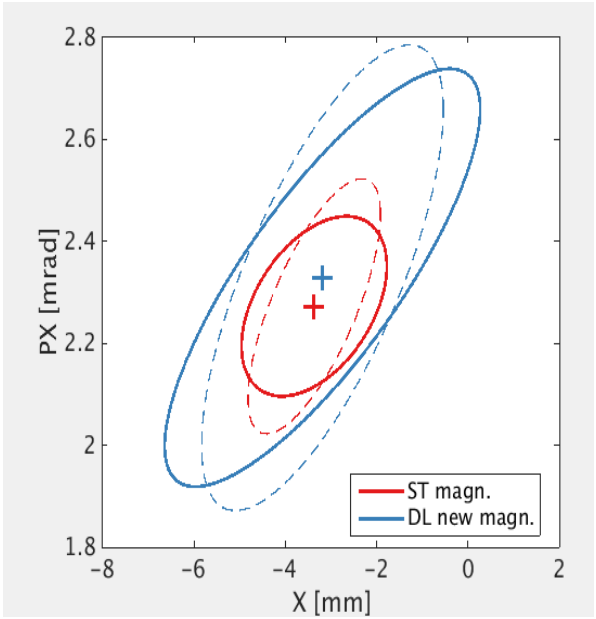


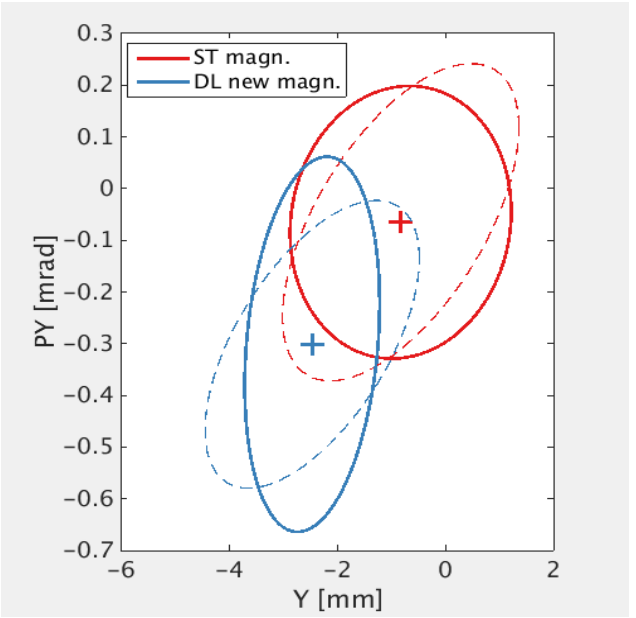
Combined beam emittance
The closure

- Perfect combined beam would be:
  - Same phase space ellipses
  - Same orbits



Combined beam on a screen (not perfect one)





Example Quad Scan results

Delay Loop emittance growth

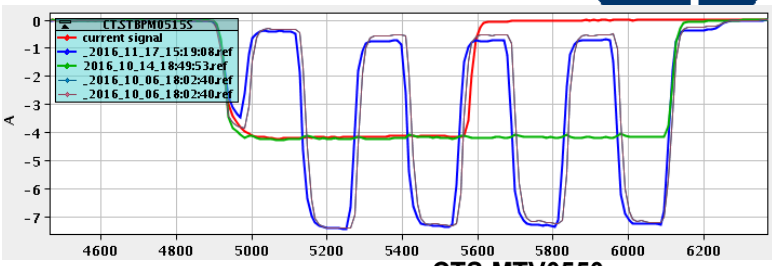
- Initially DL was increasing horizontal emittance from 60 to 250 mm·mrad
- Several correction methods applied
  (see the previous talk of Davide)
  - Dispersion Target Steering
  - Rematches based on Quad Scans
  - Model improvements using Phase Space Painting results
  - Direct corrections based on Phase Space Painting
  - **None of them was a golden solution, but each one brought some improvement**
- Interplay of corrections
  - For example, correcting dispersion affected orbit closure, & vice versa
  - The way to go: global correction (all in one go: Twiss, Dispersion and Orbit), but it was not feasible because
    - Model not accurate enough
    - Response matrix measurement for such system was too time consuming
      - klystron trips and machine drifts would spoil such measurement

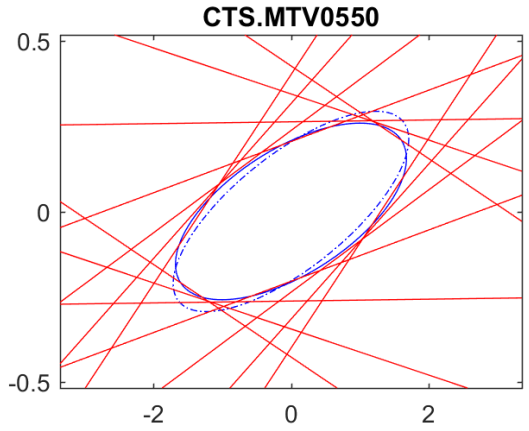
Delay Loop emittance growth

- The most effective turned out to be manual optimization looking by eye at profile on a screen
  - Setup straight beam such that it is the most narrow on the screen
  - For the delayed beam check quadrupole by quadrupole (and its combinations)
    see how they influence the spot
  - Find a setting that makes the straight and delayed beam similar
  - Measure emittance
  - Apply correction algorithms to fine tune Twiss matching, dispersion and orbit

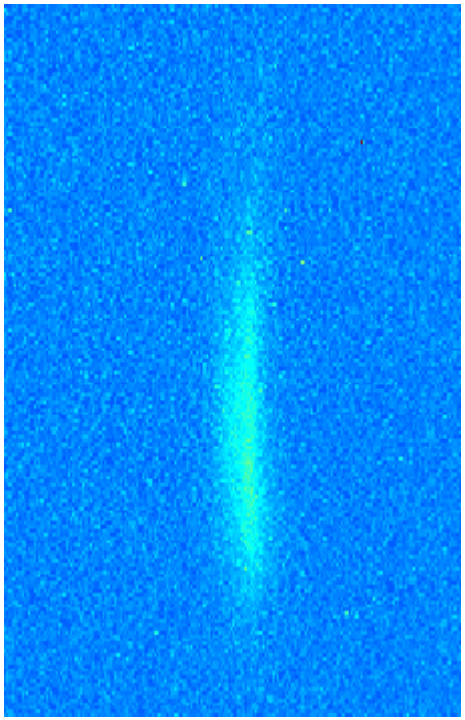
Delay Loop Combined Beam

- Emittance 92 mm·mrad
  for the delayed beam
- Combined beam below 100 mm·mrad

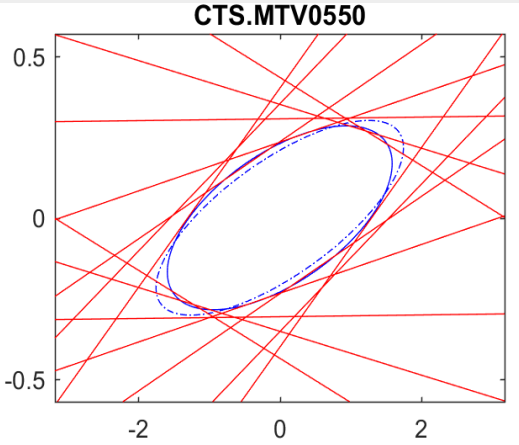




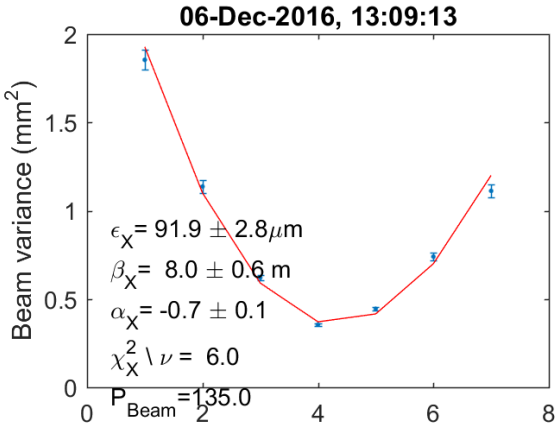
Delayed Beam

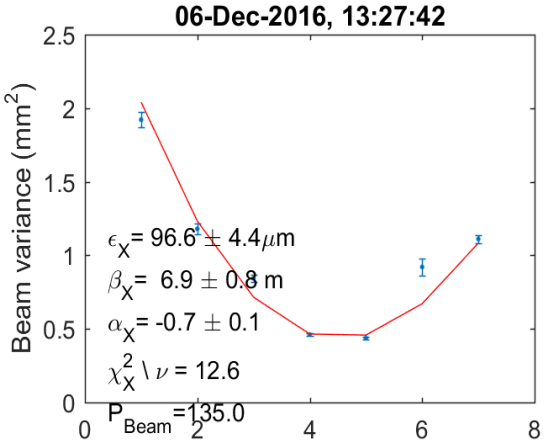


Combined Beam



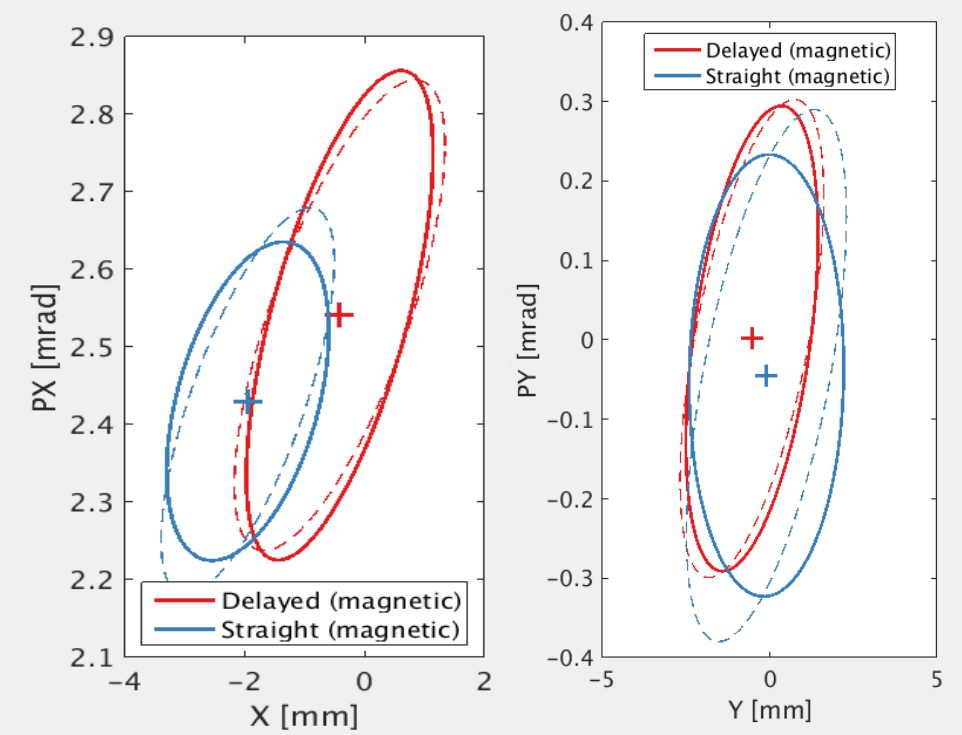
Combined Beam

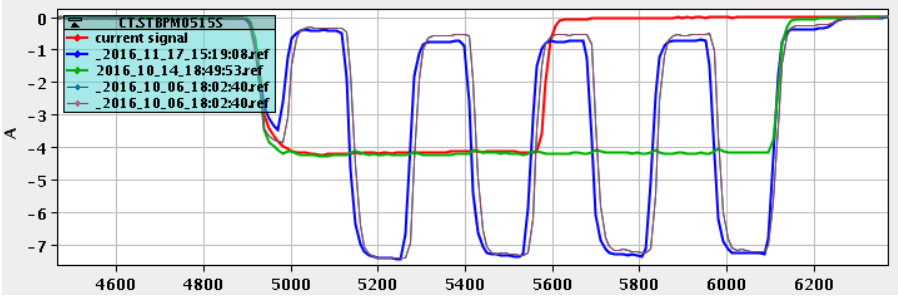


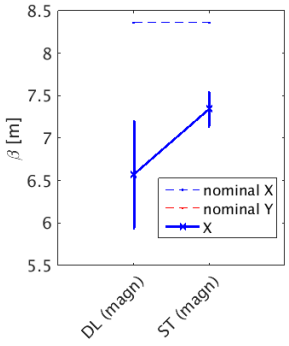


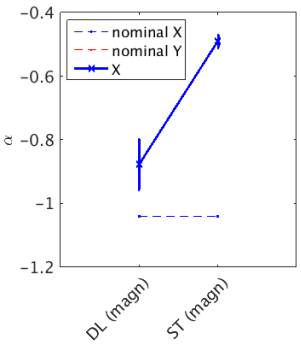
Delay Loop Combined Beam

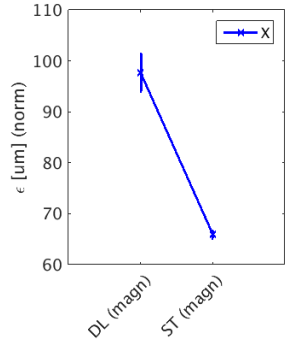
- CTS (spectrometer behind Delay Loop)





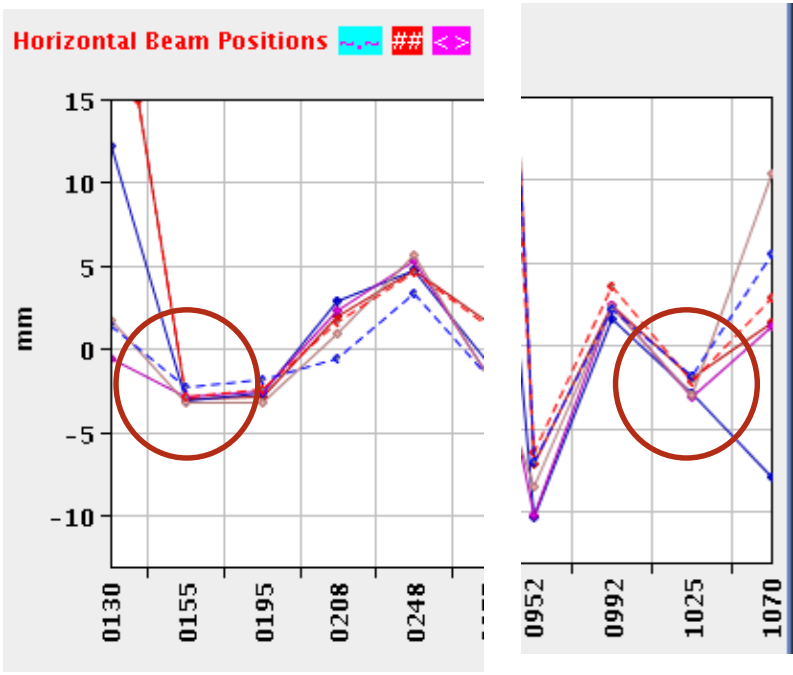






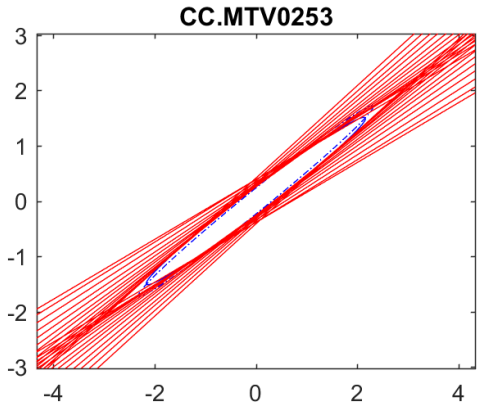
Combiner Ring

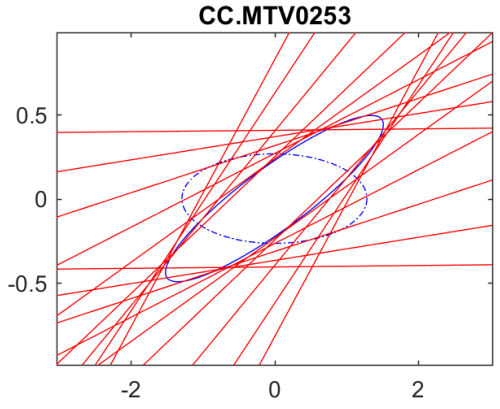
- Weaker and easier optics
- The beam can be stored for many turns
  - More turns the beam makes the better it is
- The model was much more accurate compared to DL
  - Because it was easier to measure and correct
  - Multi-turn helps: more types of measurements and higher accuracy
- The key points
  - Dispersion Target Steering
  - Automatic orbit closure
  - Rematch in TL1 to inject on the closed solution
  - **Steering through the deflectors**
    - Misalignment of the deflectors leading to almost 2% beam deceleration over 10 turns

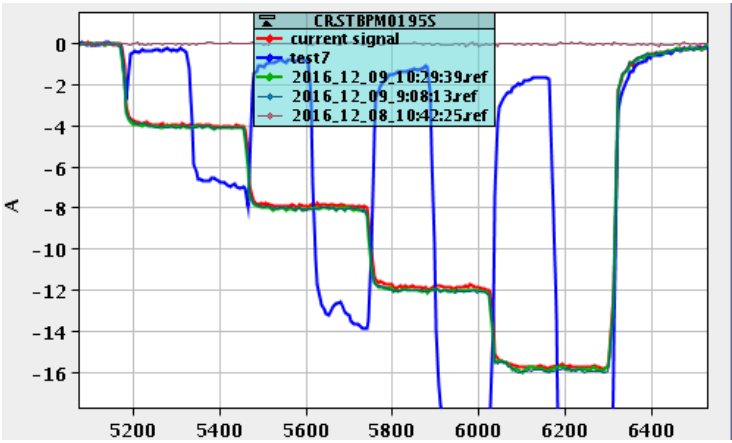


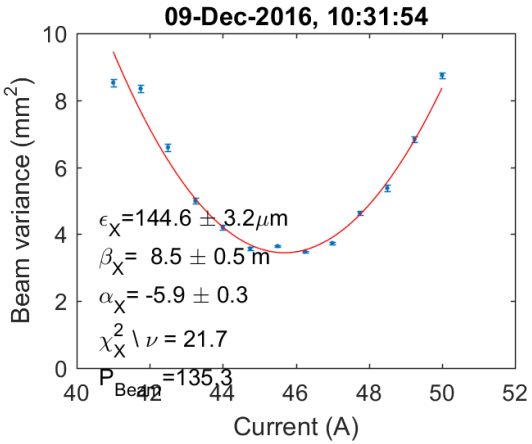
Factor 4

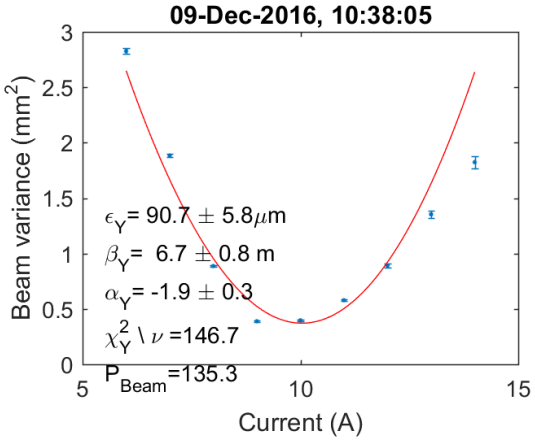
- 3 GHz beam below 150 mm·mrad target in both planes
  - H: 145 mm·mrad
  - V: 91 mm·mrad





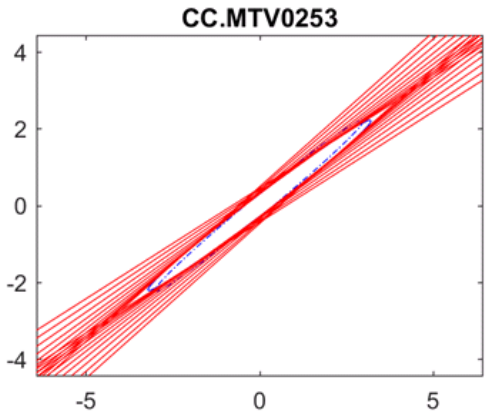


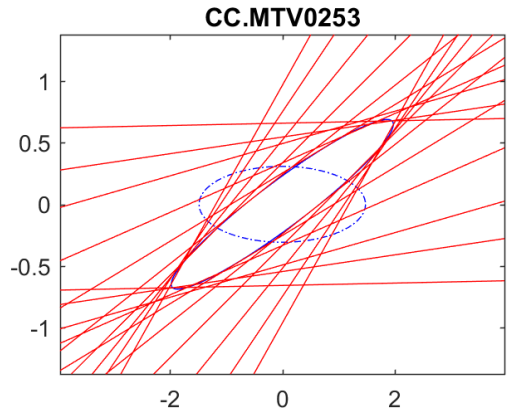


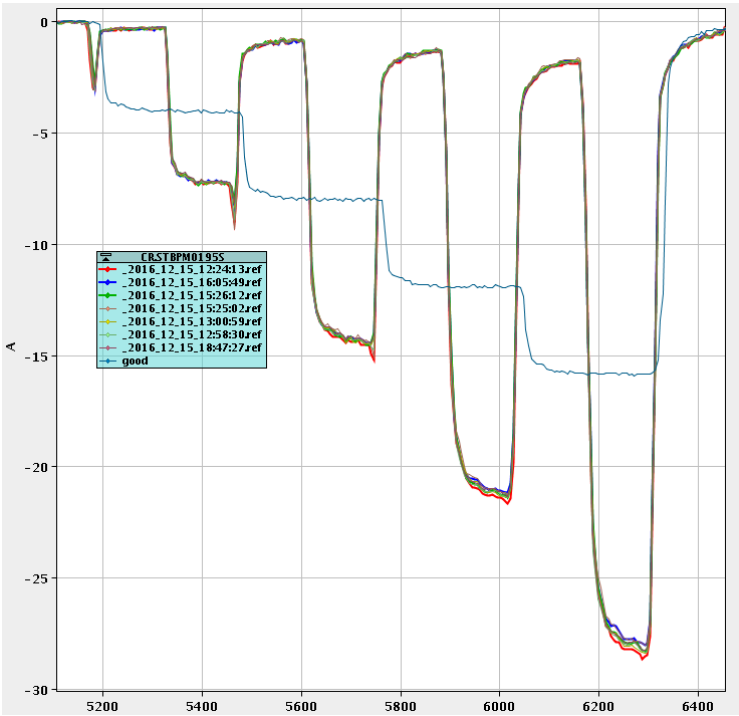


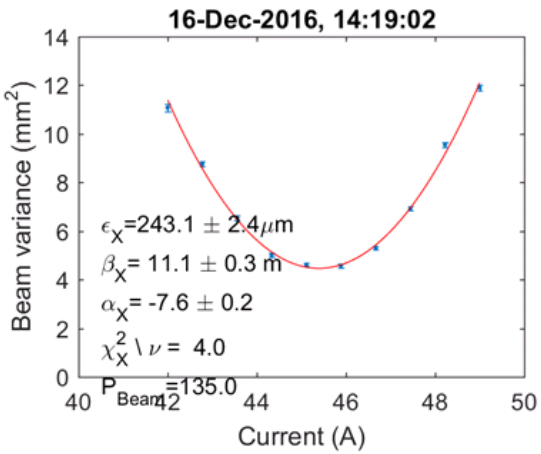
Factor 8

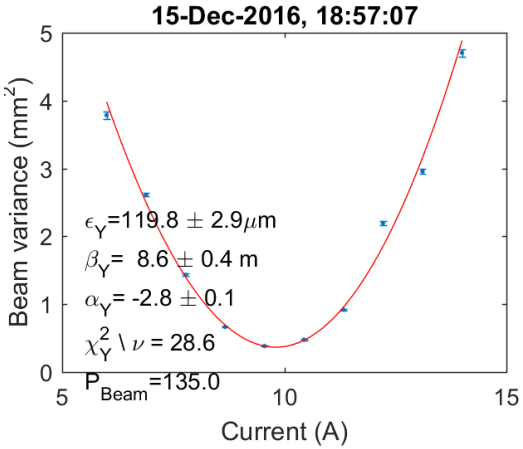
- Record measured factor 8 horizontal emittance: 243 mm·mrad
  - Many measurements below 260 mm·mrad





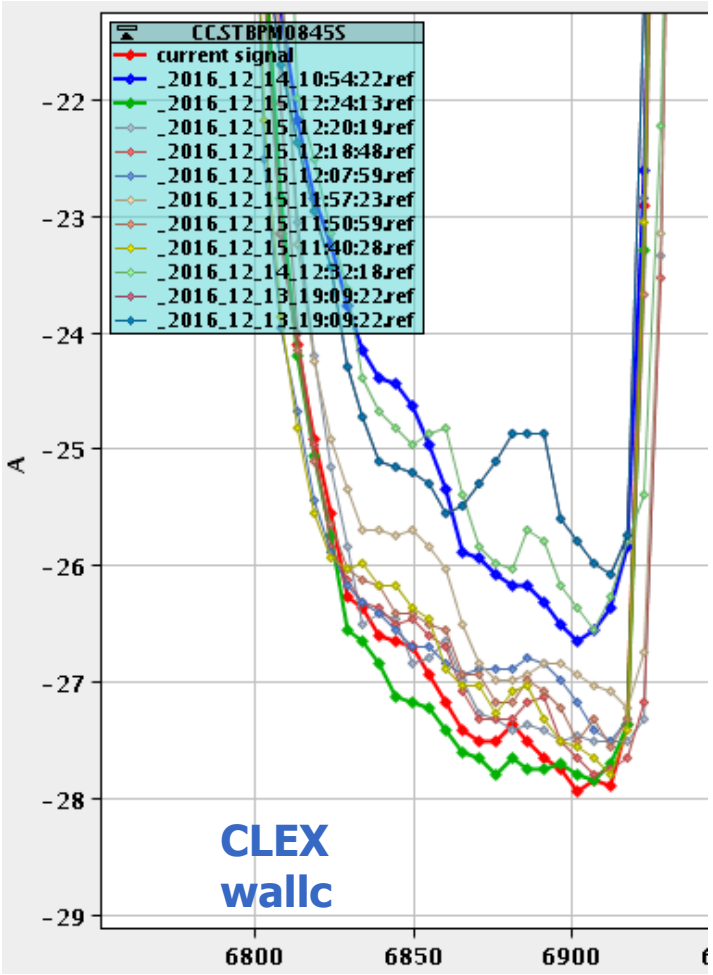


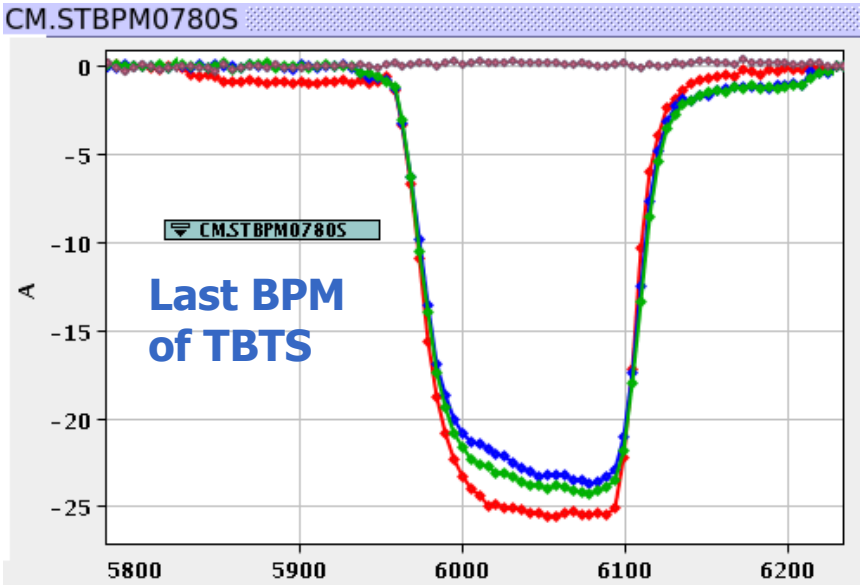




Losses

- Up to the CLEX wall basically no losses, but BPMs in CLEX recorded 1.5 A less



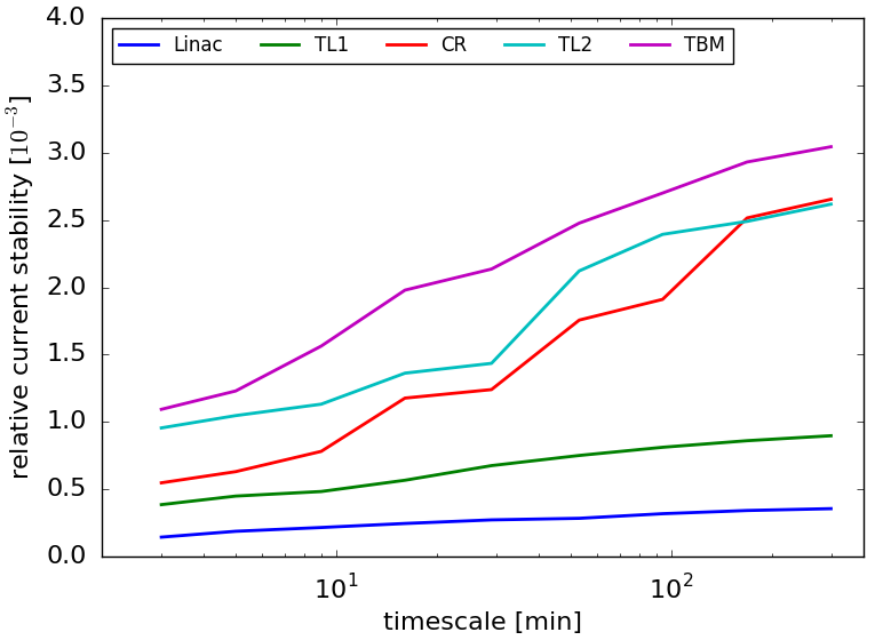


- Still, not certain how much due to losses and how much due to BPM calibration

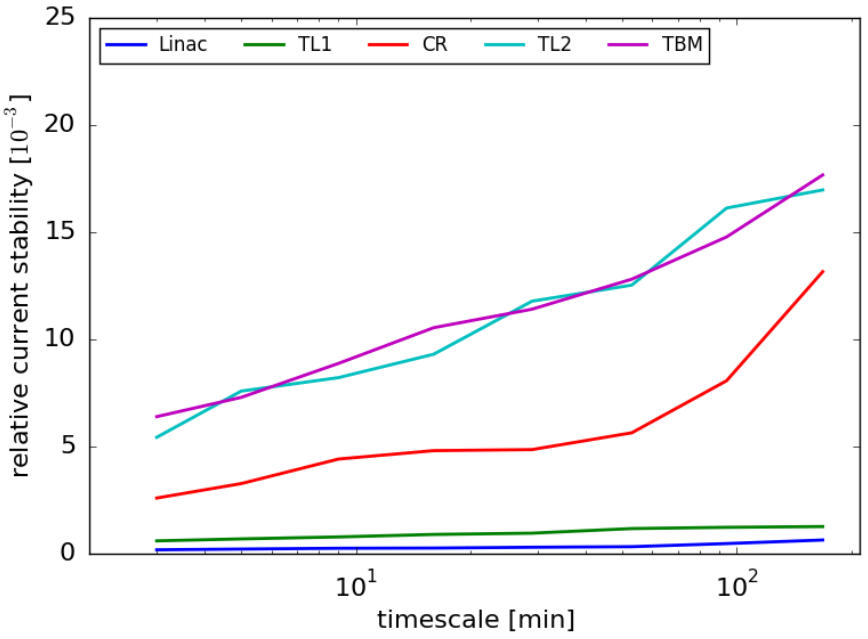
Stability

- Extensive study and optimization with factor 4
  - Improvements of feedback algorithms and associated hardware
- Unfortunately, not enough time with fully optimized factor 8 to perform full stability tuning
- Stability measurements of two beam acceleration and power production

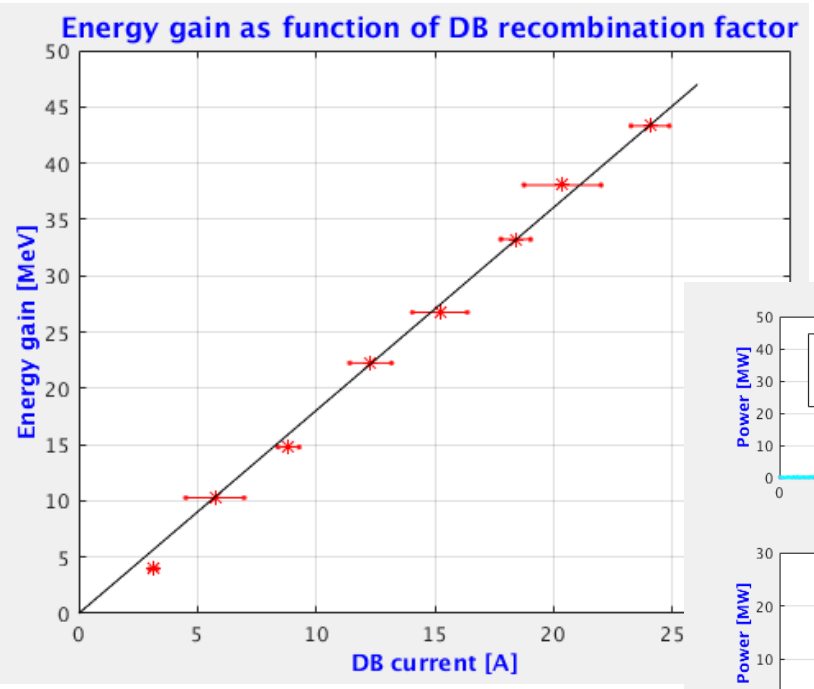
Factor 4



Factor 8

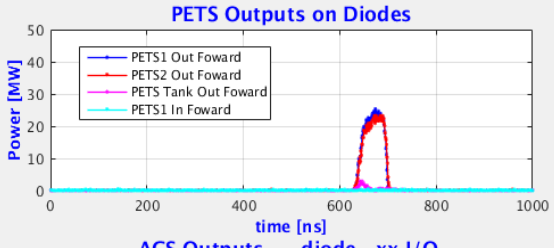


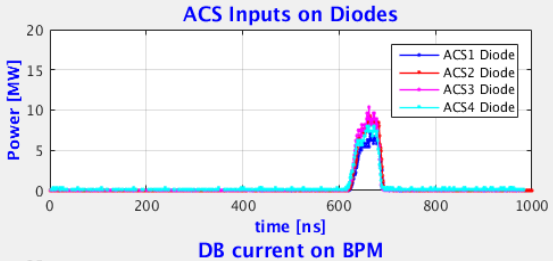
Two Beam Acceleration

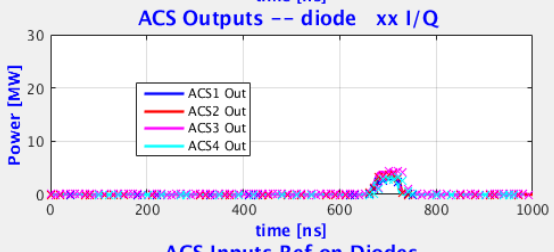


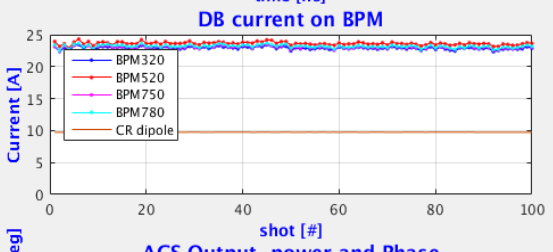
- Stable Drive Beam delivered to the Two Beam Module
  - Direct power production

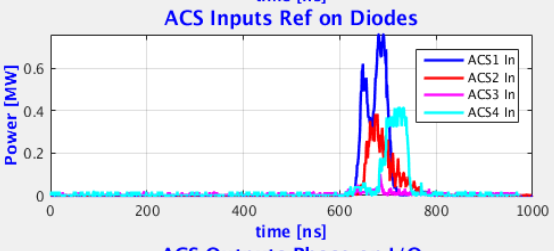
Form factor constant along combination factors

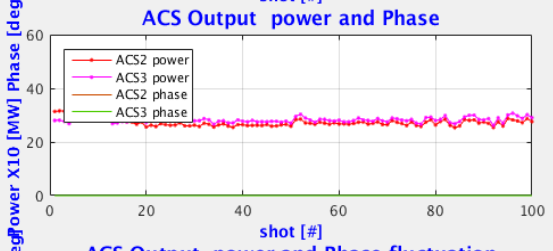


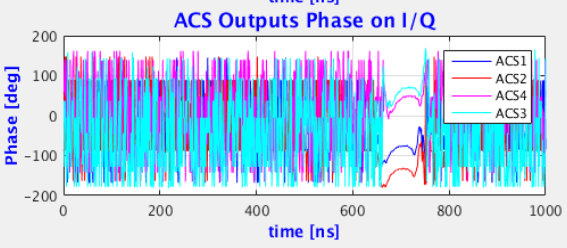


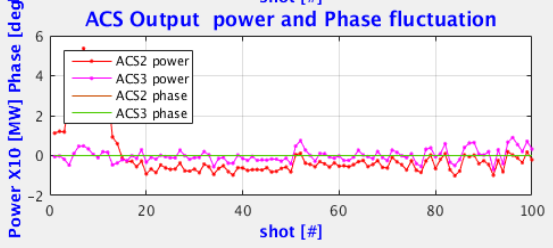








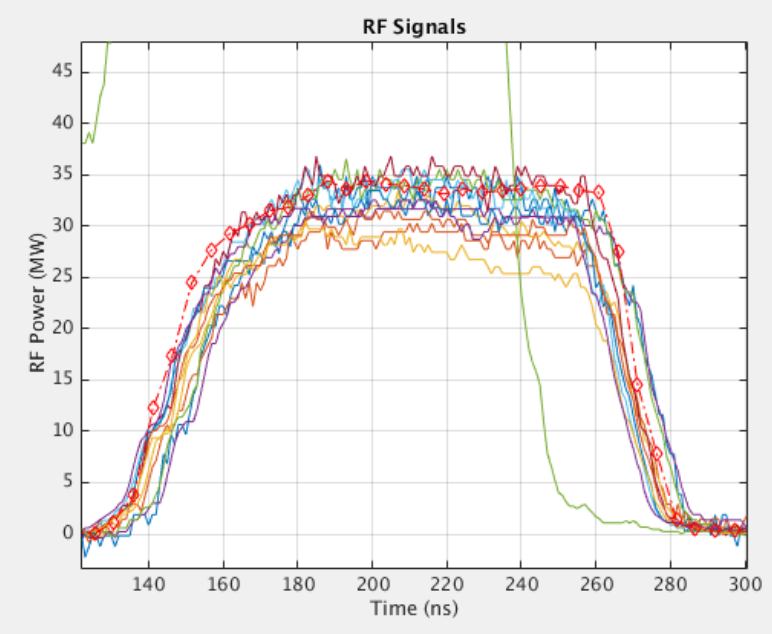




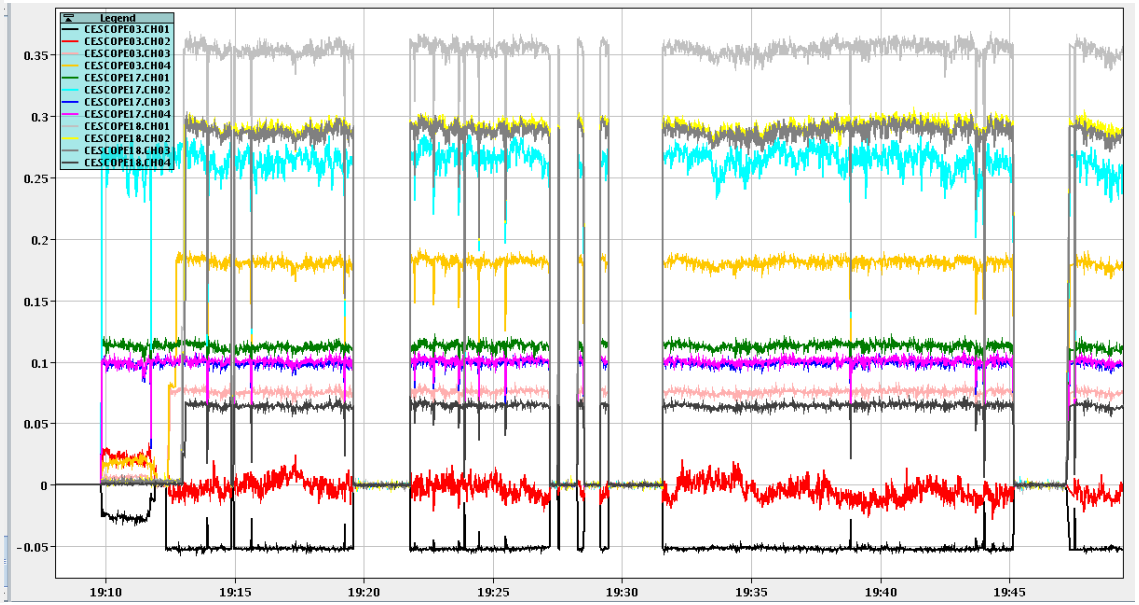
TBL

- Factor 8 beam for deceleration studies
  - Above 25A, good pulse shape
  - Beam current and RF power stability

- This time TBL did not beat the deceleration record (50%)
- Complete measurements of the incoming and the decelerated beam



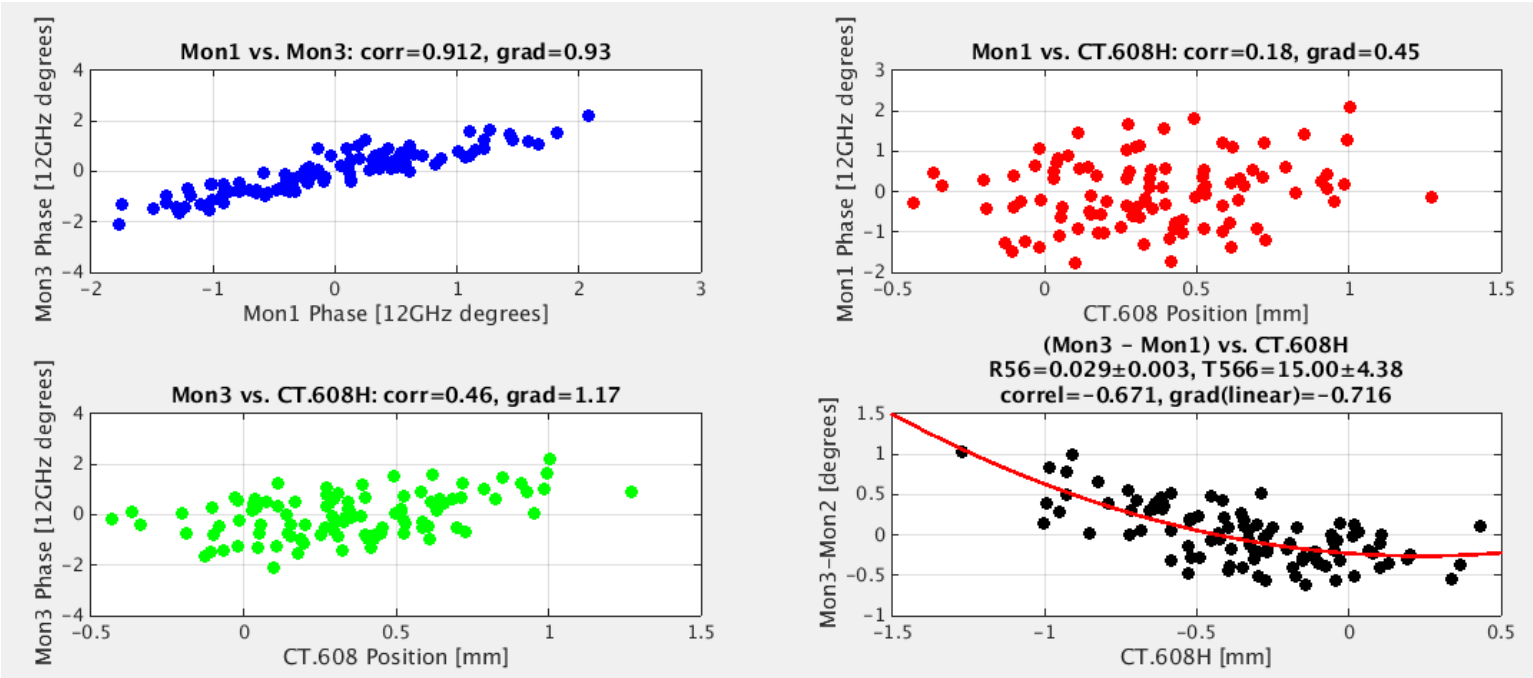
Produced RF power history (not calibrated)



Phase Feed Forward

- Feed forward requires that bunch phase does not change from the end of the Linac to CLEX
  - **So correlation between the phases is above 95% or higher**
- The main source of the extra jitter was from energy jitter
- Having R56=0 was crucial
  - **Achieved by fine tuning TL1 optics and bends in the ring**
- Still, the strong optics is very non-linear, so any energy drift spoils R56
  - **Injector & Linac feed-backs + energy feed-back were crucial**

CT.608H ~ energy
Mon1 → Linac
Mon3 → CLEX



Lessons for CLIC

- Drive beam generation and its use for two beam acceleration is feasible

- It worked well in CTF3
  - All key feasibility points were shown
  - Many extra points made and technologies developed
  - A few items, like the factor 8 beam emittance or stability, slightly below the CLIC specs, but

- Taking into account
  - 30 years old hardware not optimized for this purpose
  - The machine design (and in consequence the optics) constrained by the building and budget

    it could not get much better

- We learnt a lot,

  now we know how to make efficient drive beam for CLIC

Lessons for CLIC

- Optics can not be too sensitive to imperfections
  - Magnetic field errors and their nonlinearities
  - Misalignments
  - Orbit
  - Large energy spread and energy drifts

- Global corrections schema, i.e. correcting everything together, should be more efficient, but much more complicated, get prepared
  - Beam diagnostic allowing for fast response measurement simultaneously on
    - Emittance (together with Twiss beta and alpha)
    - Dispersion
    - Orbit

  It is needed to make the combined bunches the same
  - Specially important in case the model is not accurate enough

Lessons for CLIC

- **Everything drifts**
- Be prepared: feed-backs on all sensitive elements
  - If machine drifts then it is impossible to optimize it

- In CTF3:
  - FB: Phase and amplitude of the injector klystrons
    - The ones before compressing chicane
  - FB: Pre-bunchers also sensitive, but not as much
  - FB: Beam energy and flatness along the pulse
  - On demand FB: Beam orbit before the chicanes, the loop and the ring
  - FB: Phase loops (regulate klystron phase on measured RF phase)
  - FB: Beam loading of accelerating cavities (regulate phase loop)
  - FB: Gun current
  - FB: RF pulse flatness (not applicable to CLIC)

- Suggestion: feedbacks on Twiss (alpha/beta) and dispersion
  - Requires online (parasitic) or very fast optics measurement

Thank You!

- Backups

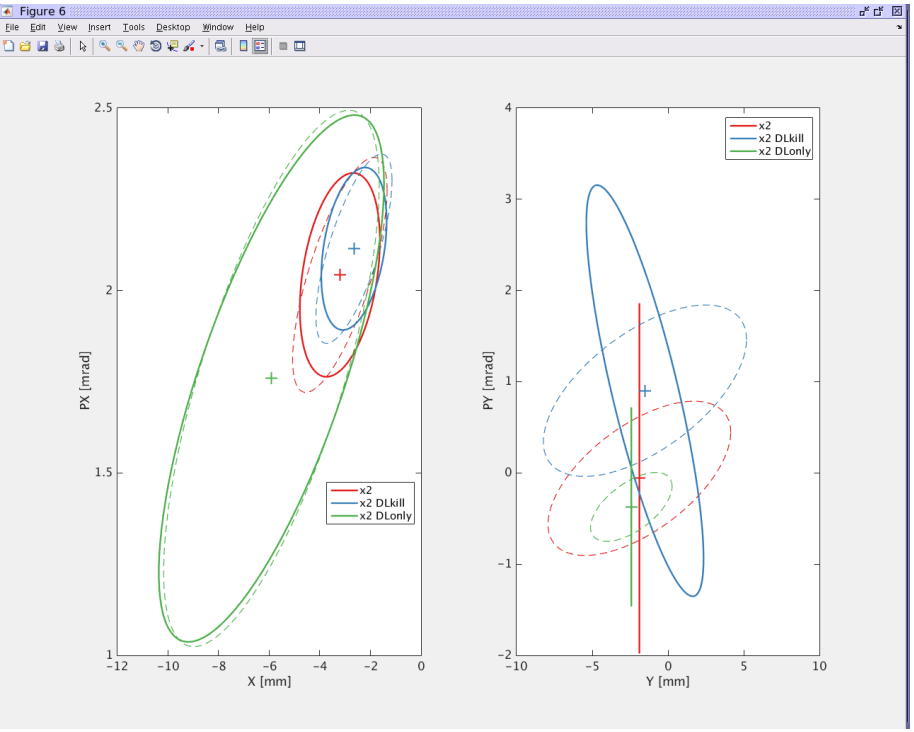


Figure 6
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x2
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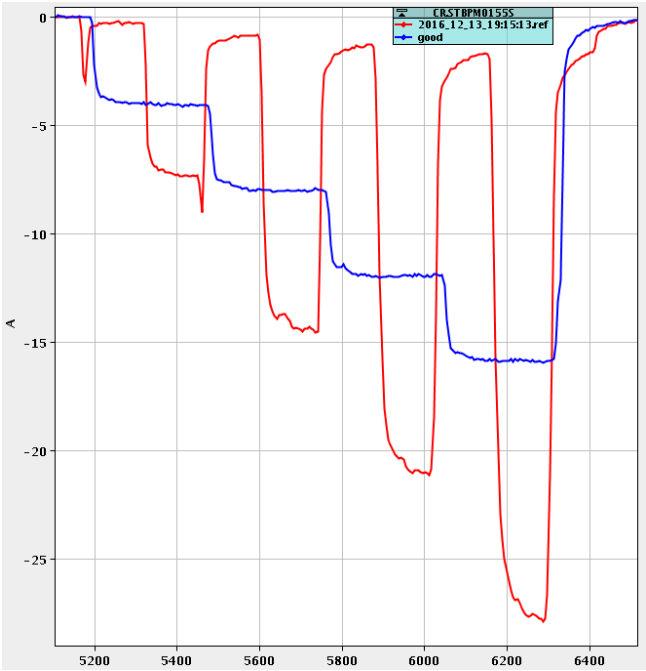
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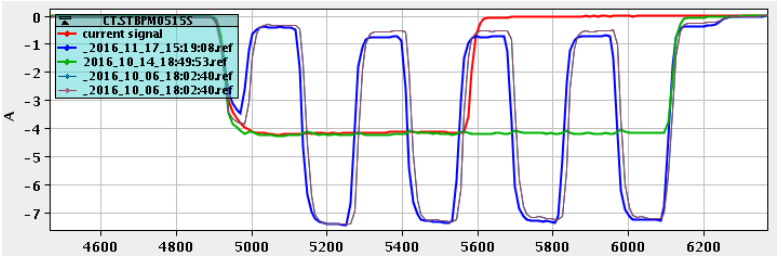
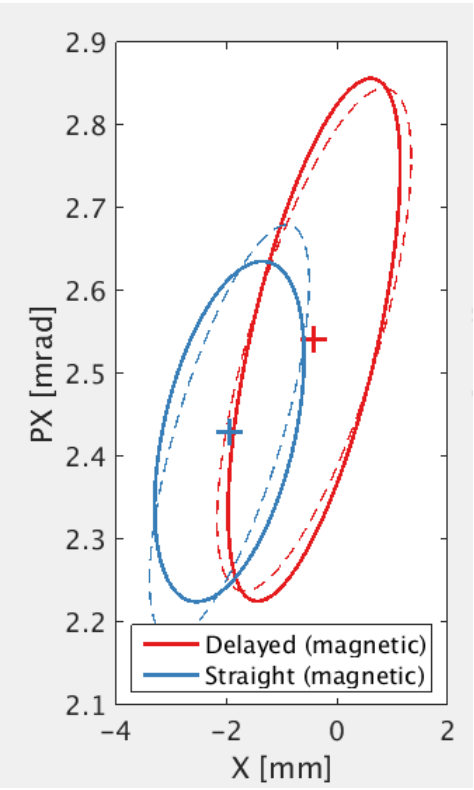
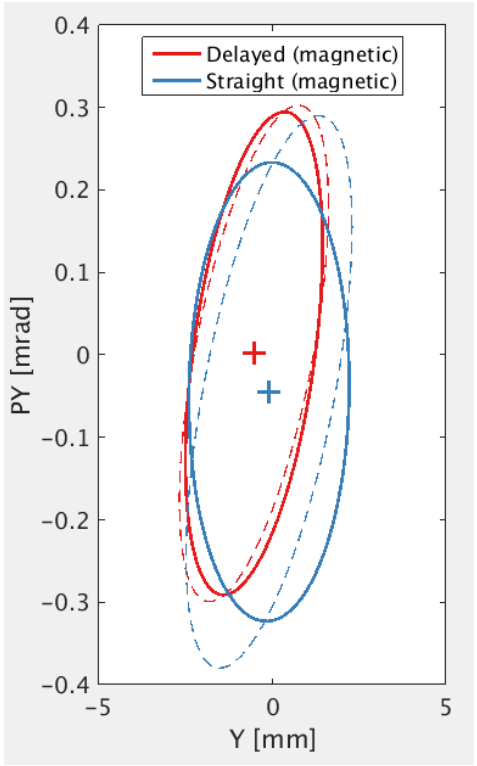
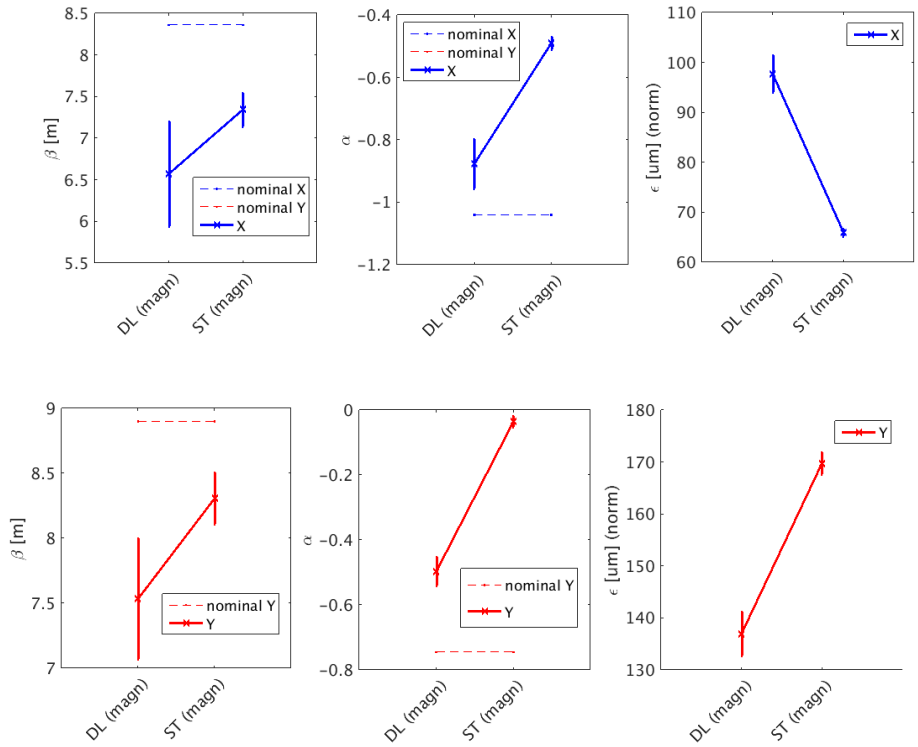
Delay Loop Combined Beam

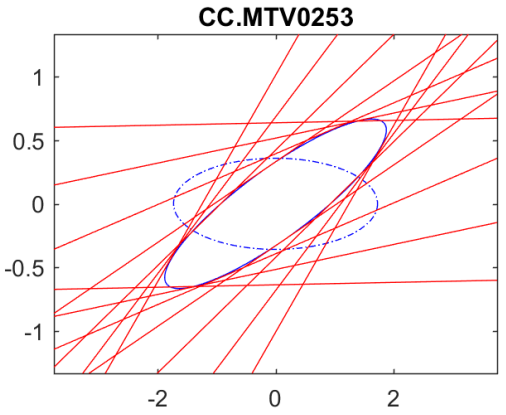
- CTS







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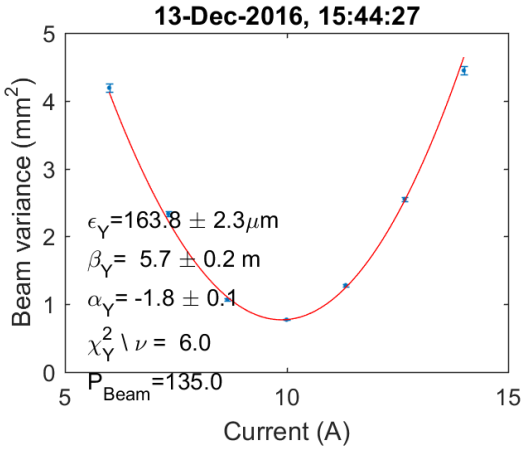
13-Dec-2016, 15:44:27
Beam variance (mm^2)
ϵ_Y=163.8 ± 2.3μm
β_Y= 5.7 ± 0.2 m
α_Y= -1.8 ± 0.1
$\chi^2_Y \setminus \nu$ = 6.0
P_{Beam}=135.0
Current (A)
0
1
2
3
4
5
10
15