Caterina Biscari, Yu-Chiu Chao, Roberto Corsini,
Anne Dabrowski, Steffen Doebert, Andrea Ghigo,
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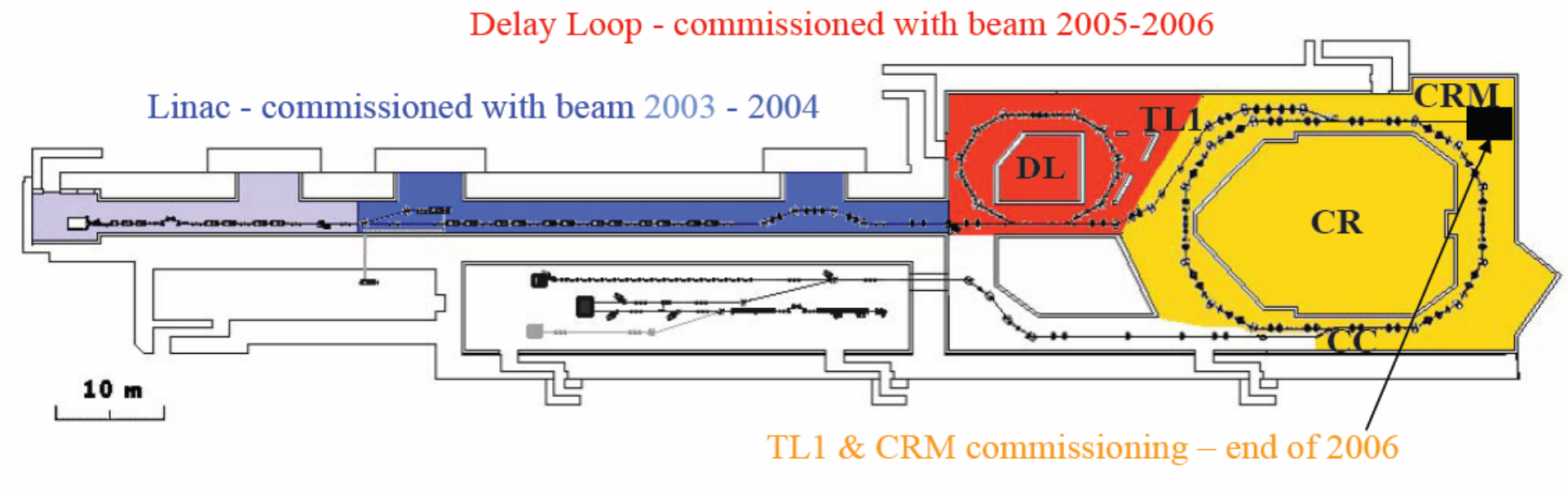
Frank Tecker, Peter Urschütz

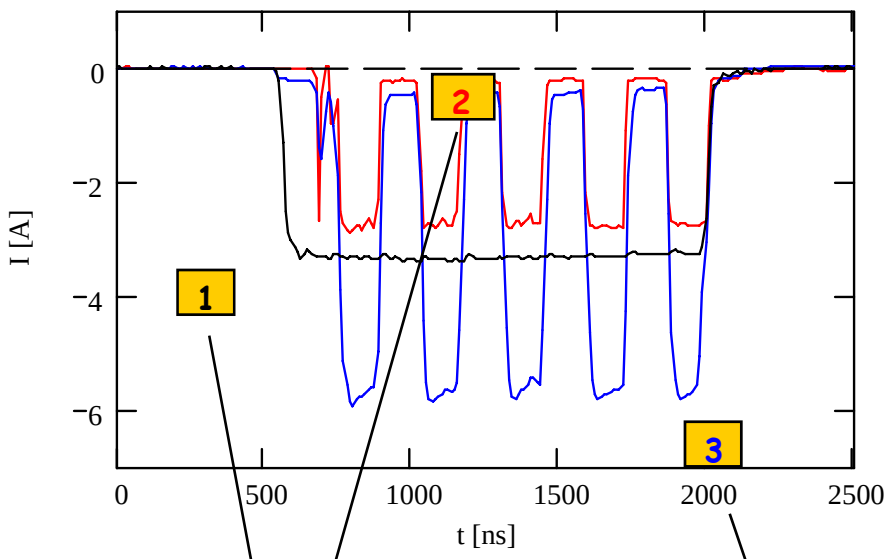
CTF3 in 2007
CR Commissioning Status
Operations and Activities

CTF3 Collaboration Meeting
CERN 21 January 2008

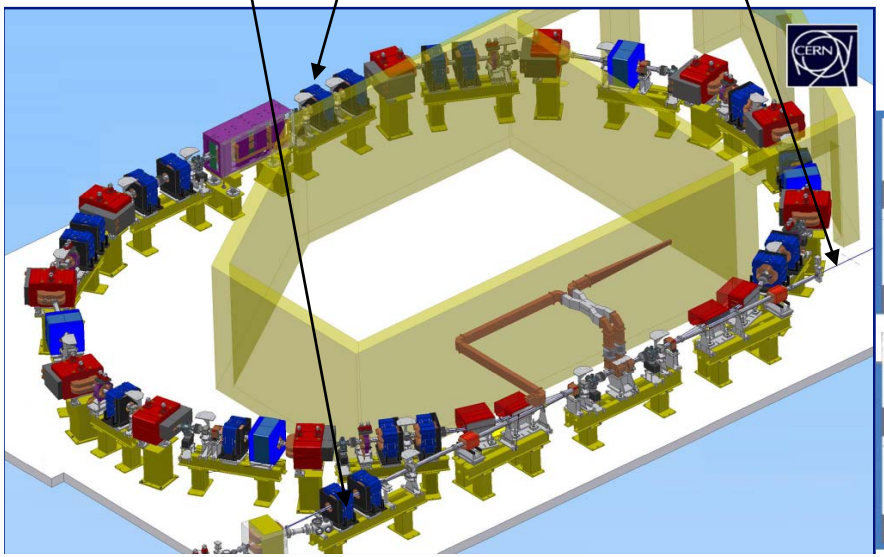
CTF3

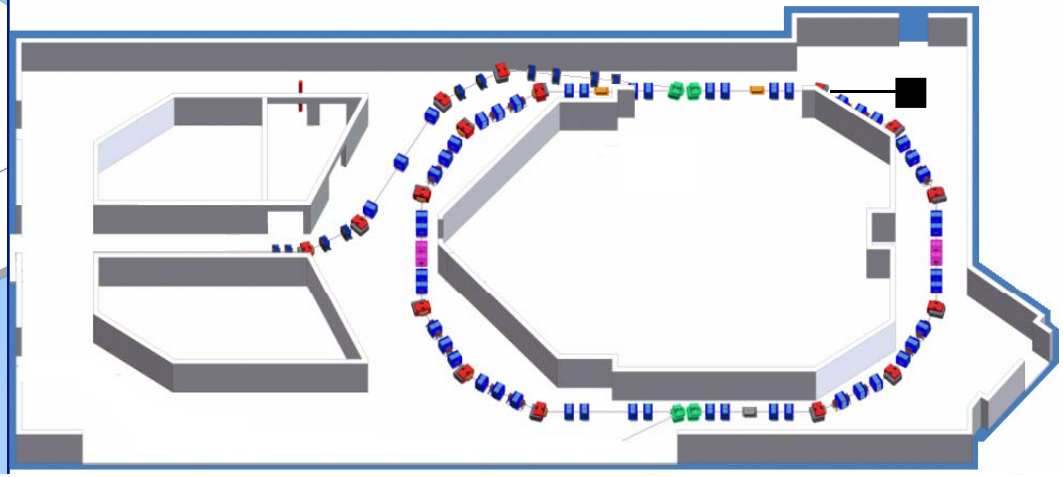

Delay Loop - commissioned with beam 2005-2006
Linac - commissioned with beam 2003 - 2004
TL1
DL
CR
CRM
CC
10 m
TL1 & CRM commissioning – end of 2006

Main points achieved in 06



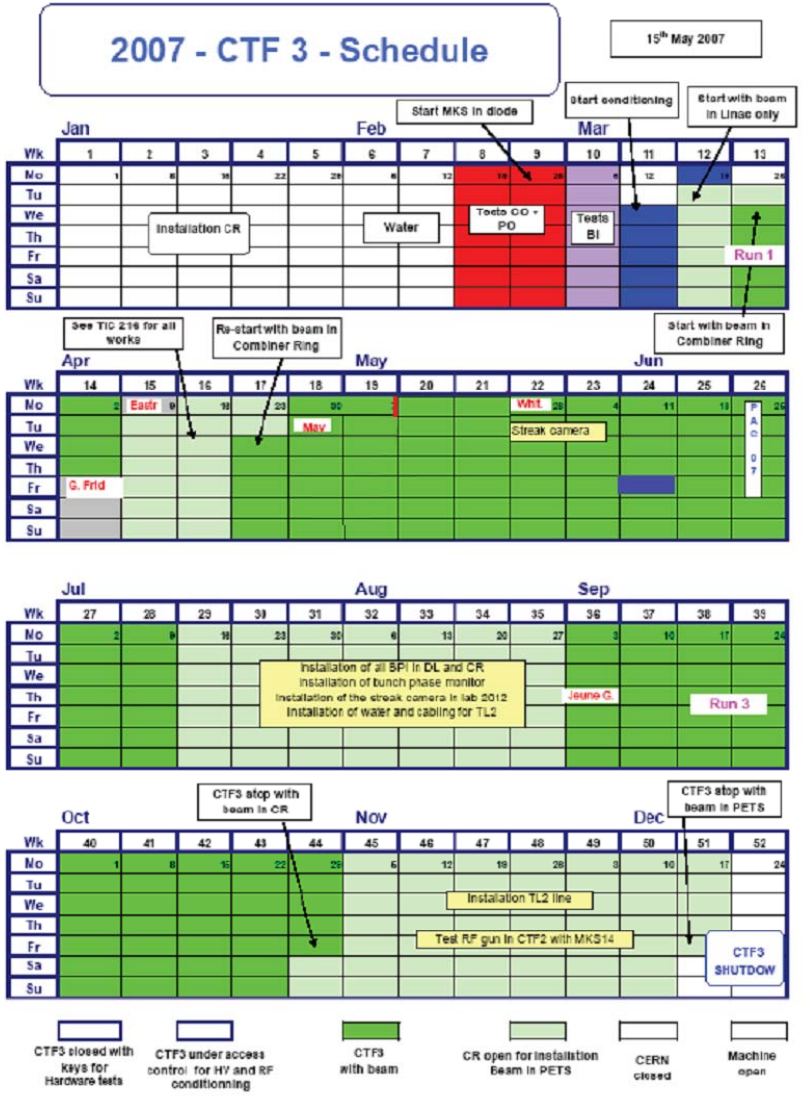
- Delay Loop Commissioned
  - 7A after DL
  - 1400 ns pulse length
- TL1 and CR injection Commissioned
  - 3.2A in TL1, 3A in CRM
  - 3GHz beam
  - Nominal optics in TL1
  - RF injection to CR



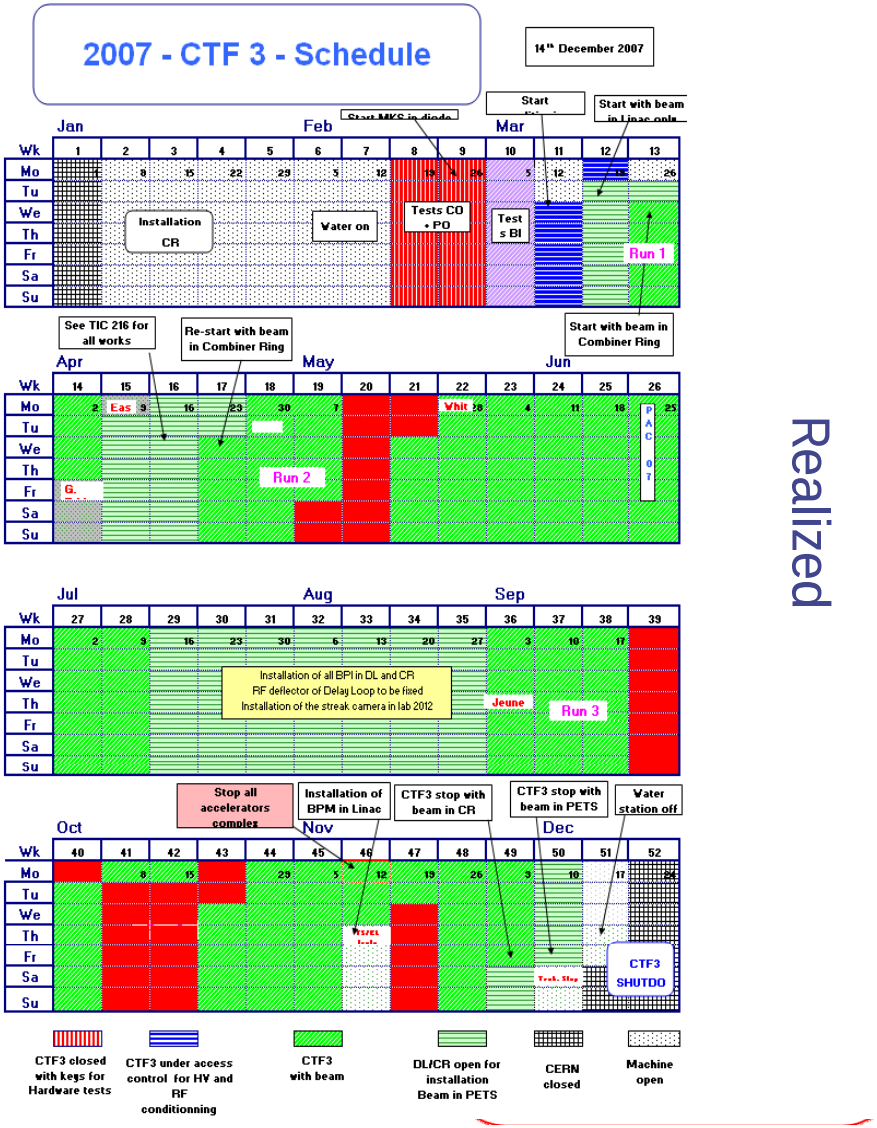


Schedule

Planned



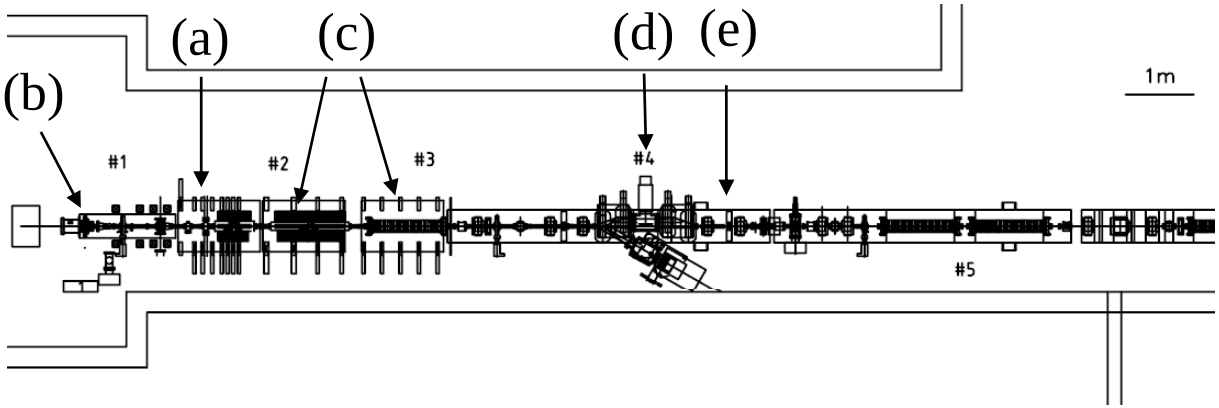
Realized



Beam setup procedure
Linac to girder 4

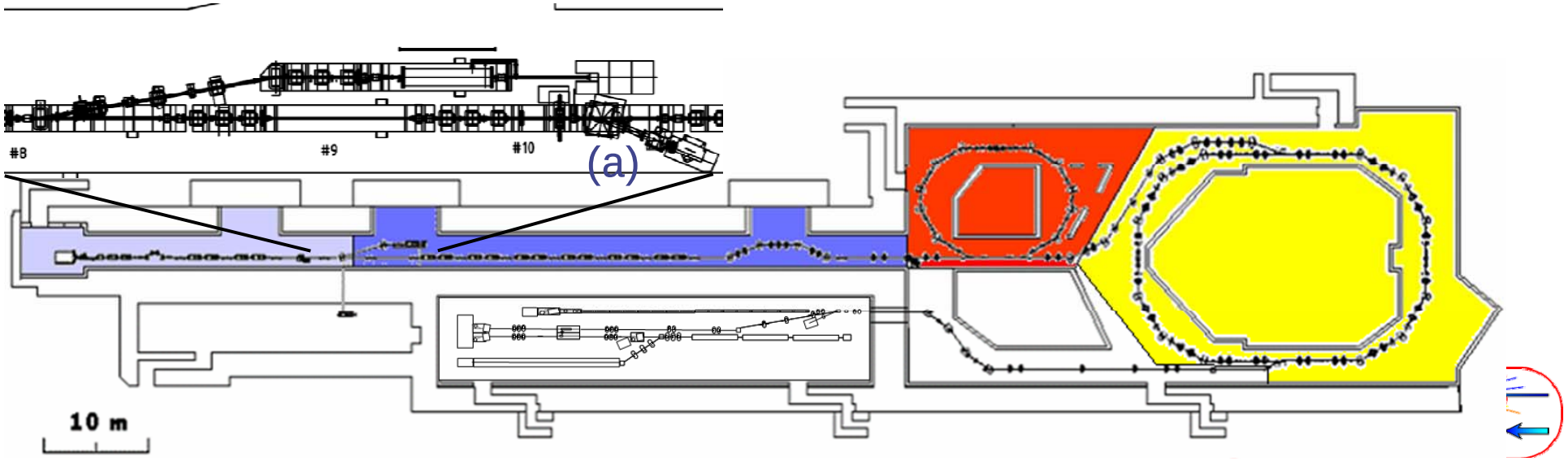
- We start with 3GHz (more stable) beam
  - Traveling Wave Tubes (TWTs) off (a)
- Adjust
  - The gun (b)
  - Phases of klystrons 2 and 3 (c)
  - The compressor chicane (d)
    - Current in bends
    - The slit gap

  to get 4-5 A beam after the chicane (e)



Beam setup procedure
Linac to girder 10

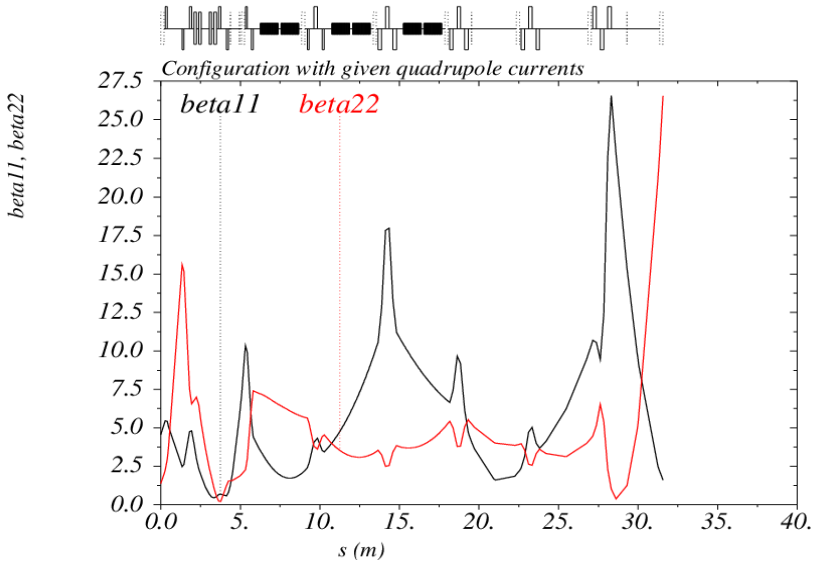
- Adjust the phase of MKS05
- Get somehow the beam up to spectrometer 10 (a)
  - Usually by scaling up and down all the quadruples together
- Beam measurements at spectrometer 10
  - Energy with the slit dump
    - Vary the bend current to get maximum signal
    - Having current-momentum coefficient for this angle one gets energy
  - Twiss parameters using quad scan
    - We vary quad strengths and measure beam profiles at screen MTV1026



Beam setup procedure
Optics Calculation

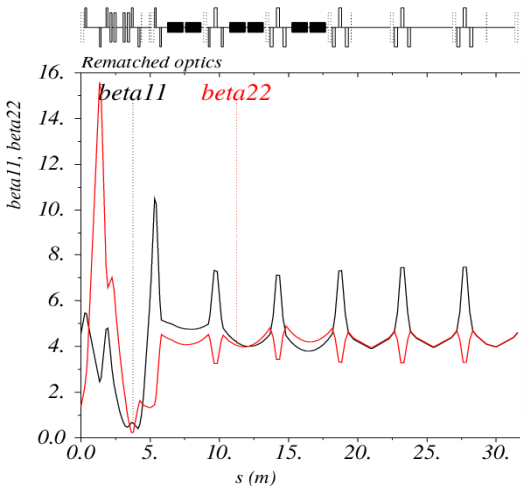
- Having
  - The energy profile along the whole linac
    - Having input power to each of the accelerating structures and knowing beam current one calculates acceleration in each cavity
  - Twiss parameters at certain location

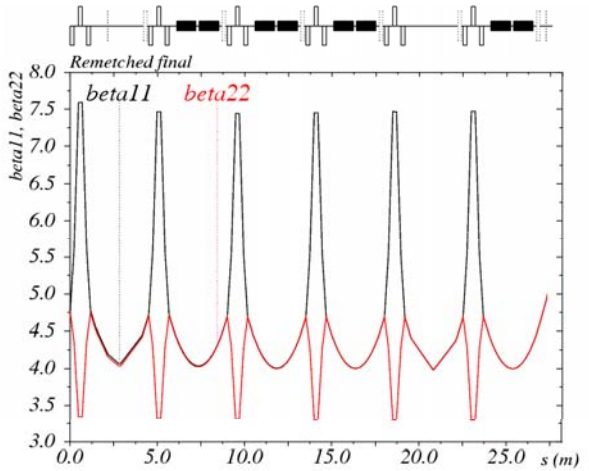
    we can calculate the optics along the machine
- We have the design optics however the exact magnet setting depends on
  - Beam provided by the injector
  - Energy profile that depends on the klystrons power

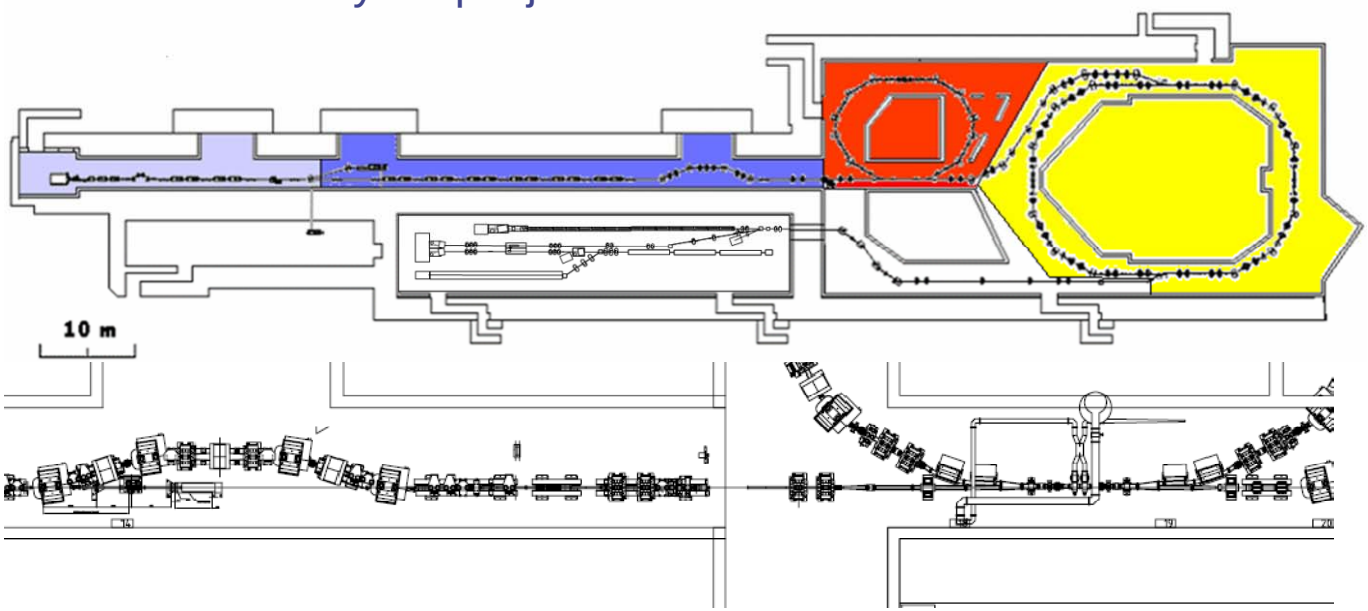


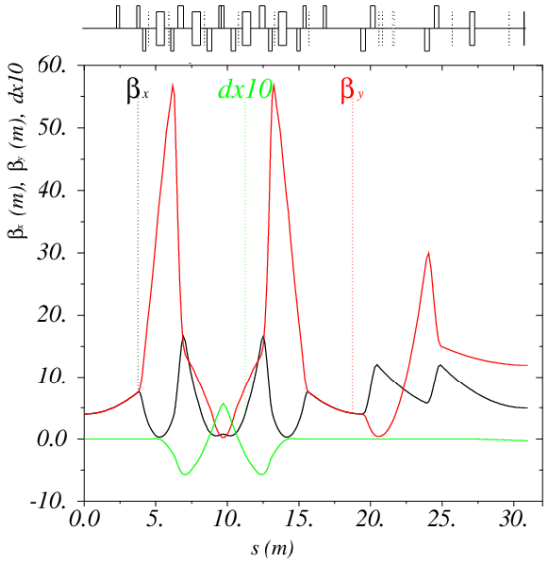
Beam setup procedure
Linac rematch

- Knowing Twiss parameters at the end of the buncher rematch the whole linac up to the Delay Loop to the nominal optics
- Adjust
  - phases of klystrons from 11 to 15
  - bends in
    - The stretcher chicane
    - Delay Loop injection



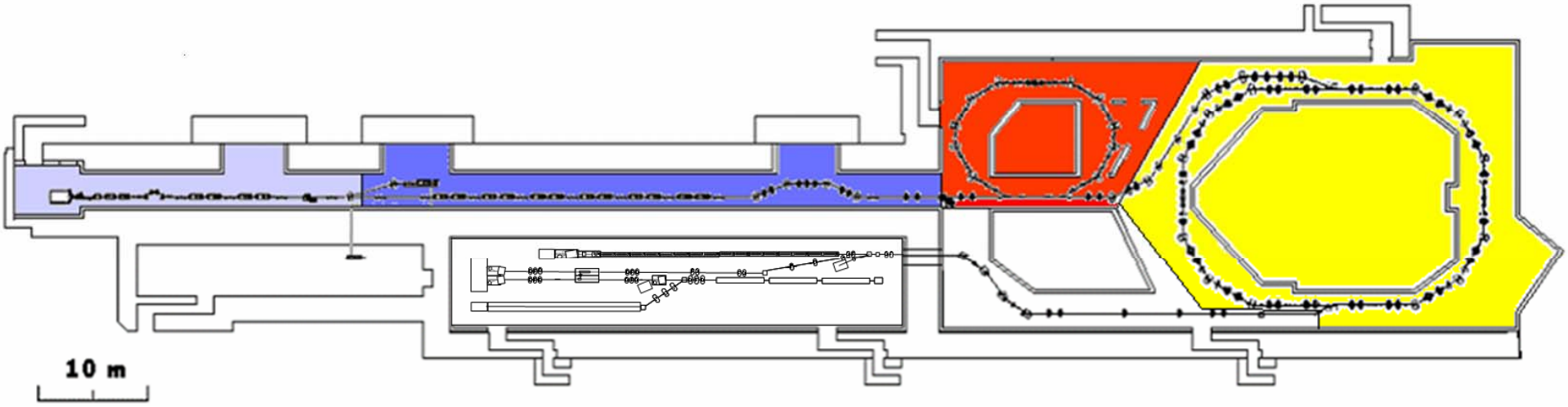






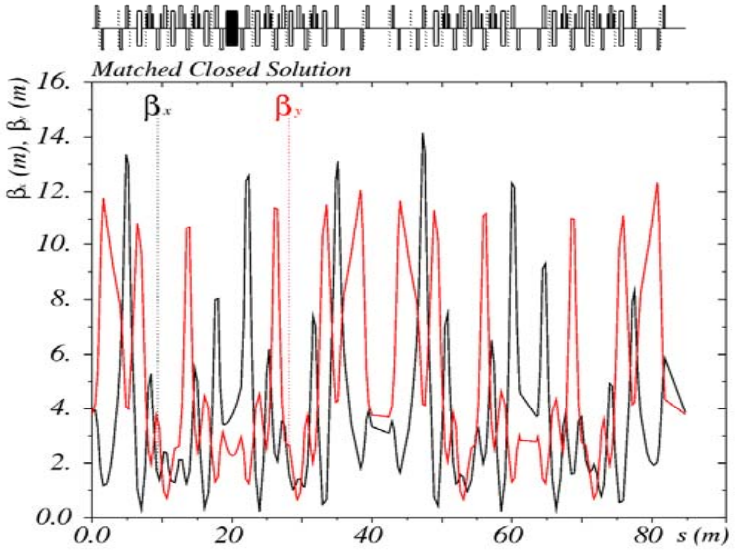
Beam setup procedure
Optics Verification

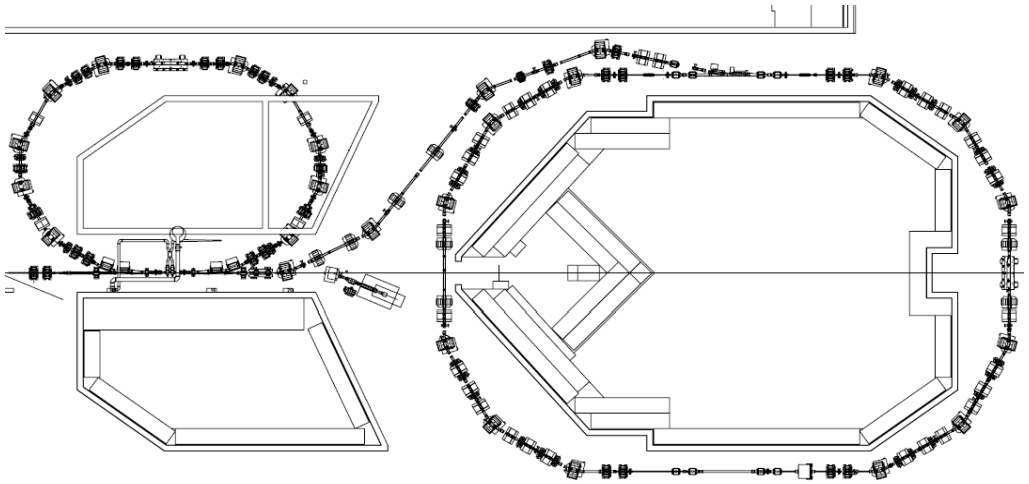
- Perform quad-scans at
  - Spectrometer 10
    - To verify the rematch
  - Beginning of TL1
- Depending on the obtained results rematch whole or part of the linac
- Check if the obtained energy agrees with the bends settings

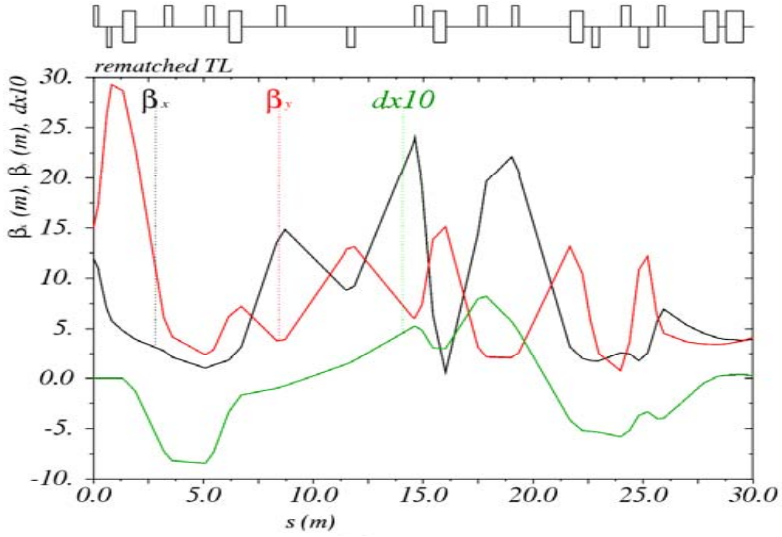


TL1 and CR optics

- Adjust the optics in the Combiner Ring to
  - The beam energy
  - Wiggler current
- Calculate isochronous optics in TL1 to match CR

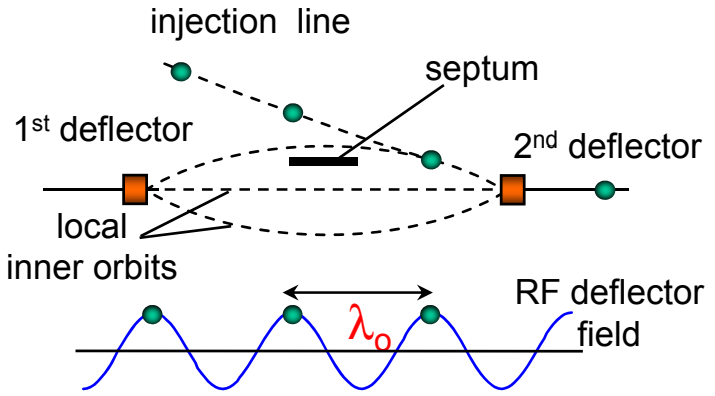


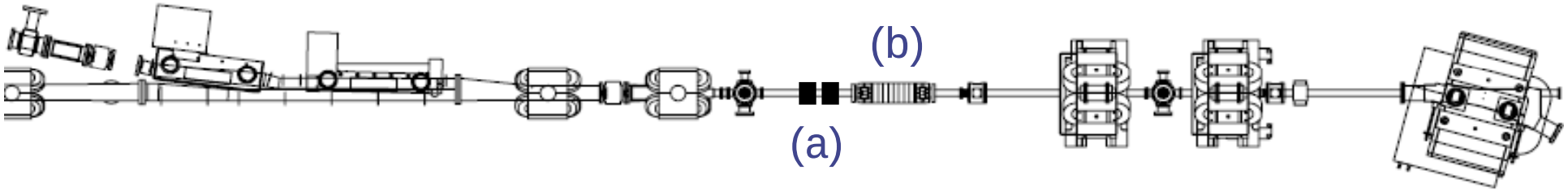




Beam setup procedure
CR Injection

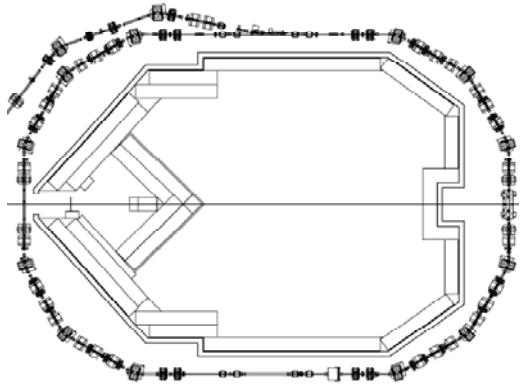
- We start with static magnetic injection using two horizontal correctors (a)
  - It allows for only one turn in CR
- Setup the septa and the orbit
- Switch to the injection with the RF deflector (b)
  - It is an iterative procedure that involves the following steps
    - Set RF power (amplitude)
    - Find zero crossing phase of the RF deflector
      - It leaves the orbit unchanged
    - Set the phase +/- 90 and switch off the correctors
    - If kick is too weak or to strong adjust the power
      - It changes the phase

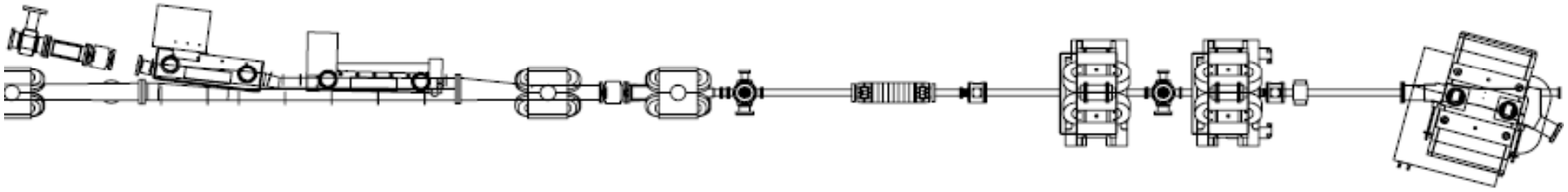




Beam setup procedure
CR Injection

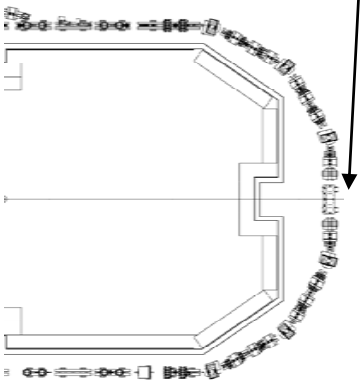
- To setup a good injection and orbit
  - Short train is injected (~140ns)
  - RF is switched off just after the last bunch is injected
- It allows for long lasting beam circulation in the ring
  - Then it is easier to find a closed orbit
  - It makes possible to apply orbit correction procedures more efficiently
  - Allows to measure the tunes precisely

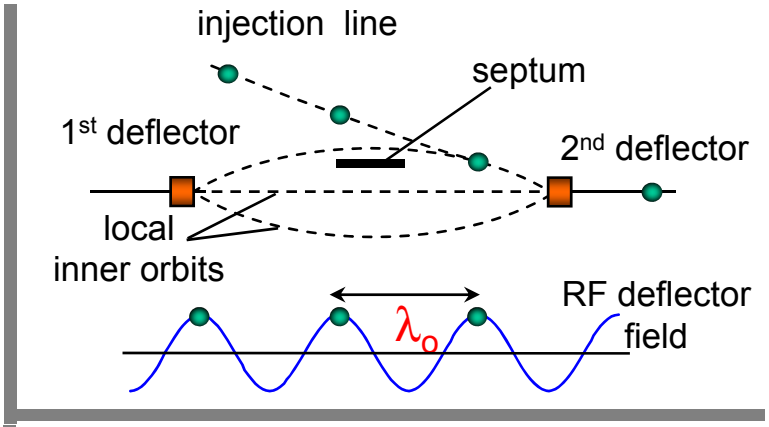


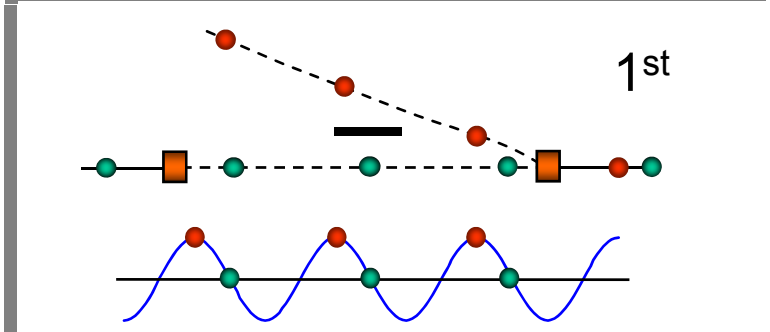


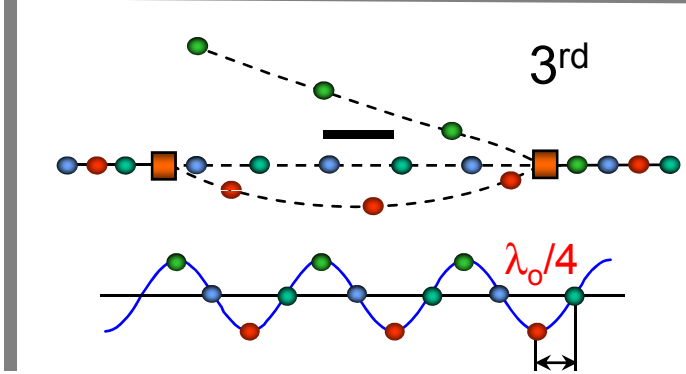
Orbit length in CR

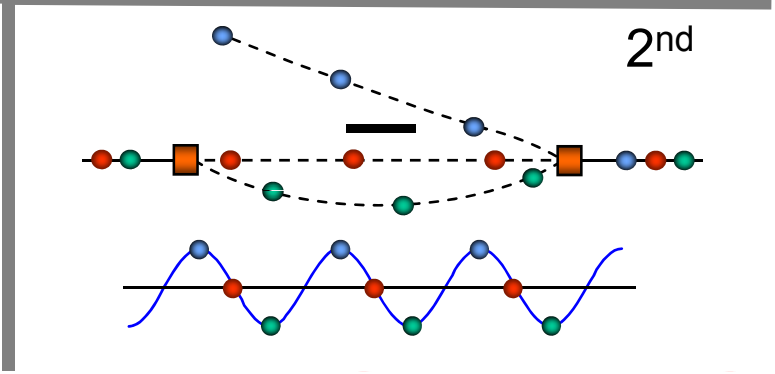
- The orbit must have the length
  $C_r = (n_t \quad ¼)\ \lambda$ *(it is „-" in our case)*
  so the beam arrives exactly
  - 1st turn: at zero crossing phase
  - 2st turn: at the crest
    - But opposite amplitude than at the injection
  - 3st turn: at zero crossing again
- Adjust the length with the wiggler











Beam Setup

- In theory the whole procedure could be completed within a couple of weeks
  - If, and only if, the machine is
    - Stable
    - Reliable
- Whenever any device changes its parameters the procedure needs to be restarted from the point the device sits!

Run 1

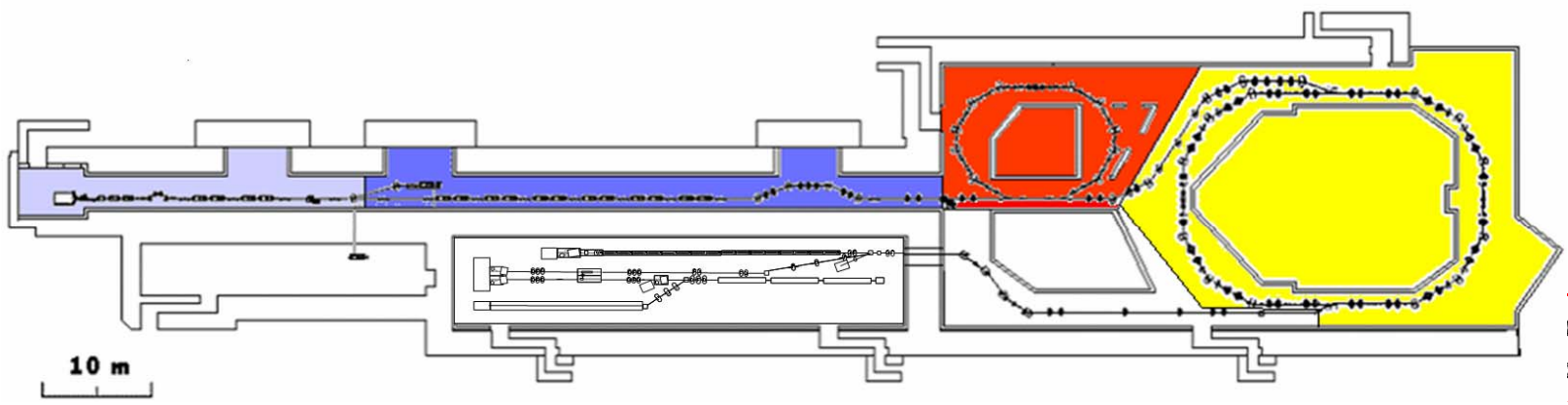
- From Mar 28 till Jul 5
  - 12 weeks
  - PETS from March 20, later nighttime and weekends
- Objective
  - Full commissioning of the Combiner Ring
    1. Full transmission in CR (4 turns), 3 GHz beam, DL bypassed
    2. Extraction of the beam to CC
    3. Optics and dispersion studies
    4. Switch to 1.5 GHz beam, recombine with DL (factor 2)
    5. Final recombination in CR (factor 4)

The week before the Easter

- One week period from March 28 till April 5 before the following installation works:
  - Identify the main hardware problems
    - Make one turn in CR
  - Set up of PETS beam, PETS operation
- Slow startup after the winter stop
  - Controls software, Timing, RF setup, Problems with the safety chain
- Beam up to CC with 25% losses
  - Not the nominal optics
- All BPI signals overcompensated and wrong calibration

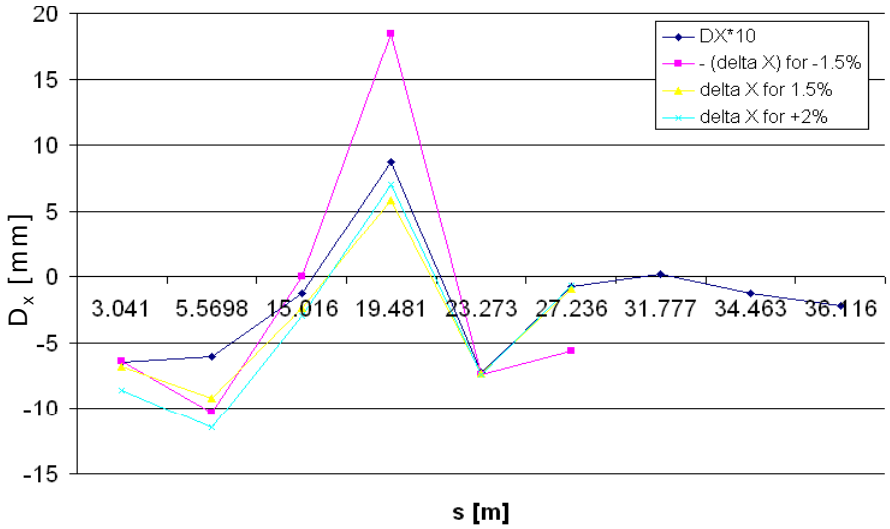
Hard Startup after the Easter

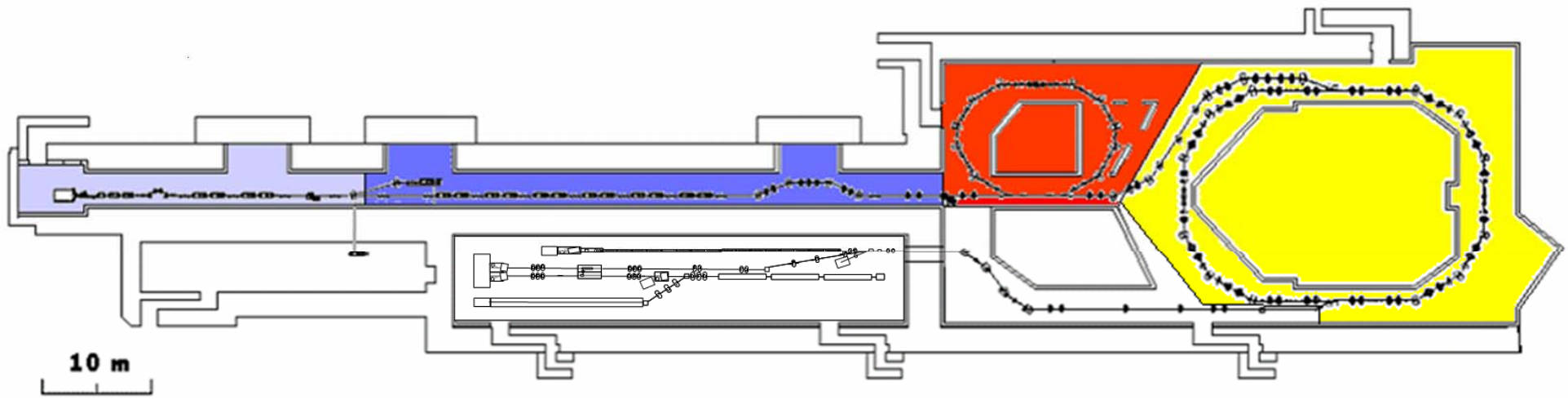
- As usual slow and difficult startup after a break
  - SF_6 leak in MKS05
  - Hardware problems with power supplies in CT
  - Jumping phase of klystron 05
    - Bad contact in the phase shifter
  - Crunched screen in girder 10
    - First available screen after the Stretching Chicane
    - Linac optics not well controlled
      - Back tracking thru all the Linac is not precise
      - Difficulties to set up the Linac optics
  - We managed to get thru the Stretcher only May 5



TL1

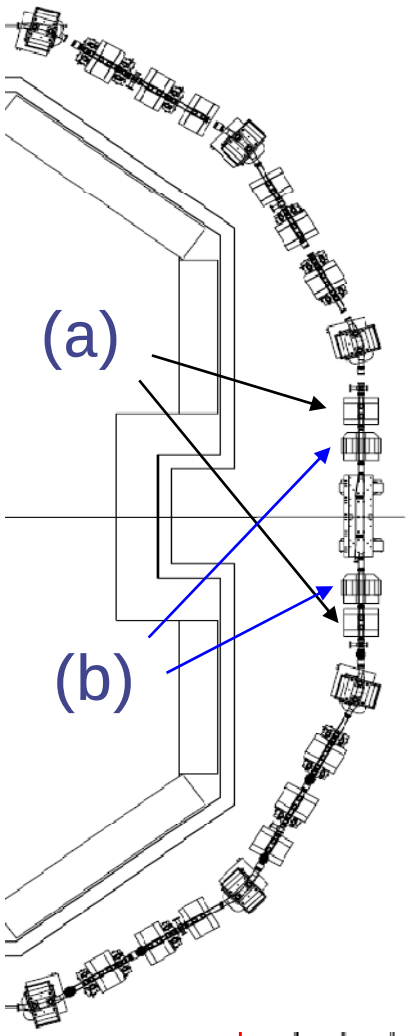
- Easily established beam in TL1
- Dispersion check
  - Using magnet scaling technique
  - Overall agreement with the model
  - 2nd order dispersion visible.





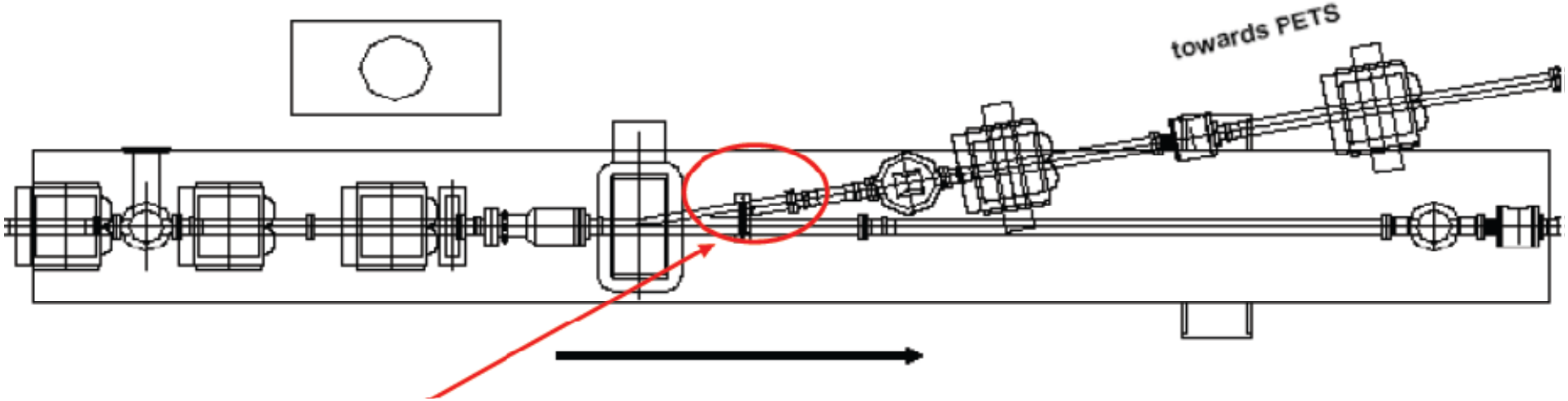
CR

- Relatively easily got the beam injected into CR
- Full transmission up to the end of the 1st arc
- And almost all lost in the 2nd arc
  - Check of all the quadrupole hardware
  - Cable for the control modules CR.QFJ0320-S (a) and CR.QDH0340-S (b) swapped
- And then...



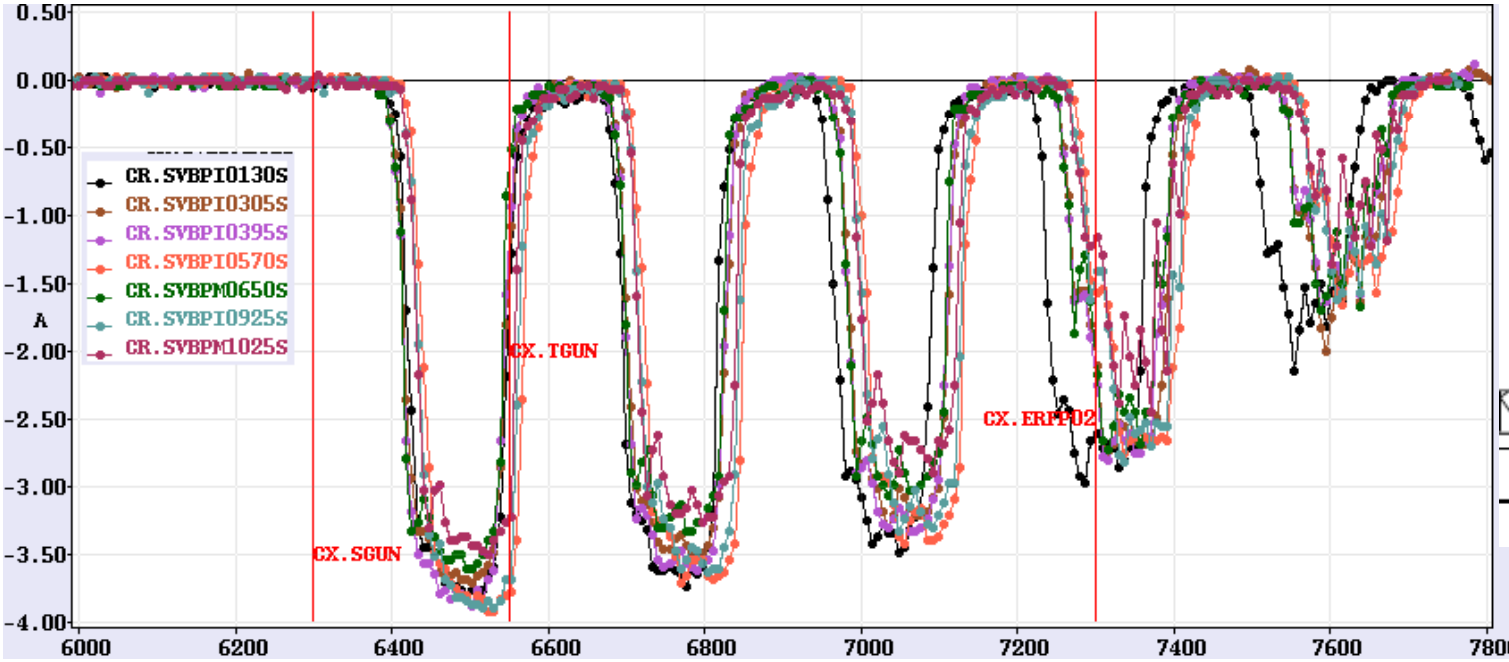
Vacuum Leak

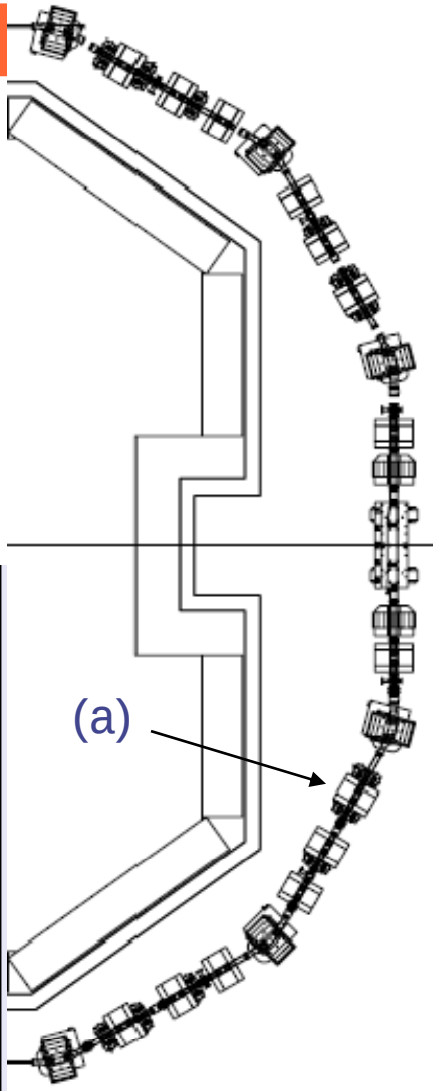
- On 12th of May
- At the place PETS line braches off
  - Flange
- Girders 7 to 10 and region up to PETS were vented
  - Stop of operation/commissioning
- Fortunately the intervention to fix the flange was successful
  - Restart on May 23rd for commissioning,

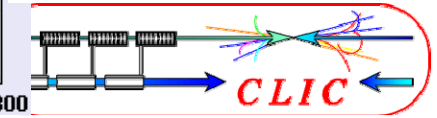


3 turns in CR

- Still can not easily transport the beam thru for one full turn
  - After few days we do another hardware check
  - CR.QFJ0415 has wrong polarity (a)
- And we got nice 3 turns (May 31)





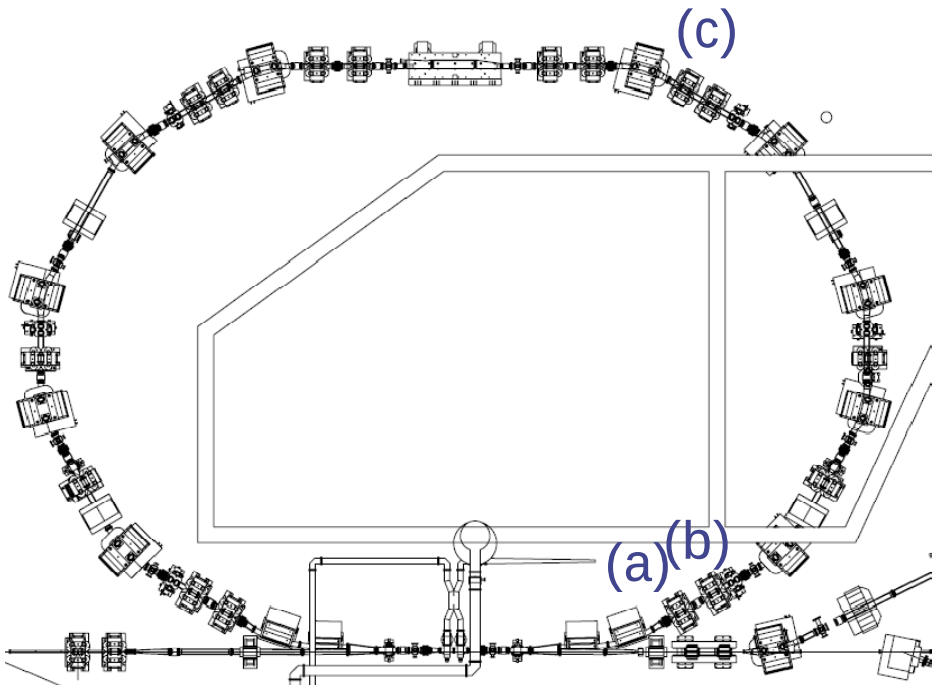


Switching to 1.5GHz

- We switched on 2 of 3 TWTs
  - One was broken
- Very quickly got beam in the combiner ring
  - MKS 02 and 03 phase adjustment was sufficient
    - The settings for 3GHz does not have to work for 1.5GHz
      - Different current, gives different acceleration
- However
    - We could not get the beam for more than 3 truns
    - Meanwhile the aluminum screen at girder 10 was exchanged
- We decided to redo properly the setup from scratch including Delay Loop

Delay Loop

- After one day of effort without success to send the beam around DL, we decided again to check quadrupole polarities
- 3 quadrupole families wrong
  - CD.QFF0130 (a)
  - CD.QDF0140 (b)
  - CD.QDF0260 (c)
  - Who was changing the cables in DL during the shut down?
- Beam thru the Delay Loop quite easily established, then
  - Especially taking to the account the not calibrated BPIs after the April intervention
- Recombination not possible due to failure of the driver amplifier for MKL02

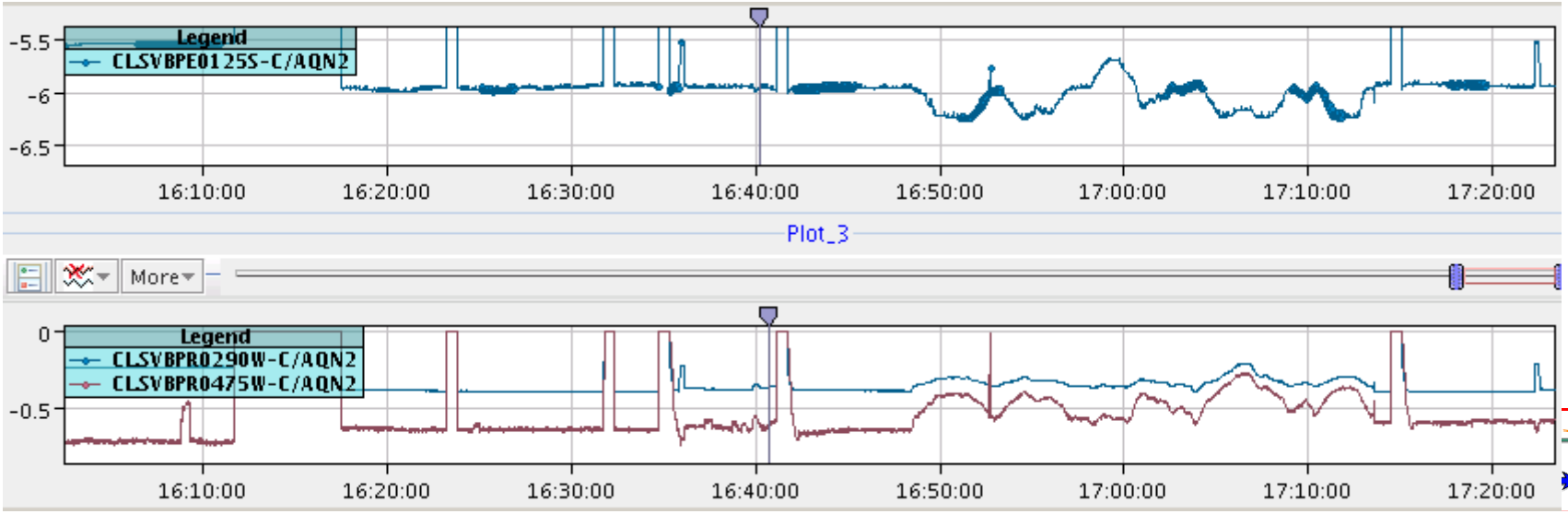


Bunch length measurements

- Measure bunch length with 1.5 GHz RF deflector (DL)
- Study and analysis by Hamed, first results:
  - For 3 GHz l = 4 mm
  - For 1.5 GHz l >4 mm
- Decision to shorten bunches
  - Slightly off-crest in MKS03
  - Set the Stretcher Chicane to half natural R_{56}=0.2

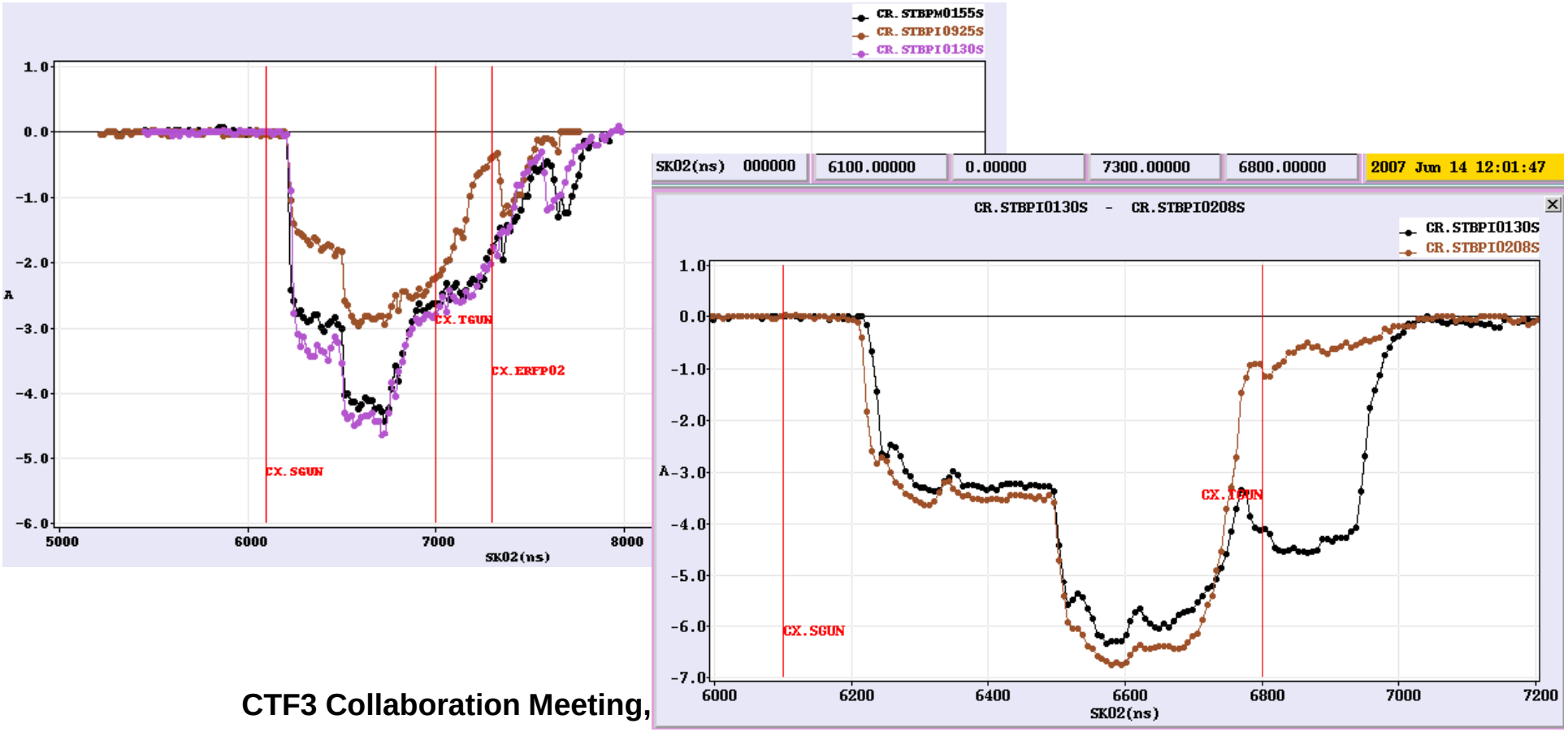
Current jitter from the Gun

- Meanwhile, the beam starts to jitter and float from shot to shot
  - We trace the problem to the jitter of the current from the gun
    - Different current -> different acceleration -> different position in dispersive regions
  - Measurements and settings of the beam become very difficult



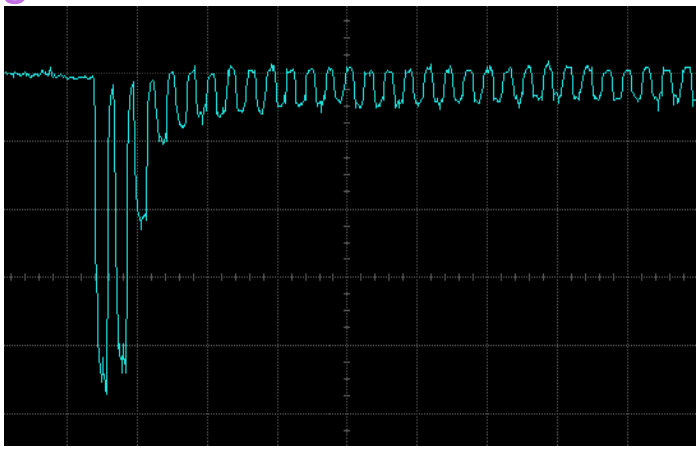
CR Recombination factor 2

- Despite the jumping beam we manage to get the first recombination on Jun 14



Run 1 Summary

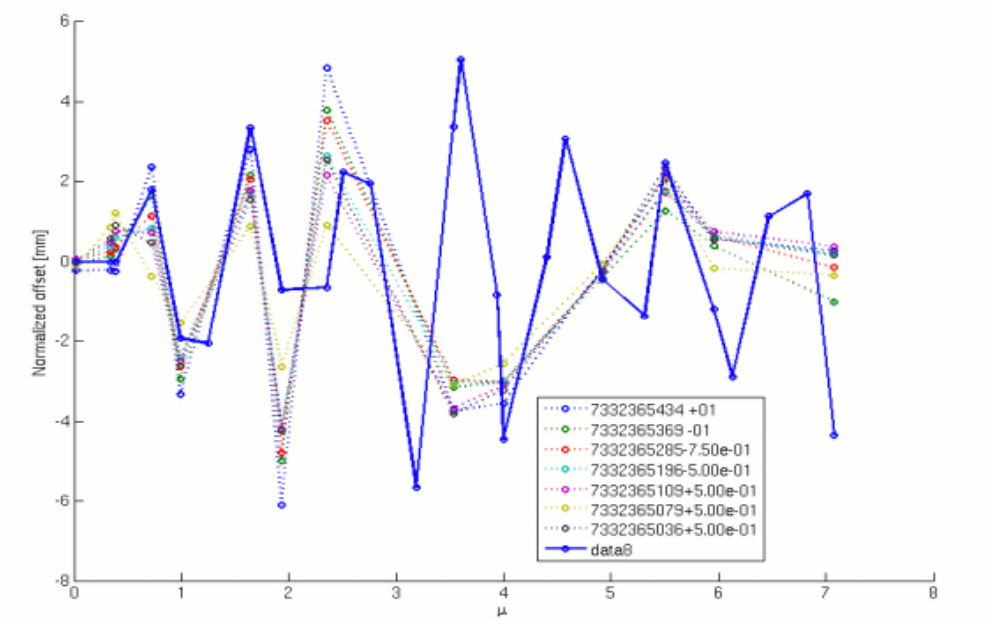
- We couldn't get full transmission for more than 3 turns
  - However, the low current remnant was doing hundreds of turns
  - With a few kinds of optics
- We were struggling with unstable gun, hardware failures and other accidents
  - Like break-ins to the machine roof (twice)
    - After such an event it takes very long to stabilize conditions and they never come to the original point. One needs to repeat setup almost from scratch



- Despite all of these we managed to get some data for the off-line analysis

Response Matrix Study

- The measured data were clearly not consistent with the model
  - And we could not find the single variable that would make them consistent
  - Later we found there were more than two...
- At this point we found
  - Correctors with wrong polarities
  - That the largest discrepancy comes from the wiggler



Preparation to Run 3

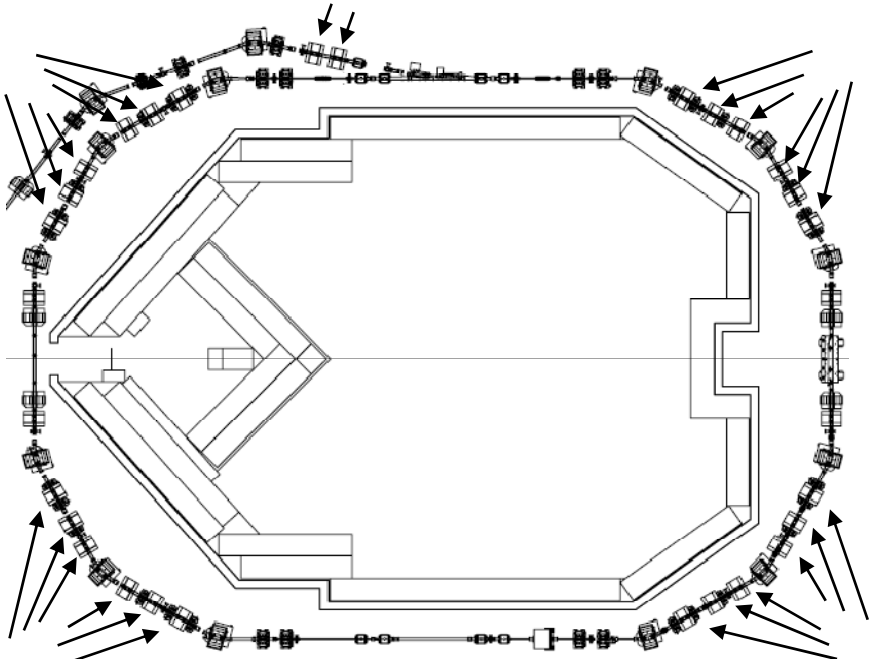
- We developed set of tools that allow to quickly test the optics and compare immediately the results with the model
  - Dispersion measurements
    - Magnet scaling
    - Using position jitter from shot to shot
      - Online dispersion monitoring
  - Response Matrix measurements
- The machine realignment
  - All elements were measured and repositioned were needed
    - Bends in CR longitudinally shifted 2mm
    - Several quads displaced about 1mm
    - Few quads skewed

Run 2

- From Sept 3 till Dec 15
  - 15 weeks
    - Planned only for 10
- Objectives ... the same that for Run 1
  - Full commissioning of the Combiner Ring

Magnetic measurements

- We started with detailed magnetic measurements
- We found that in the model we used 6.7% too low current-to-gradient coefficient for the J type quadruples
  - All the quads in the CR arcs are of the J type
  - We have been using outdated magnetic measurements



Hard Startup

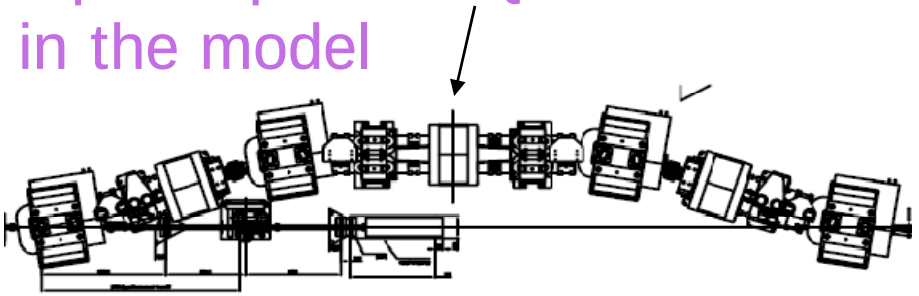
- Difficulties at the startup, as usual
  - SF_6 leak
  - Cooling water filters blocked
  - Door to the roof opened by force
- First beam in CR Sept 21 (Fri)
- Next Monday the gun mal behaves
  - Cathode Exchanged
- We restart the Linac setup from scratch (Oct 2)

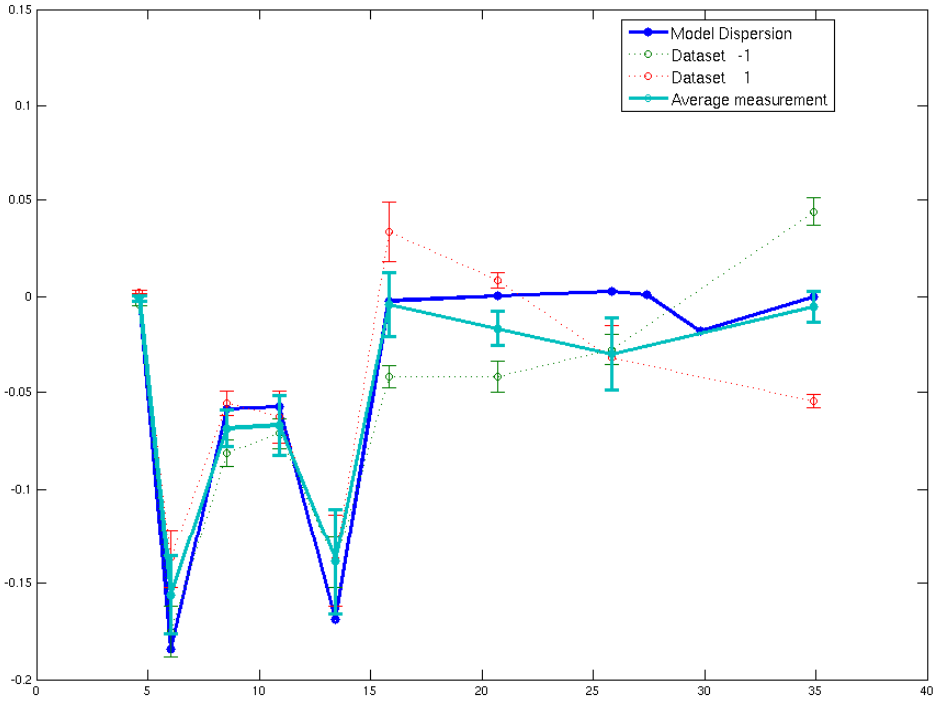
Problems, Problems, …

- Oct 9, the first flange after the solenoids burned with the beam
  - Reason unclear then
  - Repaired on Oct 15
- But then the gun gets out of order again
  - Dark current at 10mA
  - Repaired on Oct 24
  - New working point of course is different
- We restart the Linac setup from scratch on Oct 25
- Last days of October klystron 15 is dead
  - Charging power supply
    - No more spares available
  - Again, setting up from scratch

Dispersion in the CT line

- Measured dispersion in the Stretcher Chicane does not agree with the model
  - Discrepancy tracked to the quadrupole CT.QFE 0250
  - Fudge factor 0.86 applied in the model

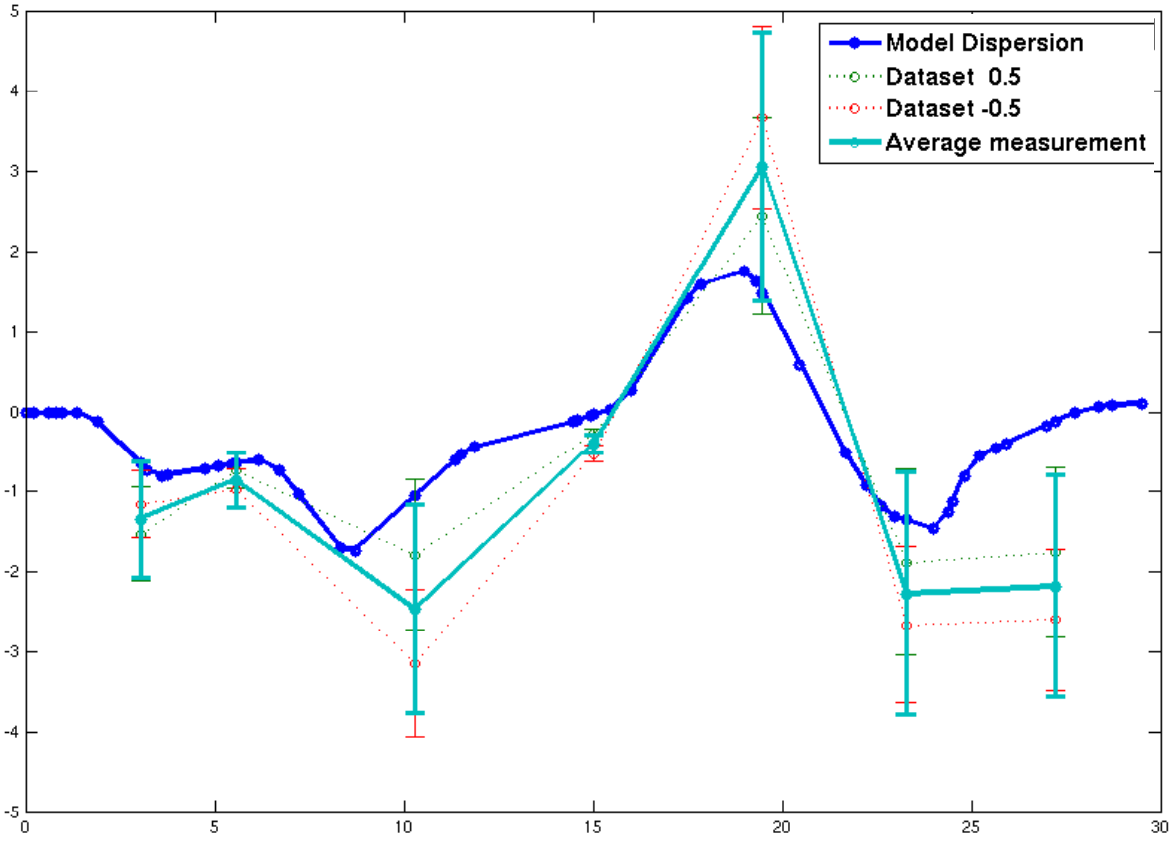




- Measured and corrected model dispersion

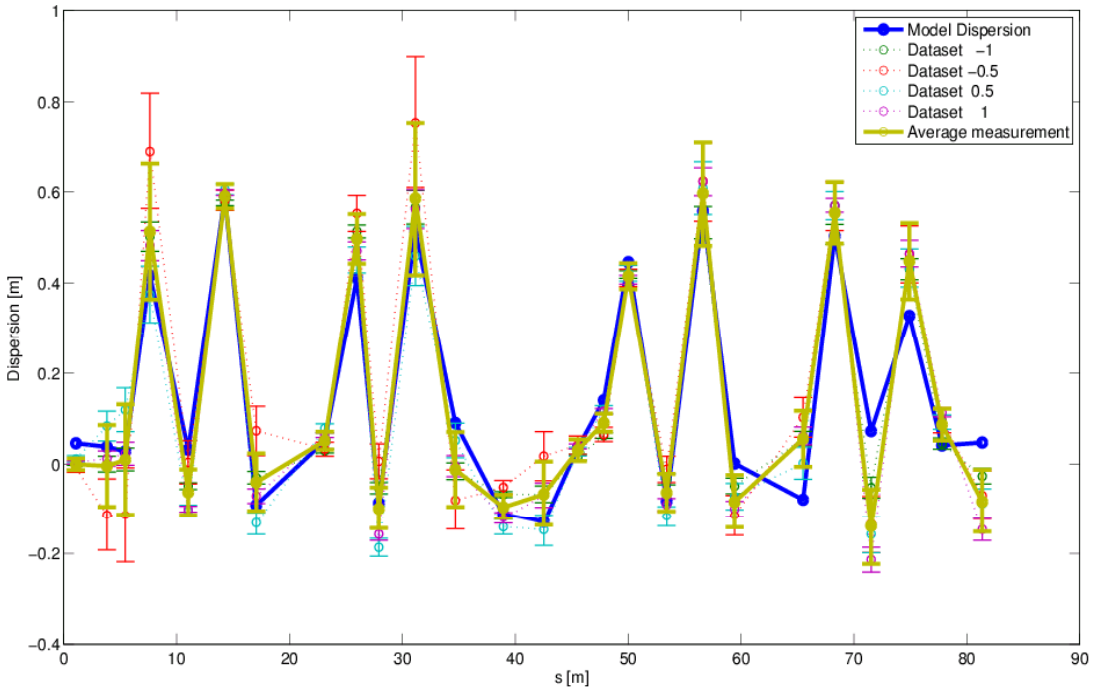
Dispersion in the TL1 line

- The model within the error-bars



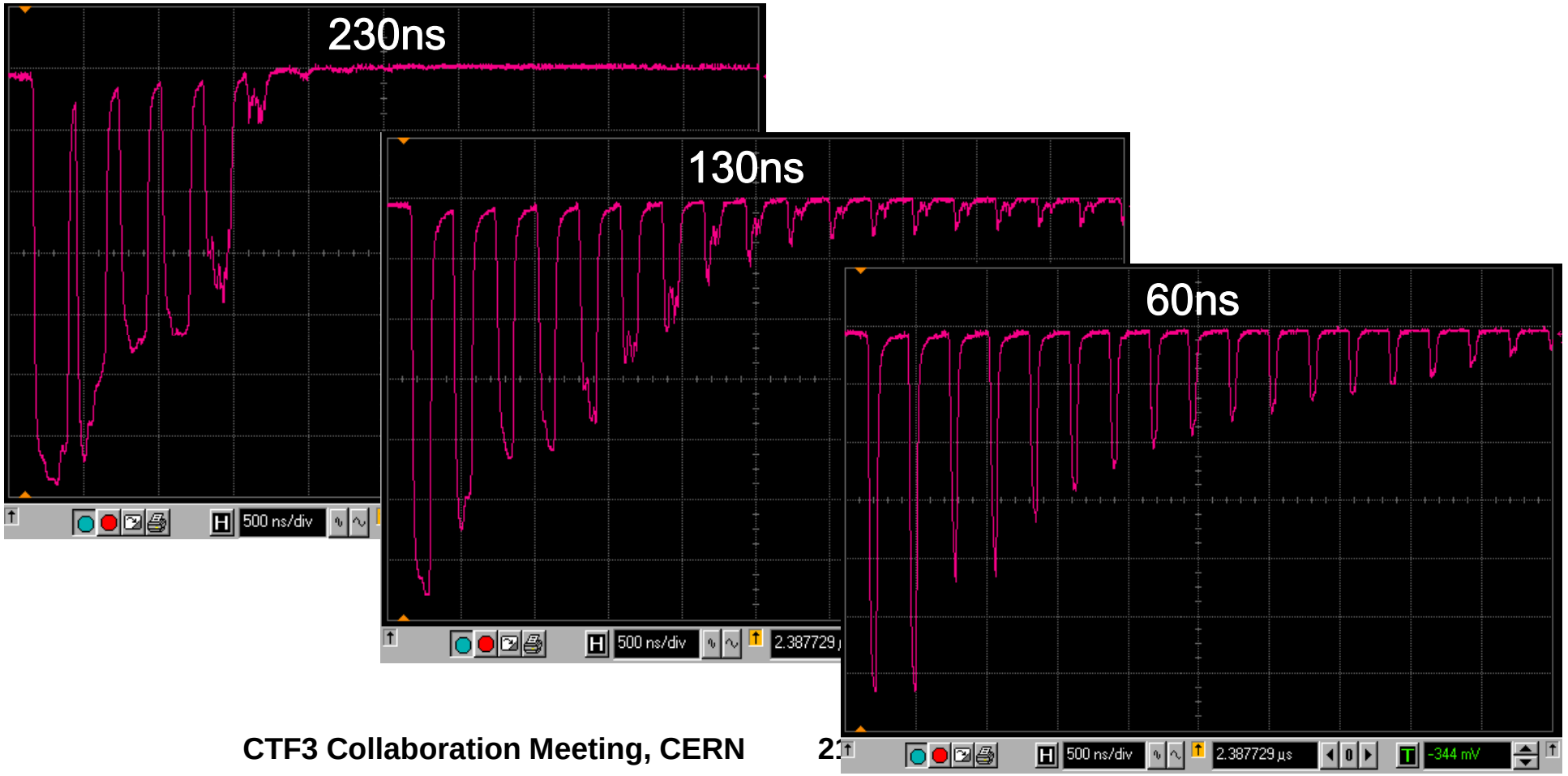
Back in CR

- This time the beam makes two turns without any problems
  - The J type quad calibration corrected in the model
- Dispersion agrees well with the model now
- However, still can not get full transmission for more than 3 turns



INSTABILTY

- And the losses depend strongly on the pulse length



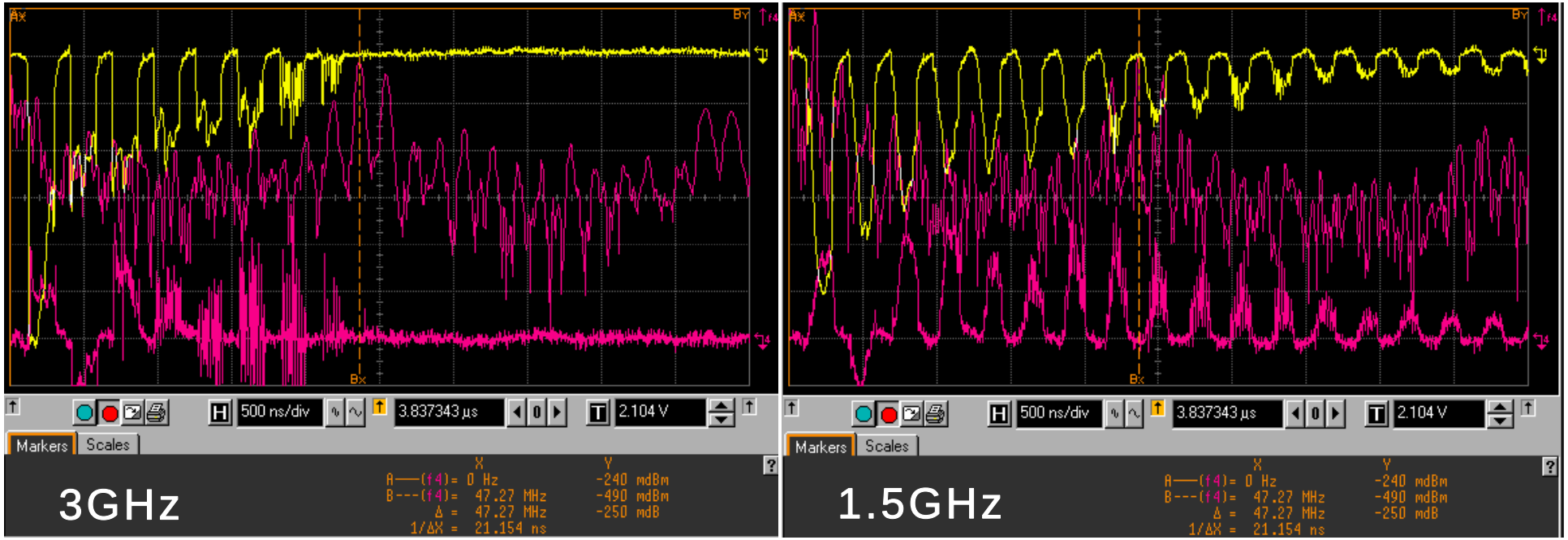
Vertical Instability

Instability (cont.)

- The pattern is very repetitive
  - On the plot we see several consecutive shots

It is not fast ion instability

- RF deflector in DL set up to kick out every second bunch from the train
  - Same charge per bunch
  - Twice smaller current
  - Twice bigger spacing between bunches
- If it is fast ion instability then the frequency should change
  - It is not

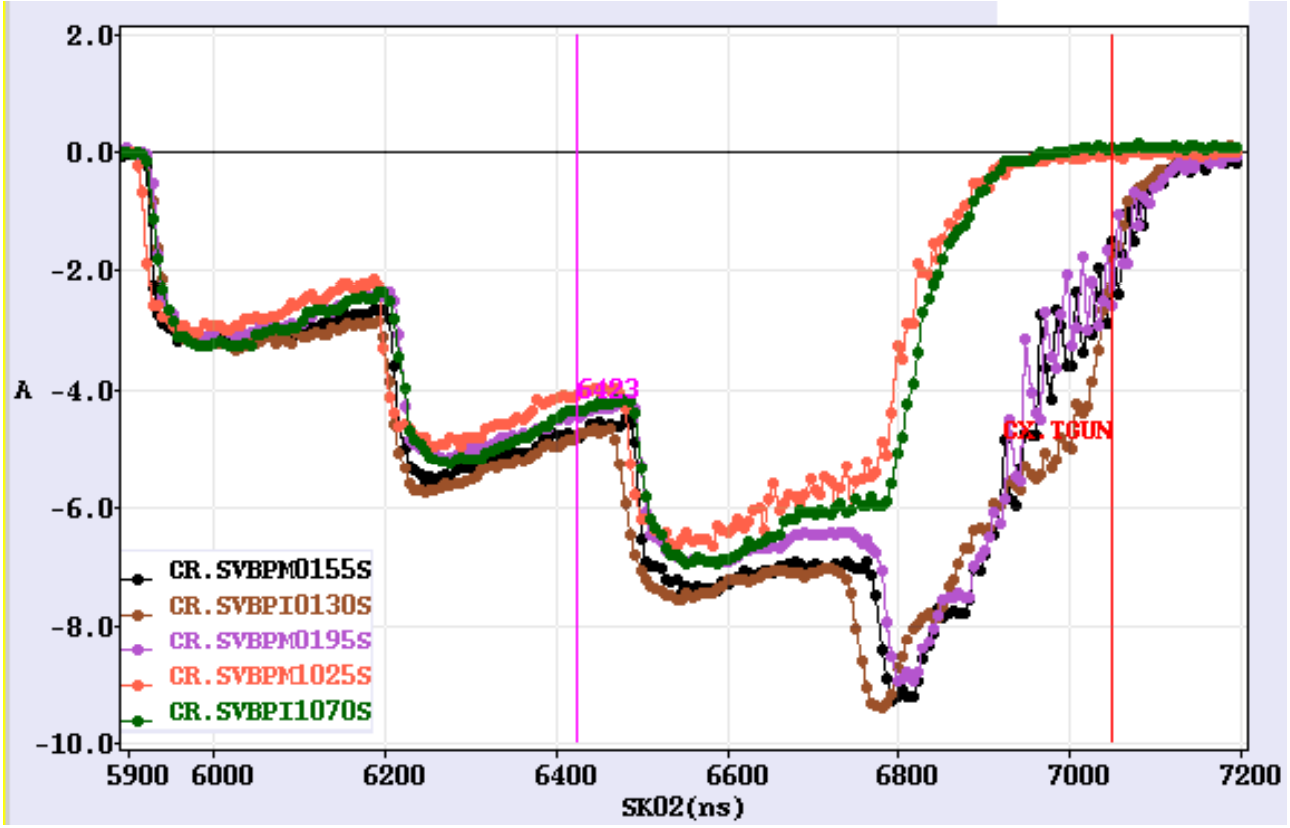


Instability studies

- Looking at sum & difference signals, we clearly see the instability developing in the vertical plane from turn to turn
- The frequency content of the vertical difference signal has a peak at 47 MHz
- Δf between the horizontal and vertical polarization modes of the RF deflectors is about 50 MHz it indicates that they are responsible for the effect

Recombination

- Never the less we try to get recombination
- Almost there on Nov 19
  - The train a little bit too short



Another long stop

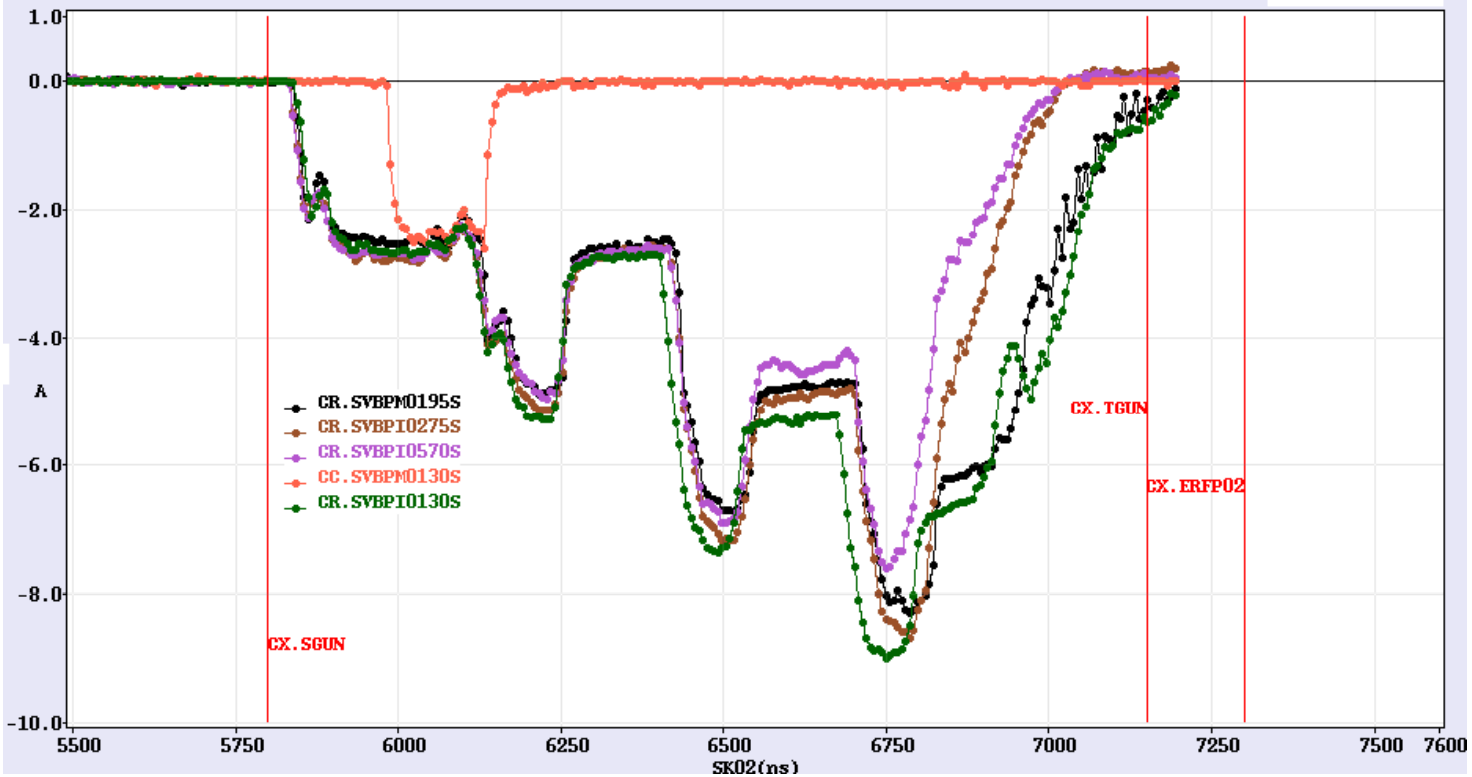
- Vacuum leak on Nov 21
  - The same place as before
    - Just after the solenoids
  - Repaired on Nov 26
- This time the reason is finally understood
  - It is the dark current that is nicely transported thru solenoids and then hits the chamber
    - Installed a temperature probe on the beam pipe at this position so we can monitor the temperature
    - The gun always off during nights since then
- MKS11 dead on Nov 26
  - Again charging power supply...
  - We need to setup the optics from scratch again

Unstable Gun

- Since the beginning of November the gun mal behaves
  - Periods of large current variation from shot to shot
  - Sudden jumps of the average current
  - Large current change along the pulse
- Not fully understood till now
- 1.5GHz beam not usable at all
  - pre-bunchers drastically amplify the energy variation with the current
    - Transporting the whole 1300ns train up to CR impossible
- Operations extremely difficult
  - Most of the time since then is spent on adjusting the optics to a new working point of the gun
  - And try to do something useful before it jumps again

Recombination

- We achieve the goal on Nov 29
- To reduce the effect of the instability cut a gap within the trains with the extraction kicker

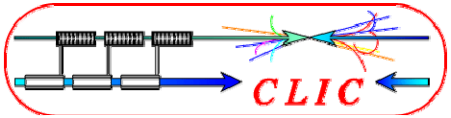


The Machine Study

- All along the Run 2 we were performing the machine measurements
  - Dispersion
  - Tunes
  - Response Matrix
  - Combiner Ring Length
  - Bunch length
- They allowed us to discover many bugs in the machine and in the model
  - Of course, that is why we do them

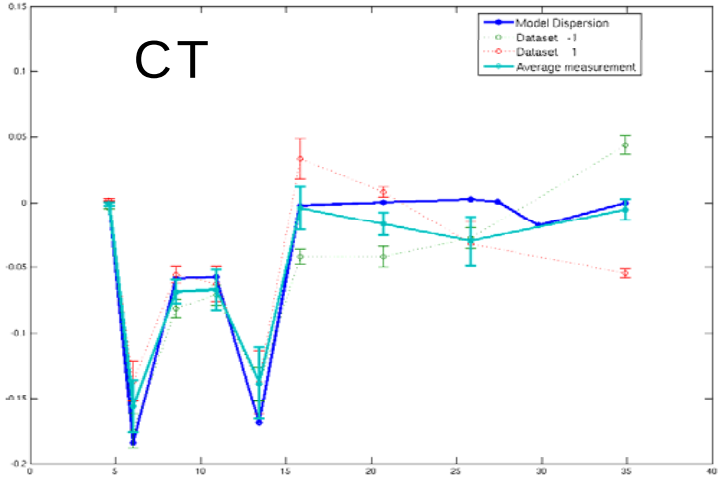
Dispersion

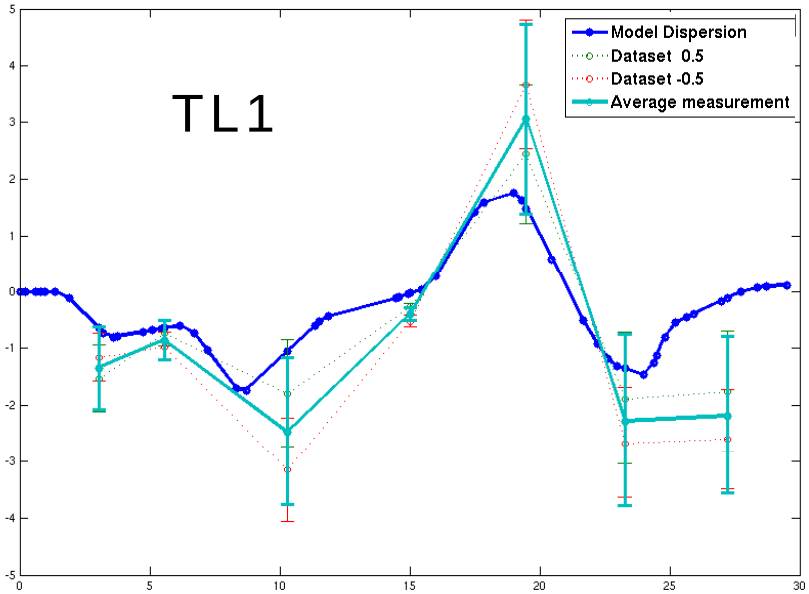
- Dispersion is measured in two ways
  - By observing the orbit change while setting all elements strengths proportionally higher or lower
    - The lattice becomes mismatched to the beam energy
    - Specialized MatLAB script doing the job
      - Read the current setting of the magnets
      - Get the reference orbit over several shots
      - Scale all the elements in the specified range about desired value(s)
      - Get the orbit over several shots
      - Return to the original setting
      - Prepare the input for MADX and run the model
      - Plot the measured and the model dispersions together
  - Measuring the position jitter from pulse to pulse
    - RMS of a pickup reading is proportional to the dispersion
    - The pattern is normalized so the dispersion in the Stretcher chicane agrees with the model
      - It is well controlled there
    - It is much less precise method comparing to the former one, however, it allows to monitor dispersion on-line
      - Facilitates the beam setup

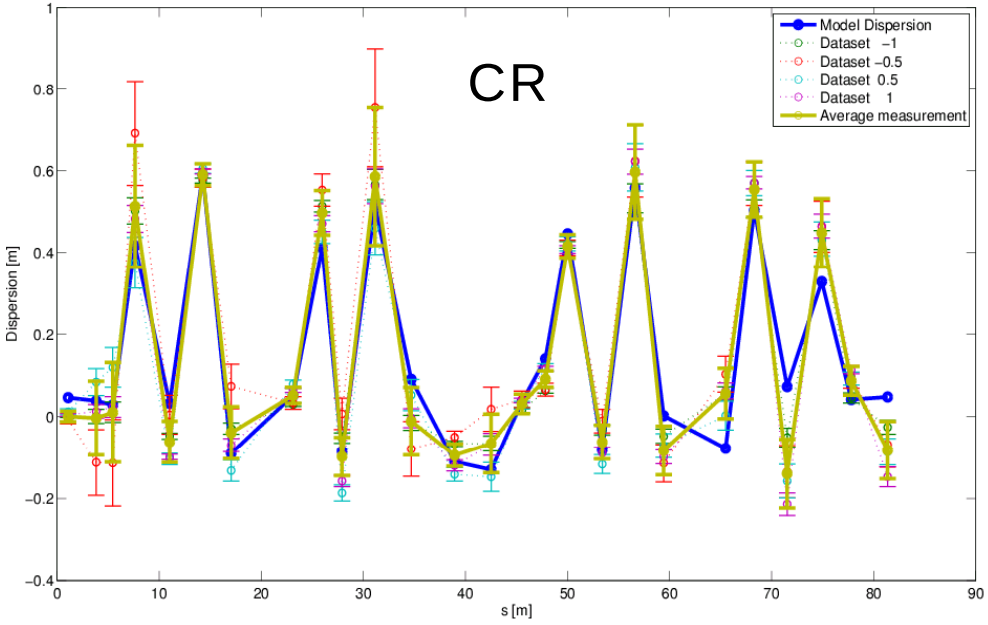


Dispersion: Results

- Dispersions agrees with the model within the error-bars





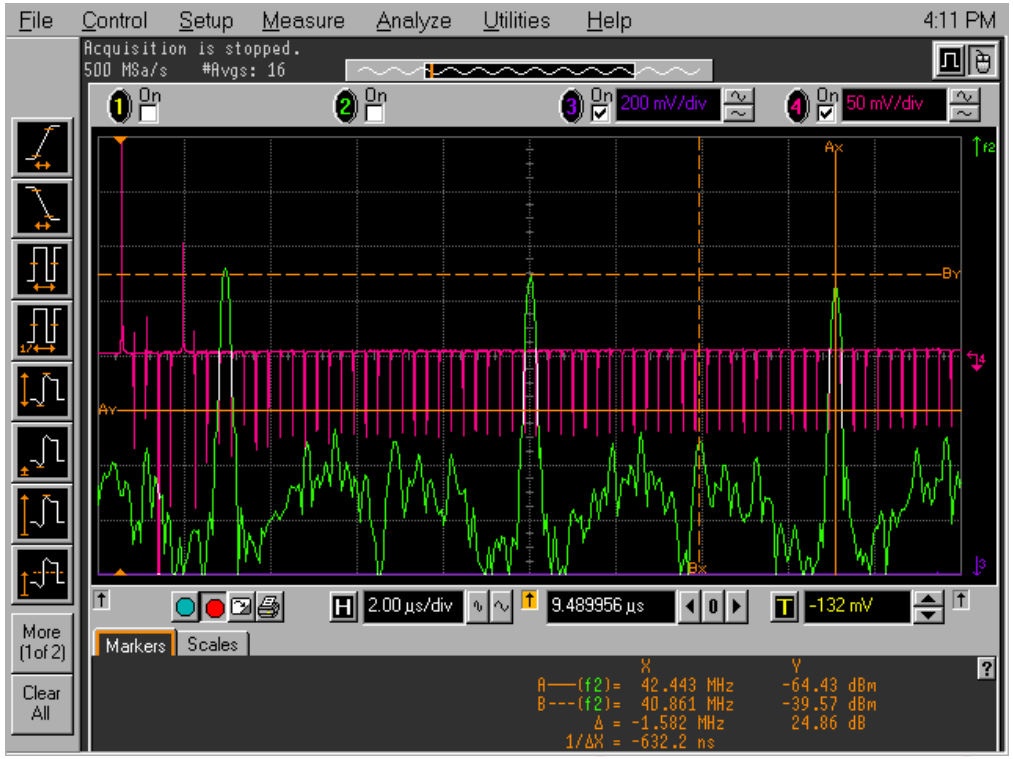


Tunes

- We measure tunes doing FFT of a pickup analog signal
  - Using a scope
- Measure distance between the main frequency peak f_{rev} and the second highest f_Q

  $Q = N \quad (f_{rev} - f_Q)\, f_{rev}$

  N is an integer that is obtained as the number of the orbit oscillations around the ring
- To distinguish the sign observe how $f_{rev} - f_Q$ changes while changing a quad strength

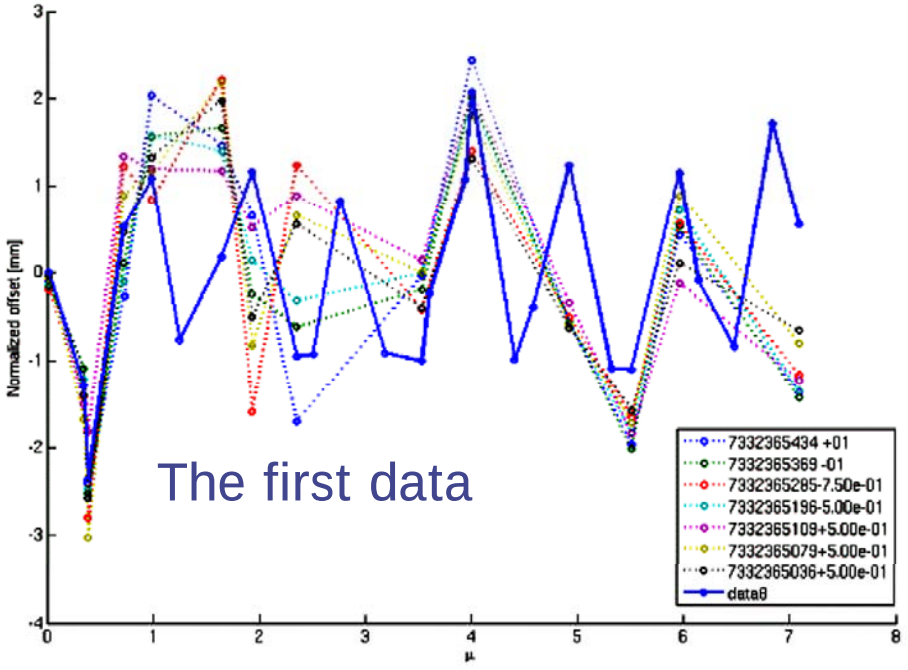


Response Matrix

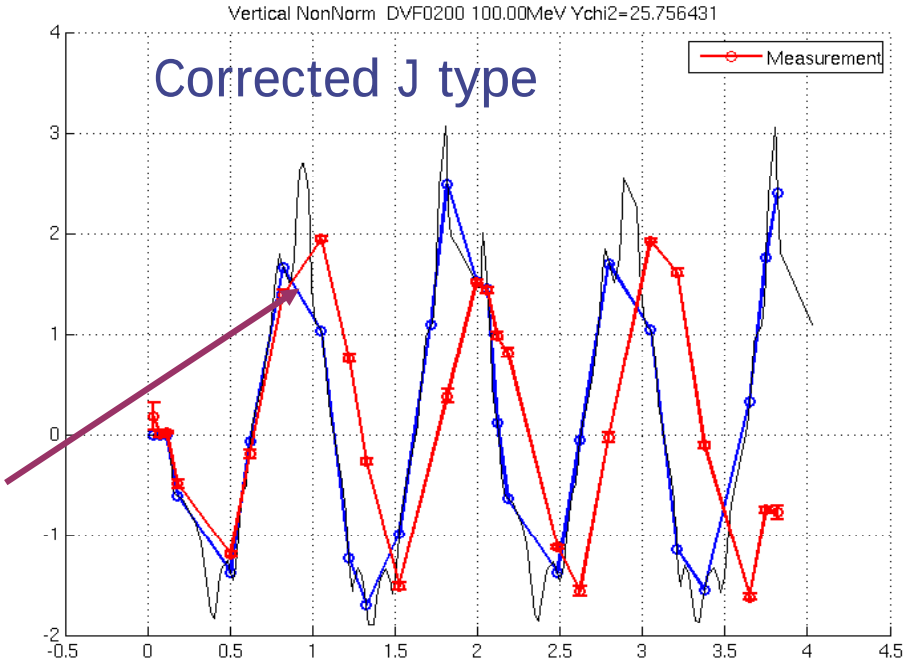
- Register the orbit position in all BPMs
- Change one of the correctors
- Look into orbit position change (difference)
- Compare with the model predicted change
- If they do not agree, the model does not describe the machine correctly
  - It is easy to localize the element that is badly modeled
    - Between the element the discrepancy occurs first and the previous one or two
  - Even if there are more errors we still can find them
    - If the kick is applied after the first error the pattern should agree
- Also this measurements are performed automatically with a MatLAB script

The Response Matrix Study

- The measurements made during Run 1 traced us to the wrong calibration of the J type quads



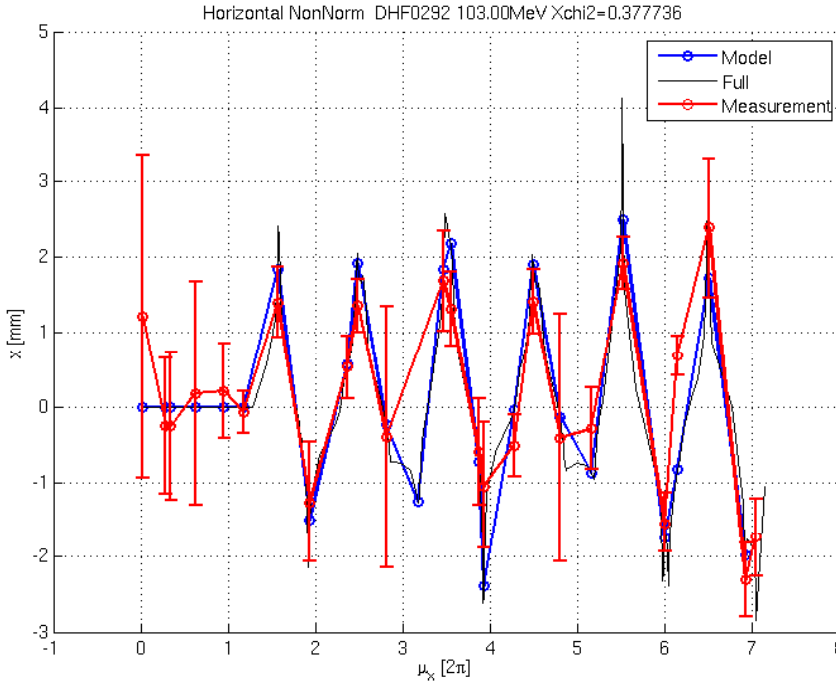
The first data

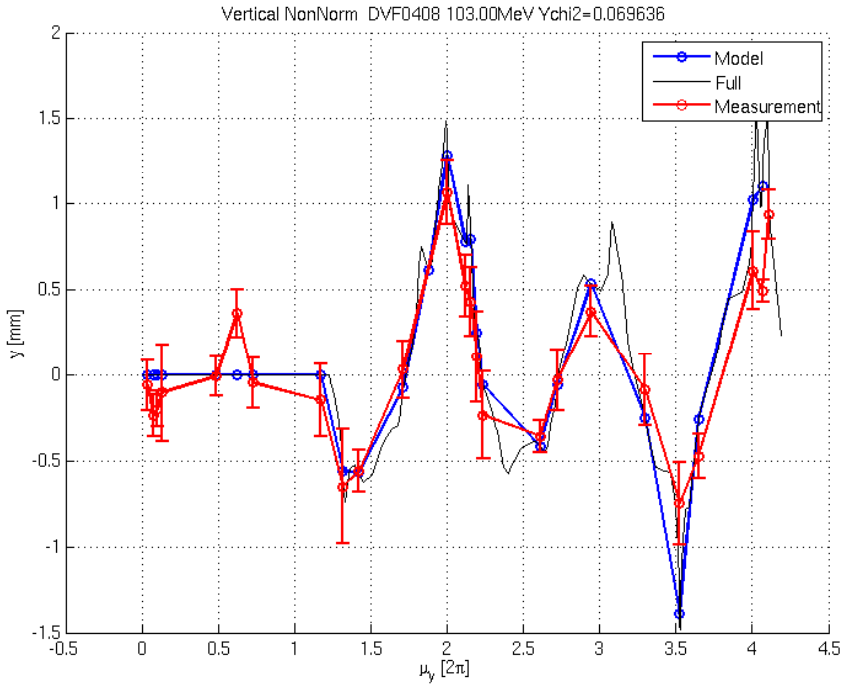


- There is another problem
  - The wiggler area

The new wiggler model

- Caterina Biscari has prepared detailed wiggler model based on the magnetic measurements of the device
  - It correctly describes the wiggler focusing
  - Since then we have no problems with setting up the beam in CR
- We still see some small discrepancy before the last arc

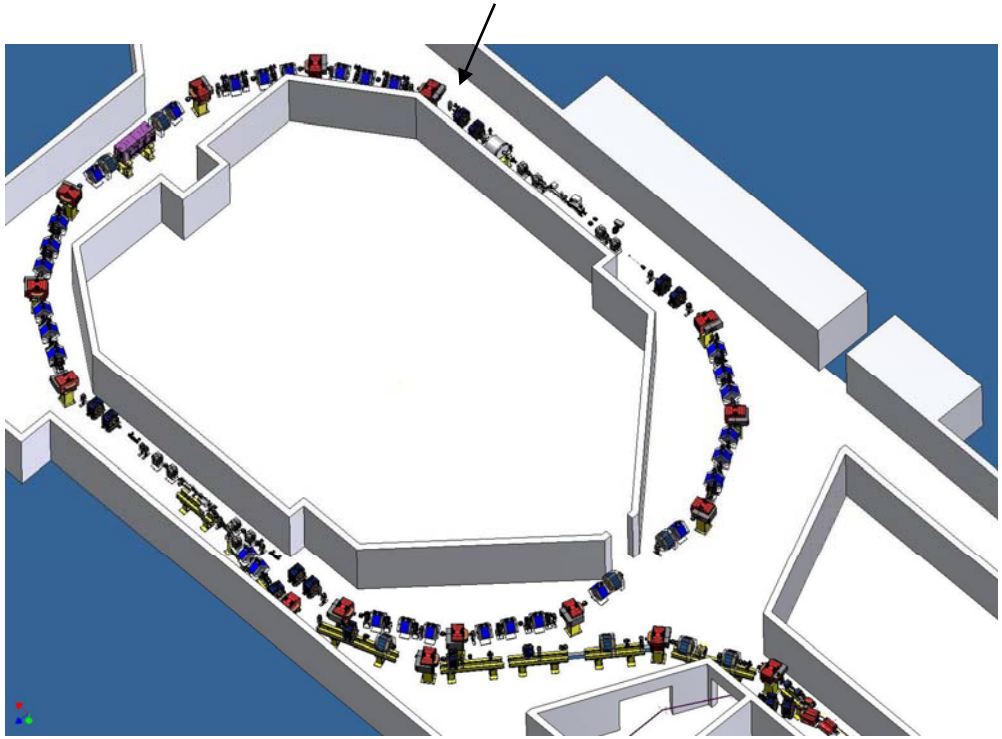


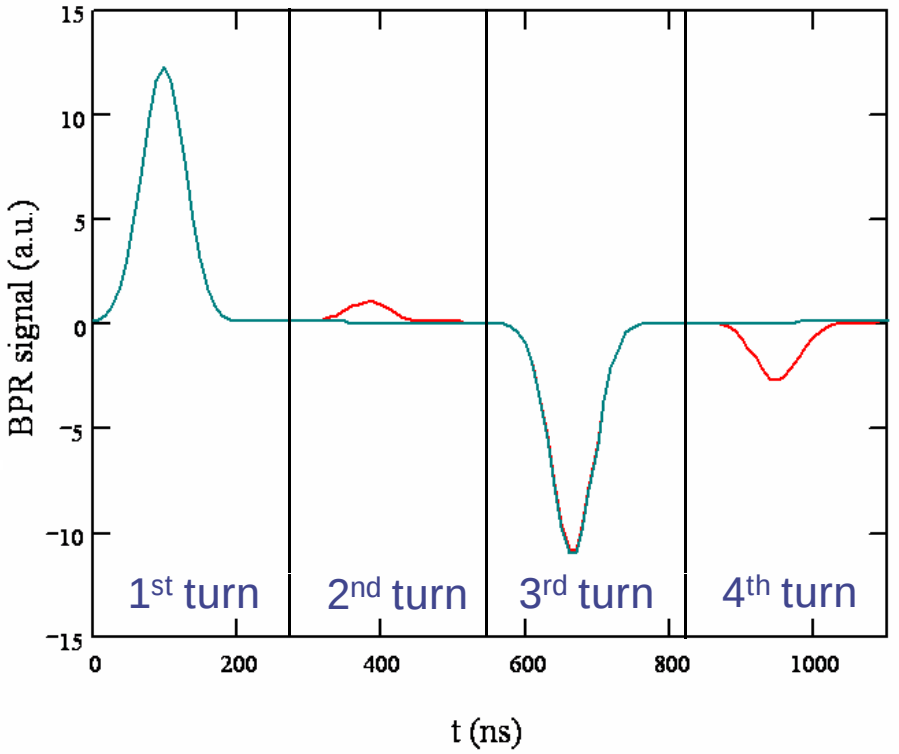


Measurement of the ring length

BPR: RF Phase Monitor

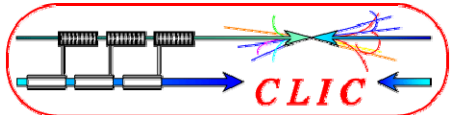
Gives sum of the beam induced signal and internal frequency (3GHz)
If beam has also 3GHz it measures phase offset between the two signals





Simulated signal

Combination factor 4
Combination factor 4 with + 5° error

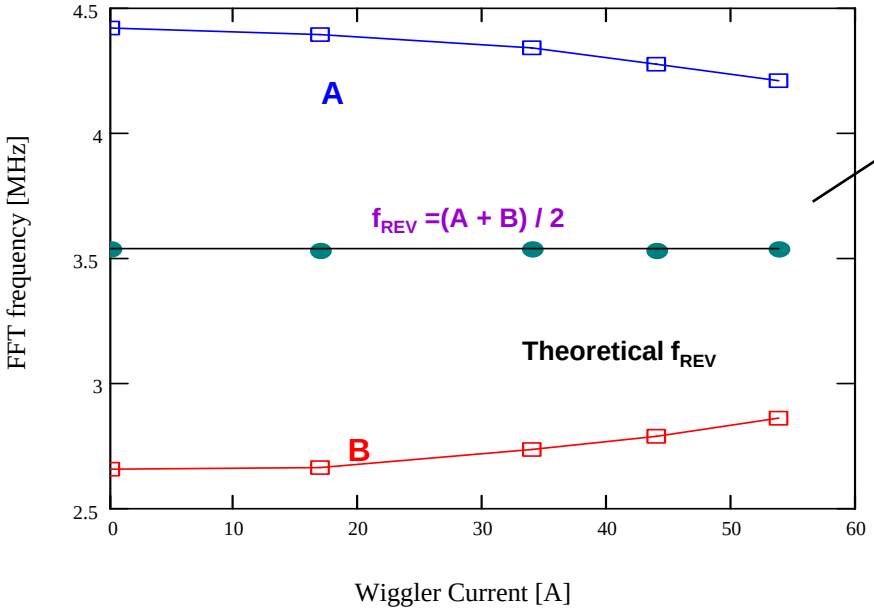


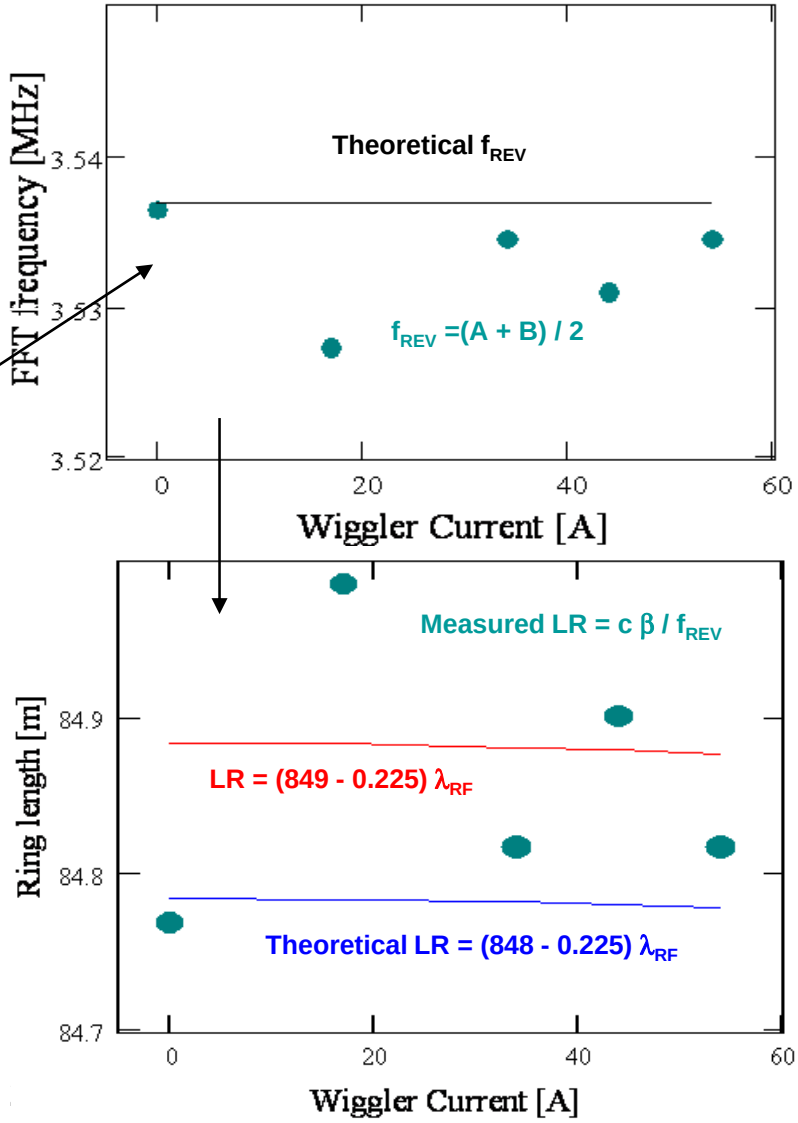
BPR measurement

- Short pulse for many turns
- FFT of the BPR signal gives the ring length
  - f_{rev} gives total ring length $L_R = (N - 1/CF)\ \lambda_{RF}$
  - Δf gives fractional part of ring length $1/CF\ \lambda_{RF}$

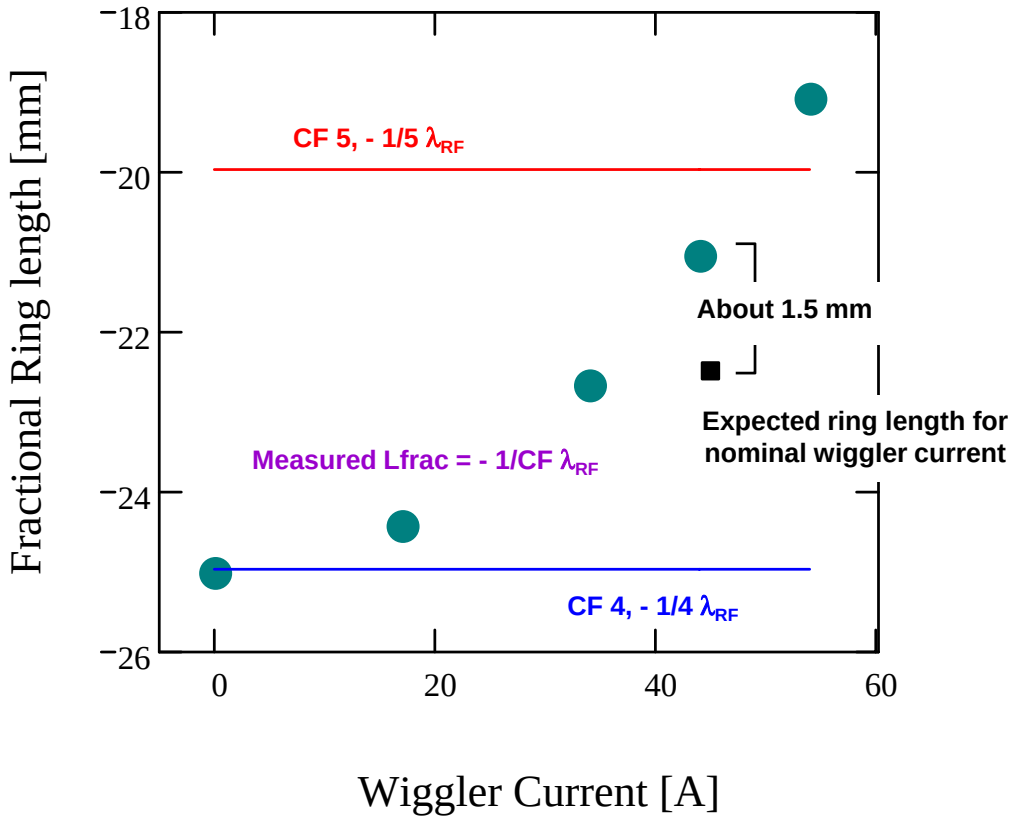
BPR measurement: f_{rev}

Measure for different values of the wiggler current



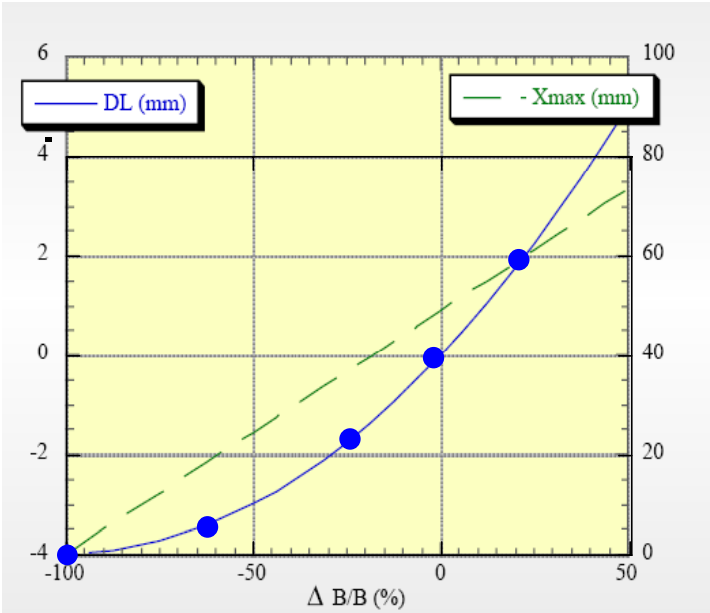


BPR measurement: Δf



expected —

measured ●

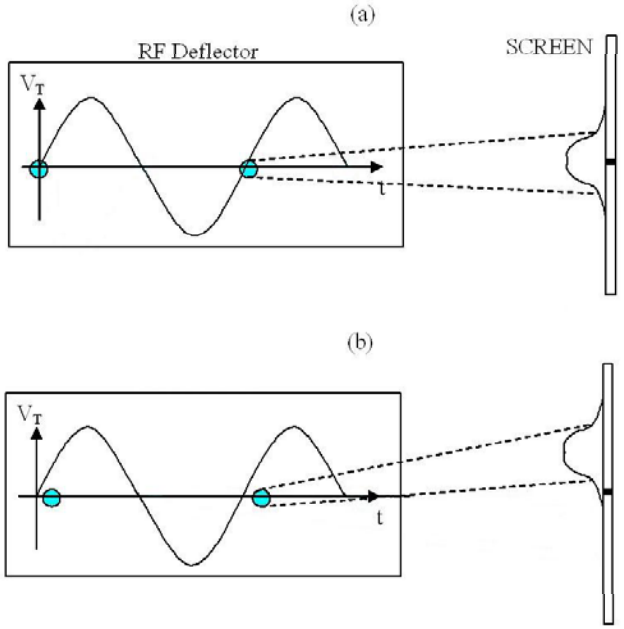


Path length variation as a function of wiggler field and maximum transverse displacement of the trajectory

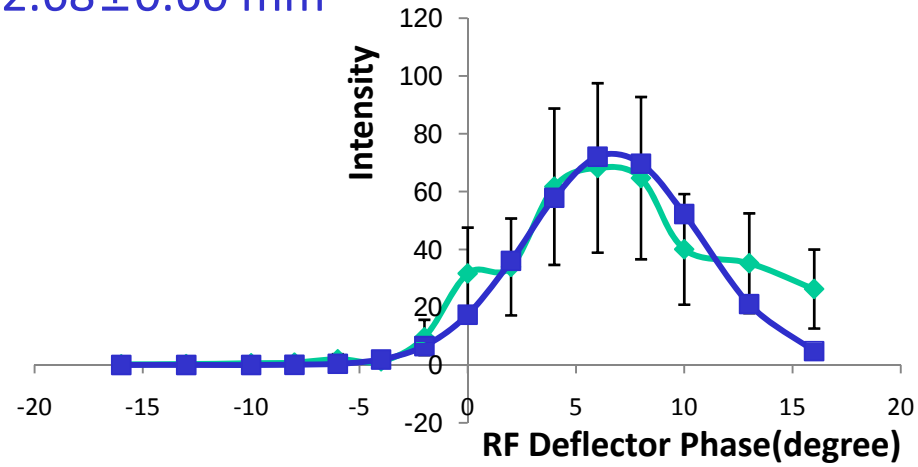
C. Biscari

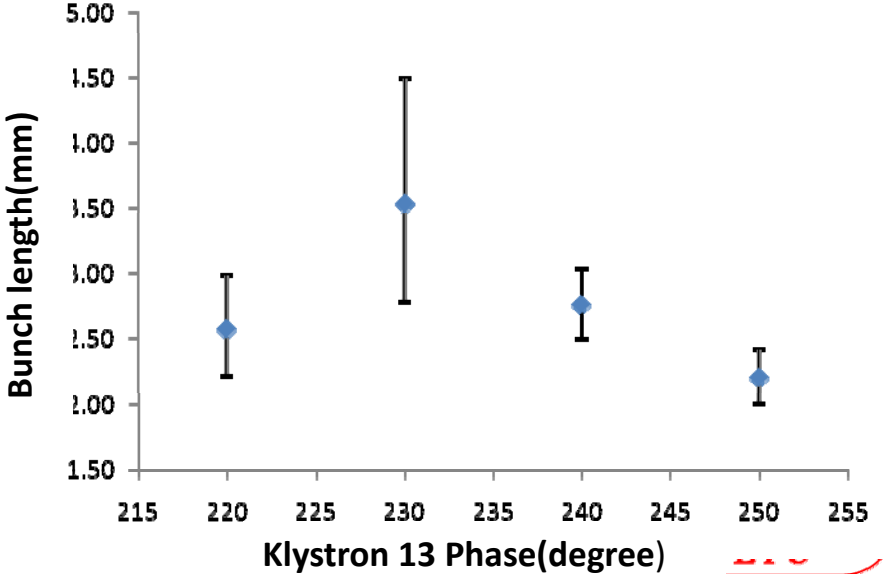
CLIC

Bunch length



$l_b = 2.68 \pm 0.60$ mm





The bunch length achieved by measuring the intensity of a thin band at middle of screen for each RF deflector phase and fitting a Gaussian distribution. The standard deviation of this chart is related to bunch length by c/f constant. c is speed of light and f=1.5 GHz is frequency of RFD. The errors are large due to the beam jitter but is good for first measurement by this method

Conclusions

- The second run was much better than the first one
  - We found all the bugs in the machine
    - Badly connected and positioned magnets
    - Bugs in the model
  - We understood why the beam did not want to stay in the machine for more than two turns
    - Instability

Conclusions

- CTF3 is not a brand new high quality machine
- It is a 2nd hand machine
- Or even 3rd hand
  - Ofcourse, it has a lot of brand new pieces
    - Otherwise it would not work at all
  - It's reliability is far from being sufficient
  - It is not a conclusion, it is well known fact
- We have shown that **it is possible to make the train recombination**
  - Even with such a machine
  - And on top with an unstable beam
- Hence, doing this with a brand new, high quality machine should be by far easier!