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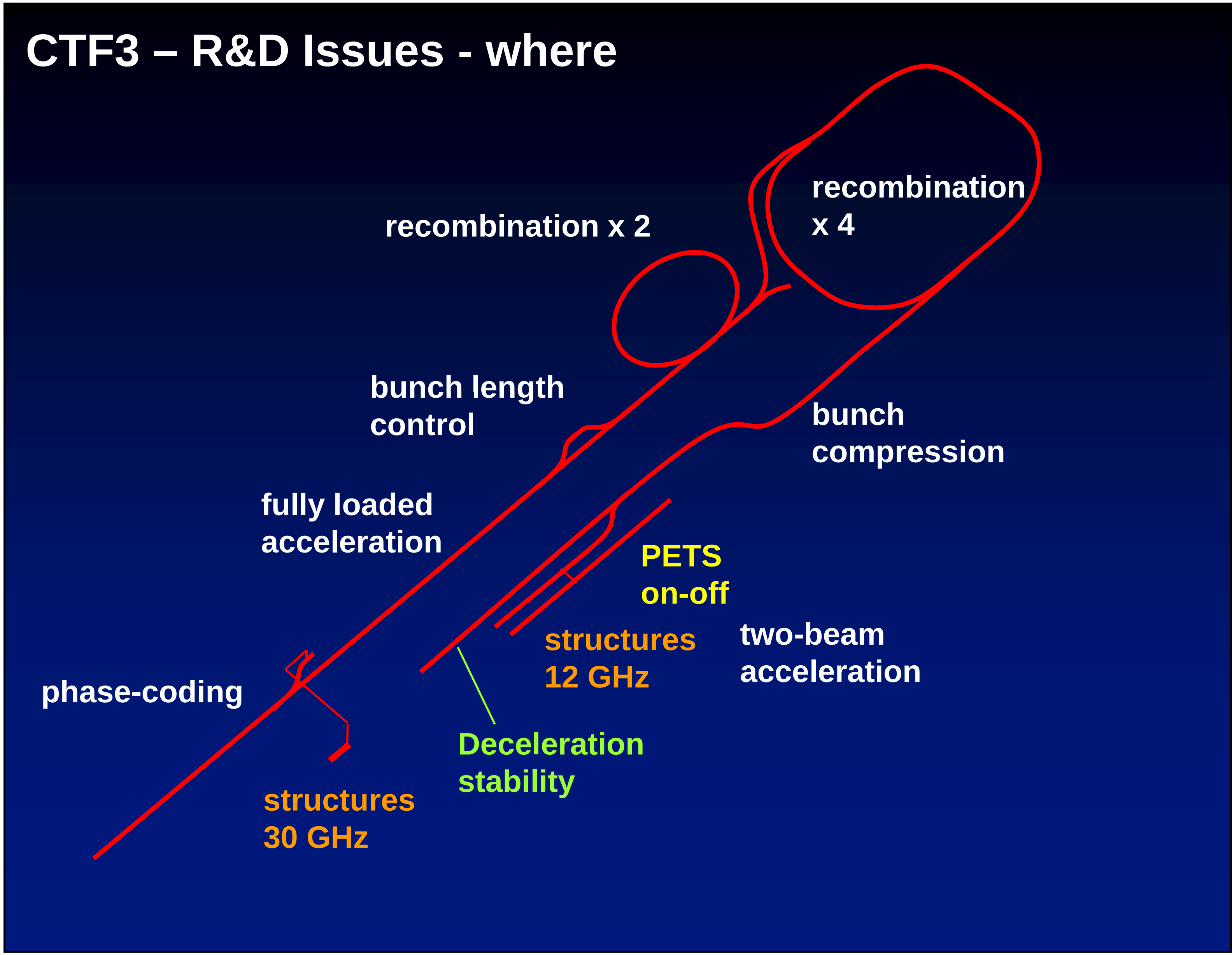
CTF3 Commissioning and Operation

CLIC Workshop
CERN 15 October 2008

CTF3 base line programme

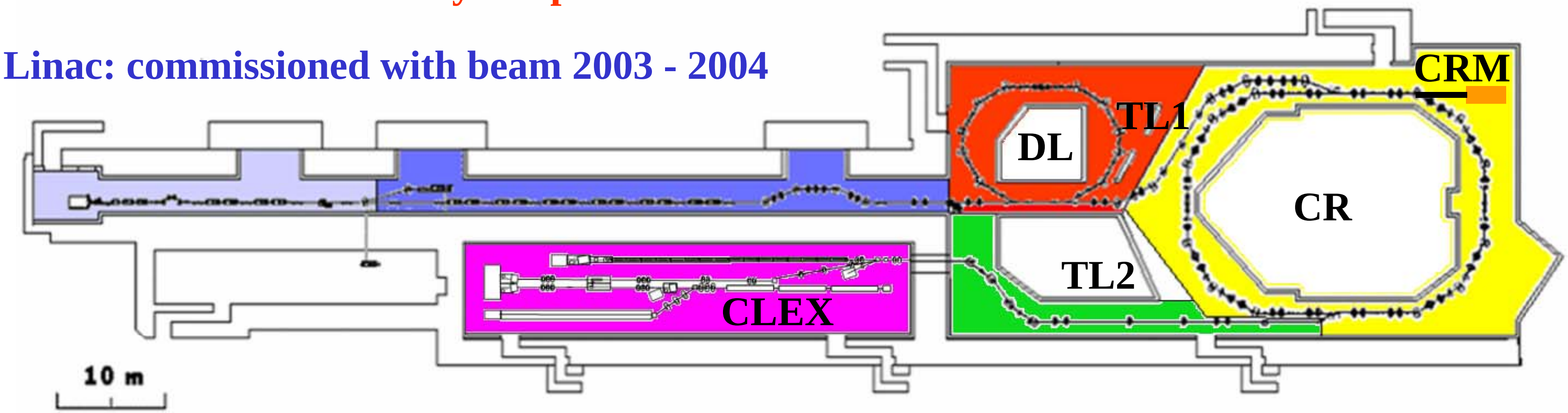


CLIC Test Facility 3

TL1 & CRM commissioned fall 2006

Delay Loop: commissioned with beam 2005-2006

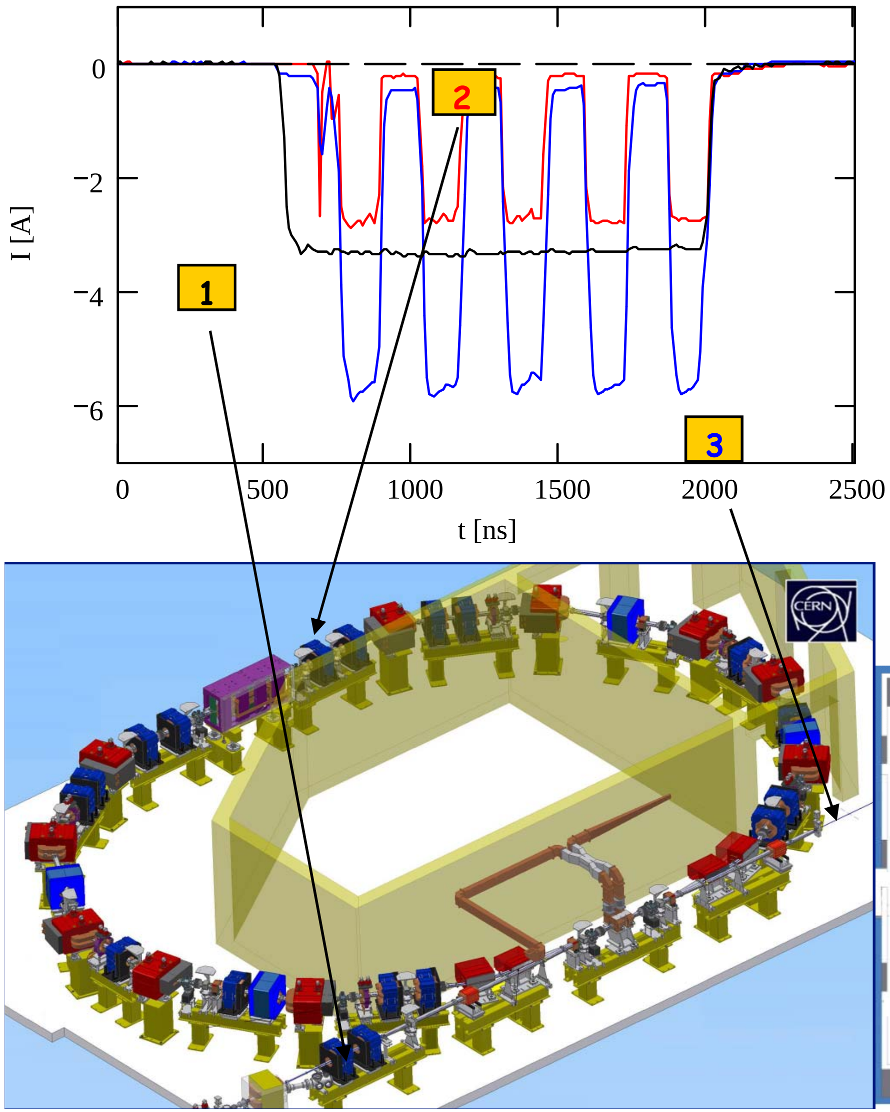
Linac: commissioned with beam 2003 - 2004



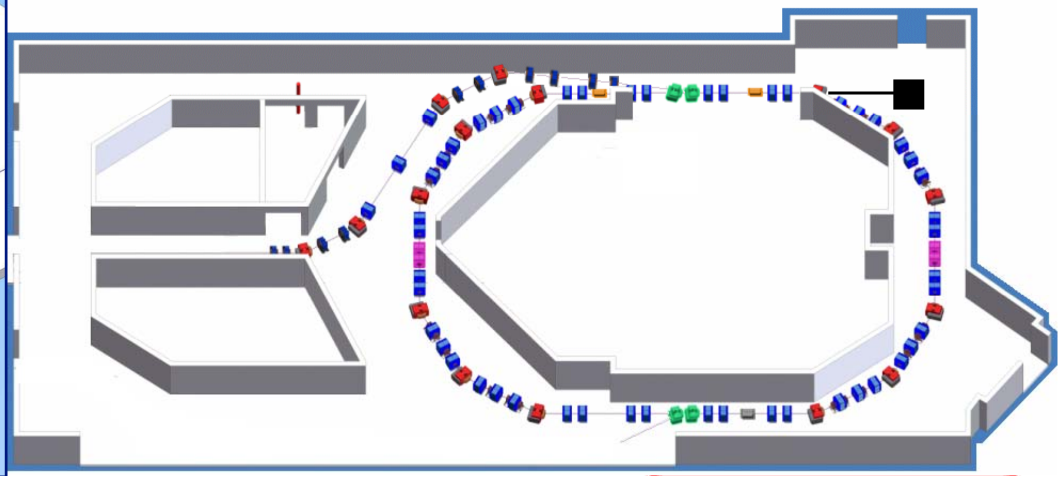
TL2 and TBTS commissioning started August 2008

CR commissioning since 2007

Main Points of 2006

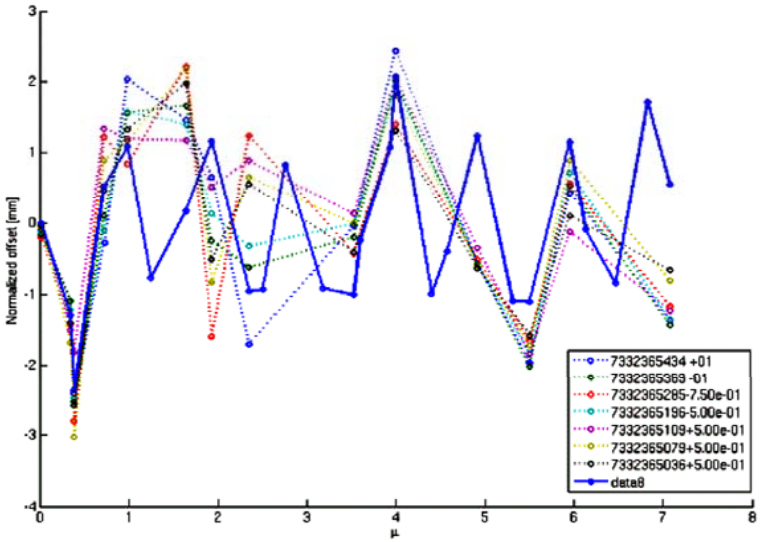


- Delay Loop Commissioned
  - 7A after DL
  - 1400 ns pulse length
- TL1 and CR injection Commissioned
  - 3.2A in TL1, 3A in CRM
  - RF injection to CR



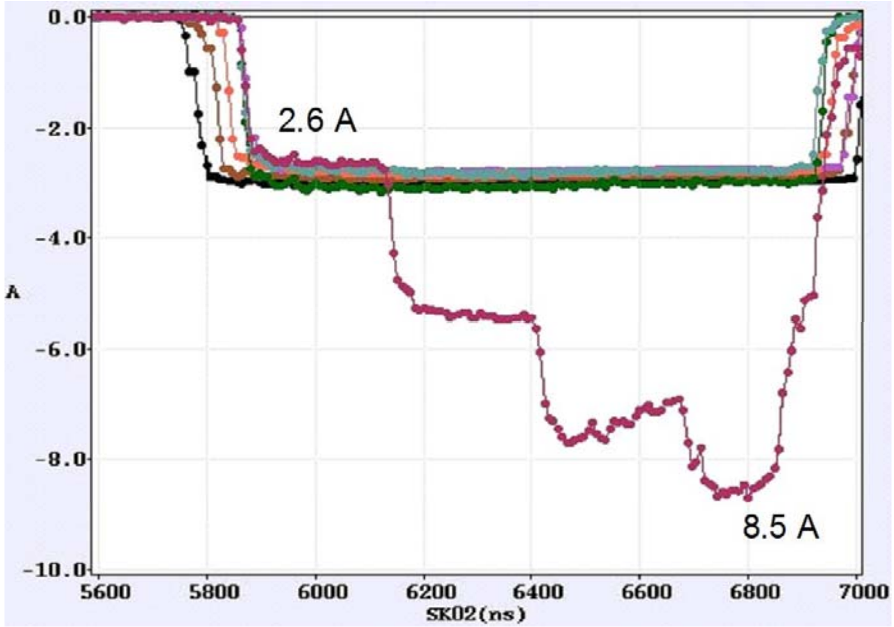
Main Points of 2007
TL1 and CR

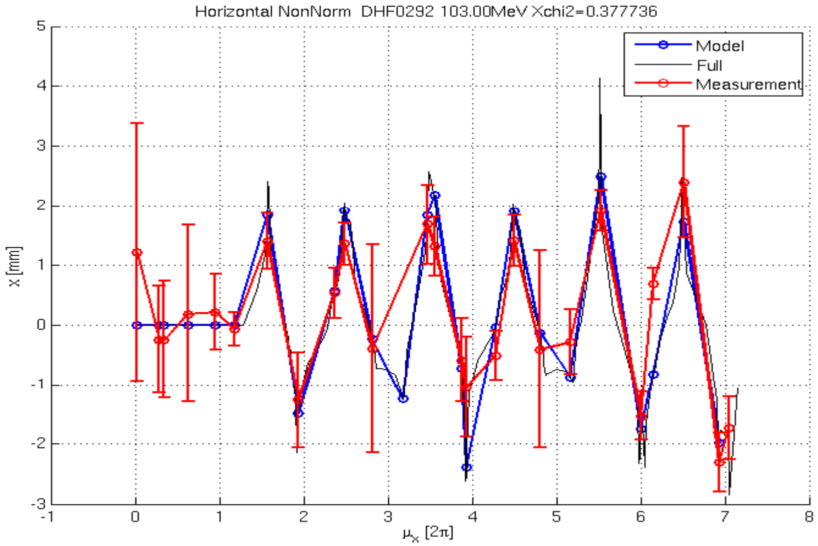
- Transfer Line 1 relatively quickly commissioned
- No major problems with establishing injection to CR
- Long and painful CR commissioning being finished only now
  - Fast Vertical Instability caused by the deflectors
  - Bad cabling of quadrupoles
  - Wrongly calibrated BPMs
  - Unstable gun
  - Inaccurate model of the ring



Main Points of 2007
CR results

- Besides all the problems
  - We have managed to recombine the train factor 4
    - OK, almost 4, but the principle was shown to be valid
  - Perform the optics studies which enabled gradual debugging and validation of the machine model

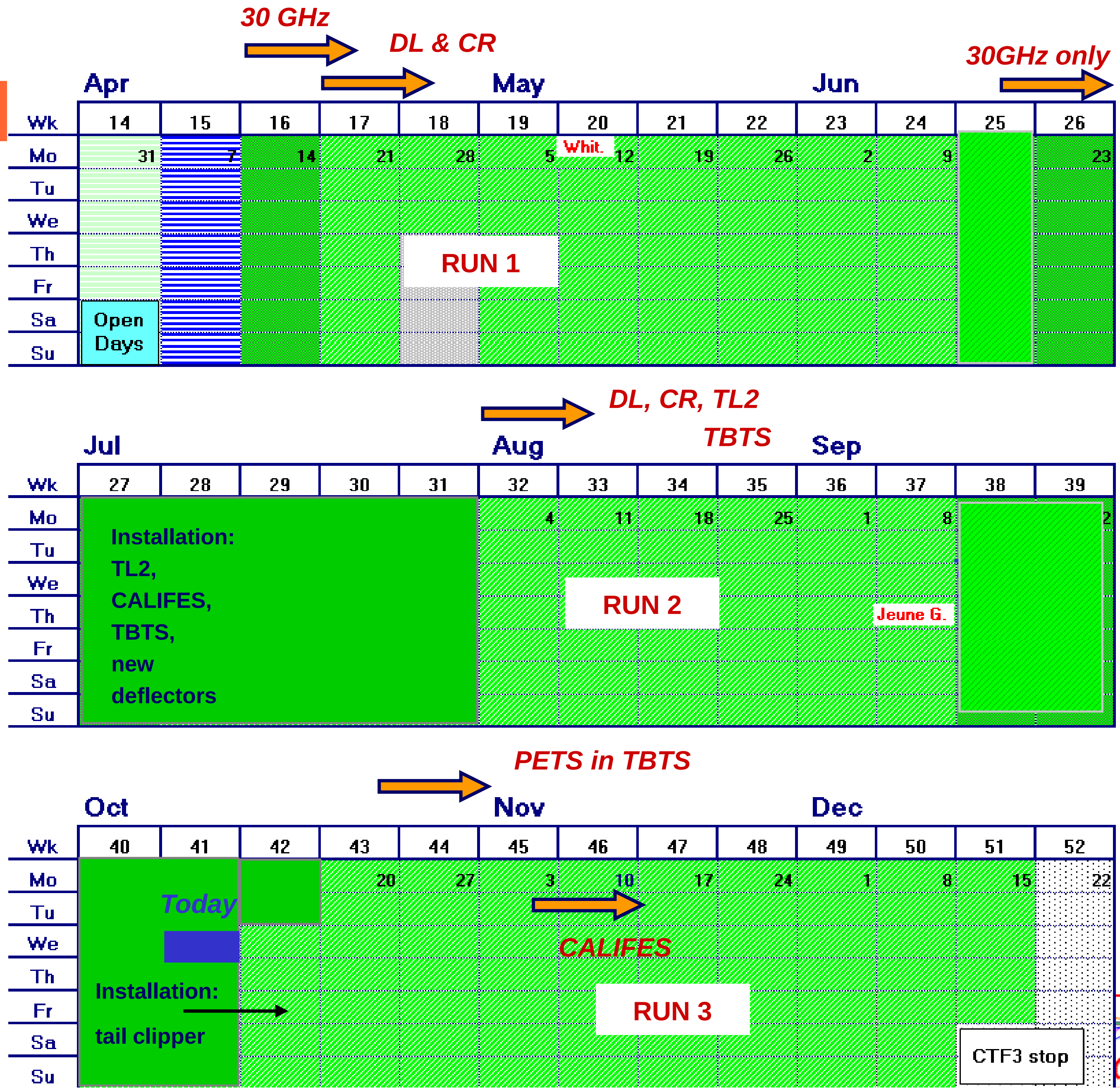




Operations

- The machine is operated in two modes
  - PETS beam for 30GHz structures tests
    - From Friday to Monday morning
    - Setup is done by CTF3 team
    - Night and weekend supervision from CCC by PS operators
  - Commissioning beam
    - From Monday to Thursday
    - Two overlapping shifts (volontary),
      - From 8AM to 4PM
      - From 2PM to 8PM
        - PhD students tend to extend it voluntarily till 3AM

Schedule 2008 v3



Linac only

Linac, Ring area, (CLEX)

2008 program – Run 1

- Find and repair the problem with the gun
- Linac
  - establish stable & documented working point
  - stability studies
  - diagnostic consolidation
- Delay Loop
  - Beam optics measurements
  - Re-establish recombinations
- Finish the commissioning of CR
  - Perform set of optics measurements
  - Validate the machine model
  - tune and β function dependence of vertical instability
- Test new devices and techniques
  - EuroTeV BPMs
  - Bunch length measurement with RF pickup
  - Transient compensation
  - Dispersion Free Steering and other automatic algorithms

2008 program – Installations 1

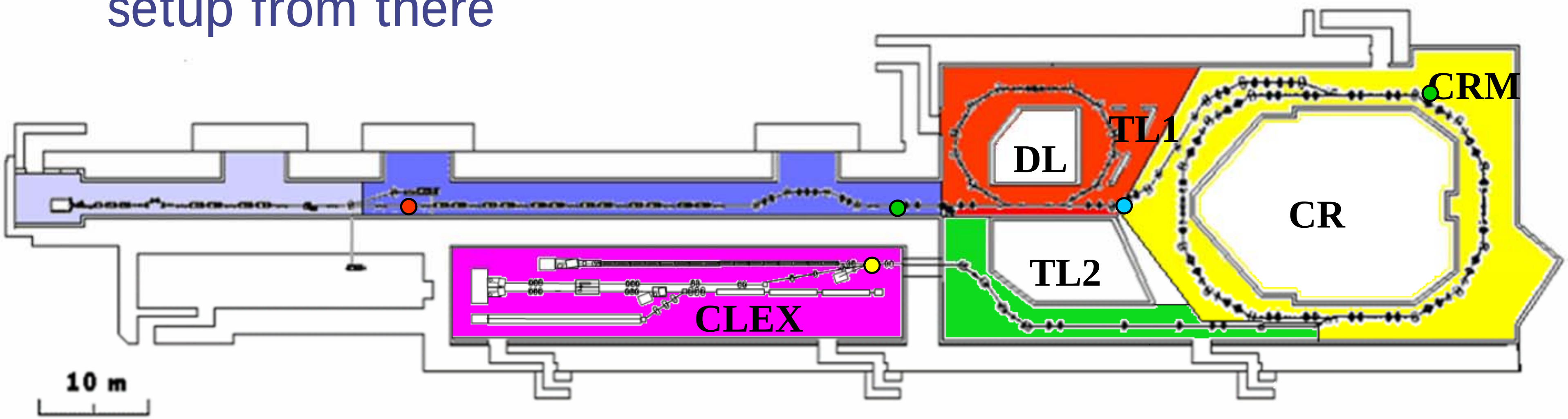
- Technical break in summer for
  - Complete TL2 installation
  - Install new deflectors (!)
  - Complete CLEX installations
    - When the dump after CR was removed to make place for TL2 personnel was not allowed to enter CLEX when the beam was in DL or CR (and vice versa)

2008 program – Run 2

- Run 2
  - Commission the new RF deflectors
  - Re-setup beam recombination in CR
  - Full recombination with DL and CR (factor 8)
  - Commissioning of
    - TL2
    - TBTS (no PETS)
    - First trial for CALIFES
- Installations 2 (beginning of Oct)
  - Tail clipper
- Run 3
  - Commissioning of
    - CALIFES
    - TBTS (wtih PETS)
    - Coherent Diffraction Radiation tests

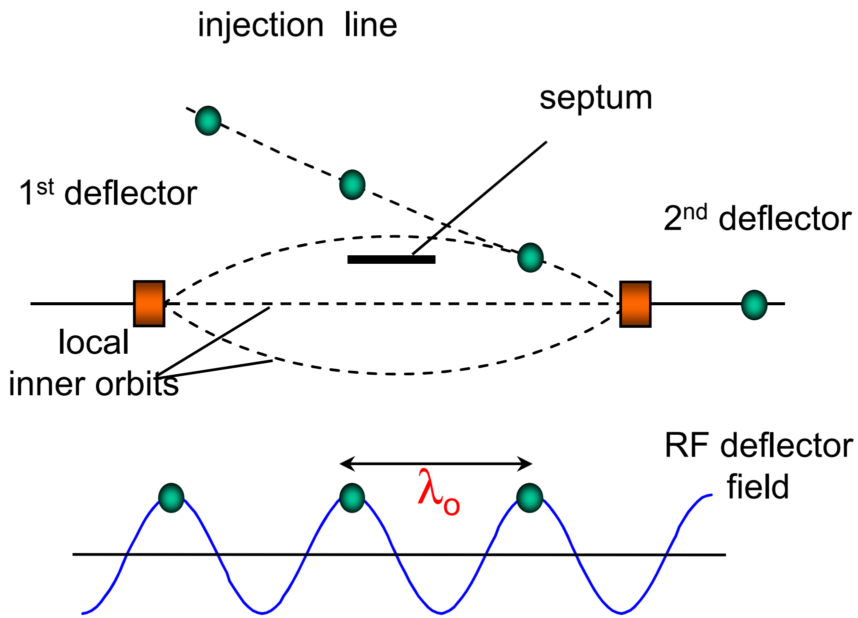
Machine Setup on one slide

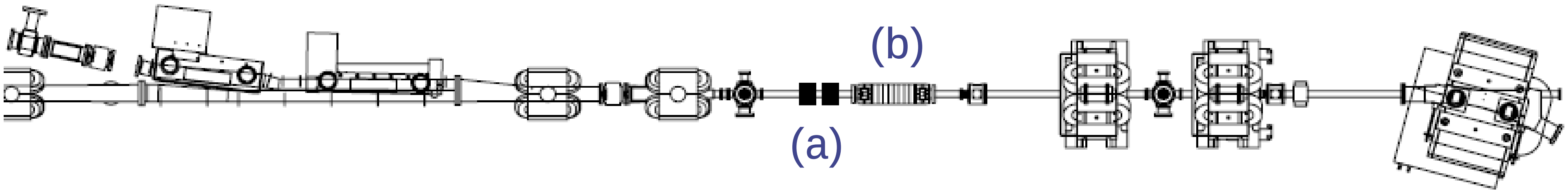
- Machine setup is based on quad scans
  - Beam is set-up to the screen on girder 10
    - Phases of acc-structures up to girder 10 are adjusted to get full loading
  - Twiss parameters are measured and whole linac is rematched
    - Phase adjustment for the rest of the structures
    - Energy profile is measured at girder 10 and elsewhere is calculated
  - Another quad scan is made at CTS
  - TL1 and is matched to the CR closed solution at this given energy
- If something changes at given point, we must redo the setup from there



CR Injection

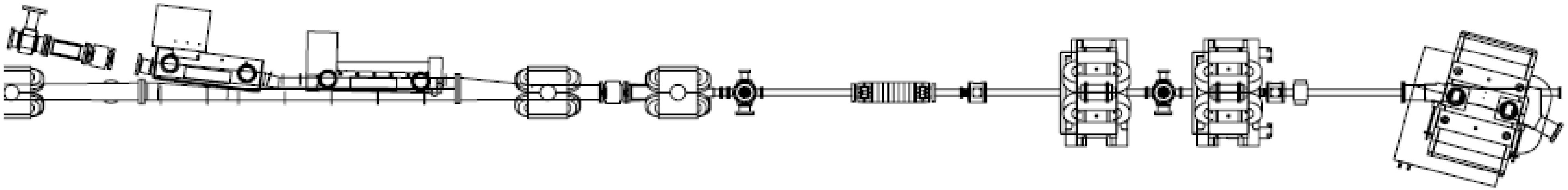
- Beam recombination in CR is made with time variable bump





Long circulating CR beam

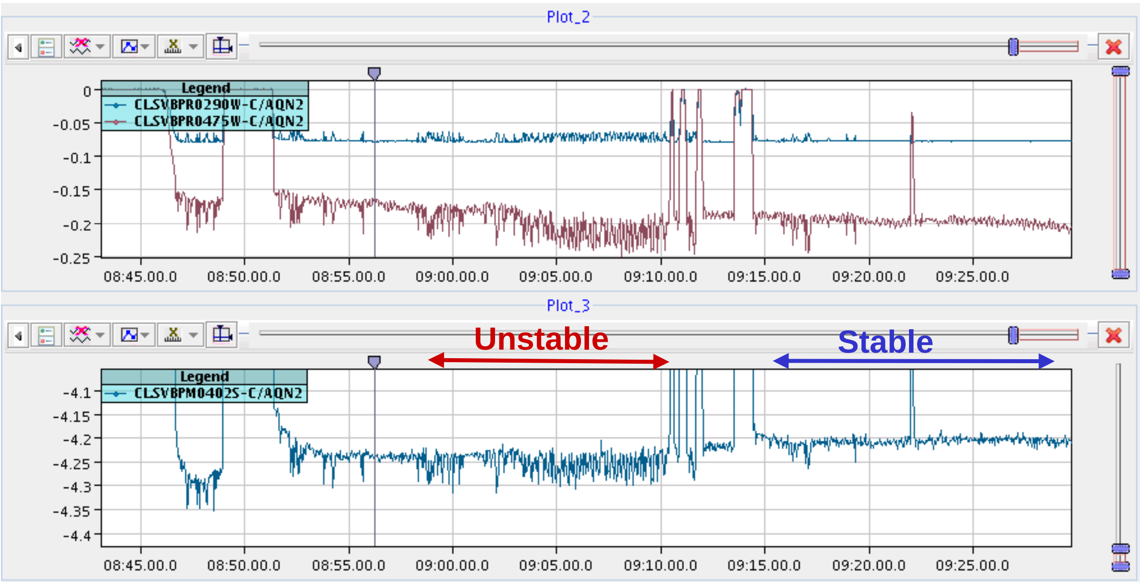
- Many measurements require long ciruclating beam in CR
  - Tune
  - Closed orbit correction
  - Closed orbit length measurement
- The beam is injected to the ring RF deflectors
  - The klystron timing is adjusted so the RF pulse ends when the last bunch of the train leaves the deflector
  - Since those are travelling wave cavities with short filling time the RF is gone before the first beam of the train comes back to the deflector
  - This way beam makes several hundreds turns before it irradiates too much energy thru synchrotron radiation to be fitted in the acceptance



Unstable gun

- Already since the first run of 2007 we observe large beam jitter that originates from the gun instability
  - The current is slightly different from shot to shot
  - Since we operate in the fully loaded mode
    - phases are adjusted so all the RF energy is transferred to the beam

    bunches with different current are accelerated differently
  - It leads position jitter in the dispersive regions
    - What makes the setup and measurements very hard!



Unstable gun (cont.)

- Finding the problem was difficult and tedious
  - the system operates on high voltage (130-150kV) and hence specialized knowledge and equipment is needed for investigations
    - On top of that the device is constructed by LAL and the designer is retired
  - It was finally found that the high voltage power converter produces chainsaw-like signal
    - however according to the manufacturer the device itself was OK
  - After inspection in-situ one of resistors was found cracked
    - connecting capacitor bank to the ground
      - at low voltage the resistance was 0, but when 150kV applied than it was conducting thru arcing
  - And later another resistor found cracked
    - between capacitor bank and the high voltage deck
  - Since than (end of September 2008) the gun behaves OK
    - However, we are not certain that it was the core of the problem and it is going to come back at some point

Optics Studies and Model Validation

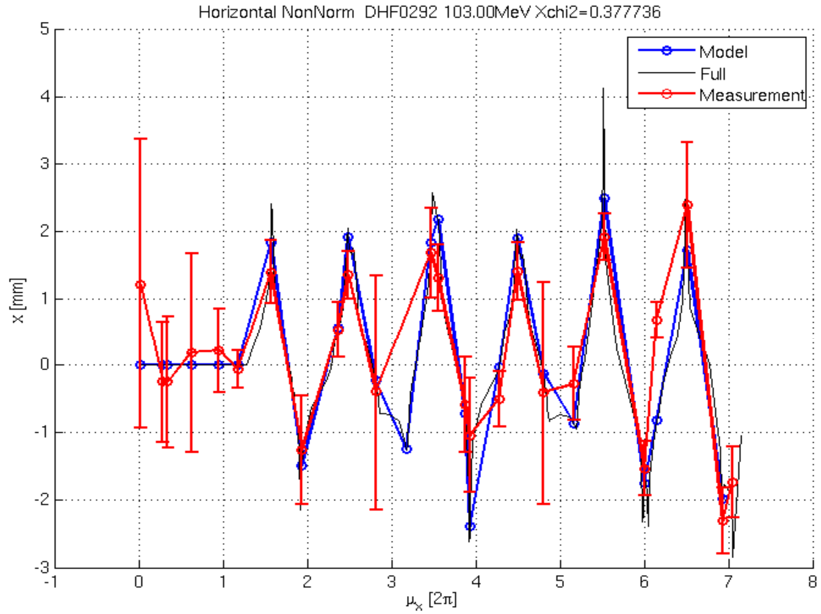
- The main reason for extensive optics measurements is verification that the model predicted optics well agrees with the measured one, and if they don't
  - Machine was not build according to the specification
  - There is a bug in the model
  - One can not back-hand the setup with the model calculations
- We performed the following optics measurements
  - Dispersion
  - Response Matrix
  - Tunes
  - Combiner Ring Length
  - Bunch length
  - Quadrupole current to K1 coefficient

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 relatively 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
- The measurements are automatized with a MatLAB script

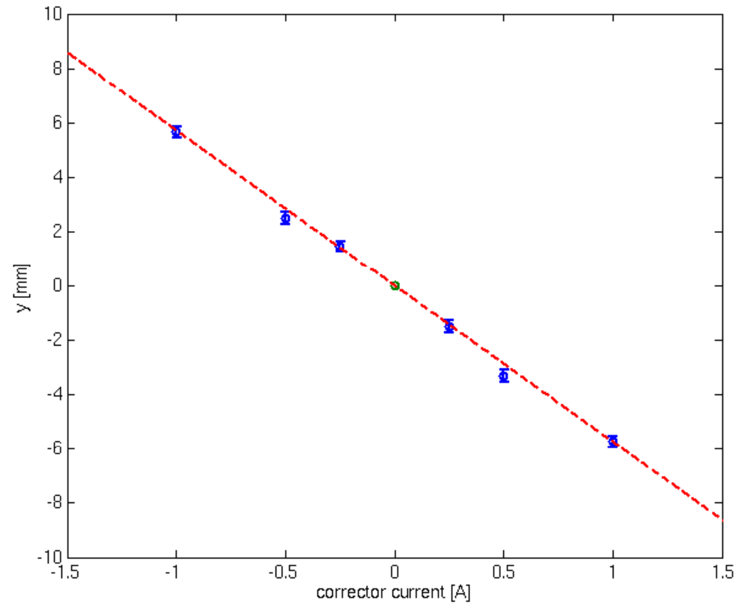
The Response Matrix Study

- Already during 2007 runs response matrix study allowed to find few problems with the CR model
  - Current to gradient coefficient for J type magnets (5%)
  - Wiggler focusing
- Some discrepancies were still present
  - They were not localized in a precise location
  - Large statistical uncertainties originating in the gun instability did not allow to find the subtle problems quickly



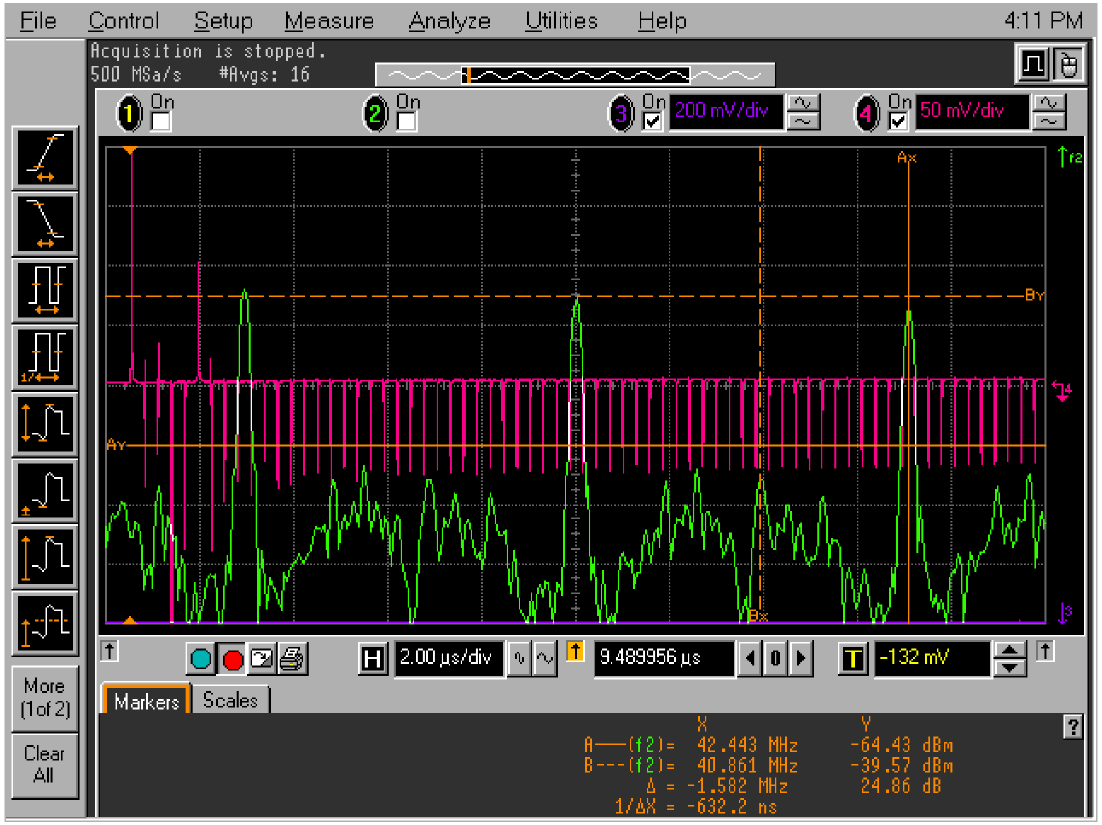
High precision Response Matrix measurement

- For each corrector we performed larger set of measurements with different values of the kick, starting with very small values
  - Response should be linear with the kick
    - Points that do not lay on the line defined by the majority of the (low amplitude) points are not concidered
    - Fit to the remaining points defines the matrix element much more precisely.
  - The is way we reduce uncertainty of the measurement



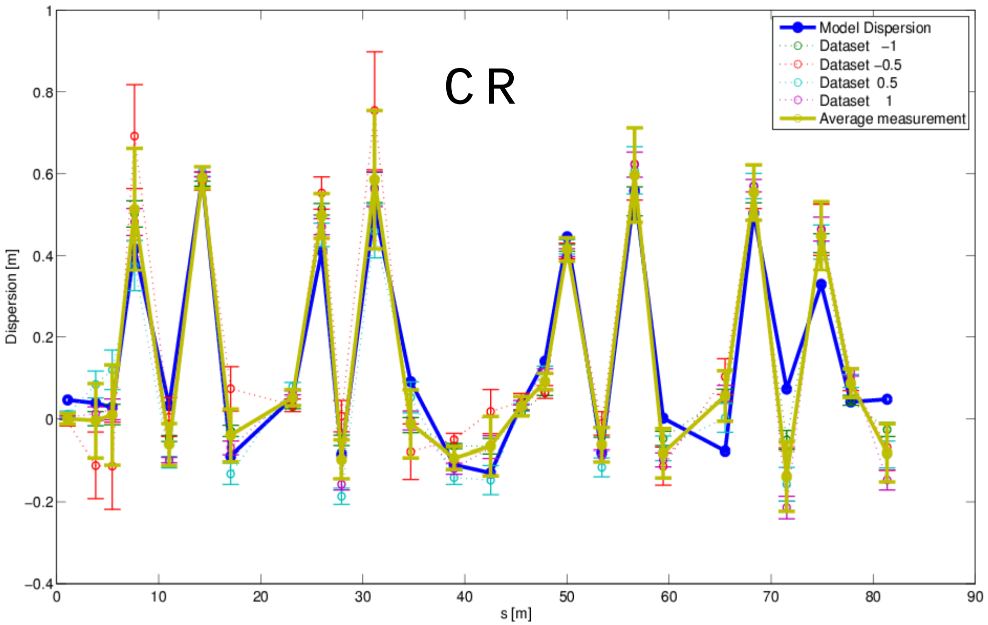
Tunes

- We measure tunes doing FFT of a pickup analog signal using a scope
  - More about it in the next presentation



Dispersion

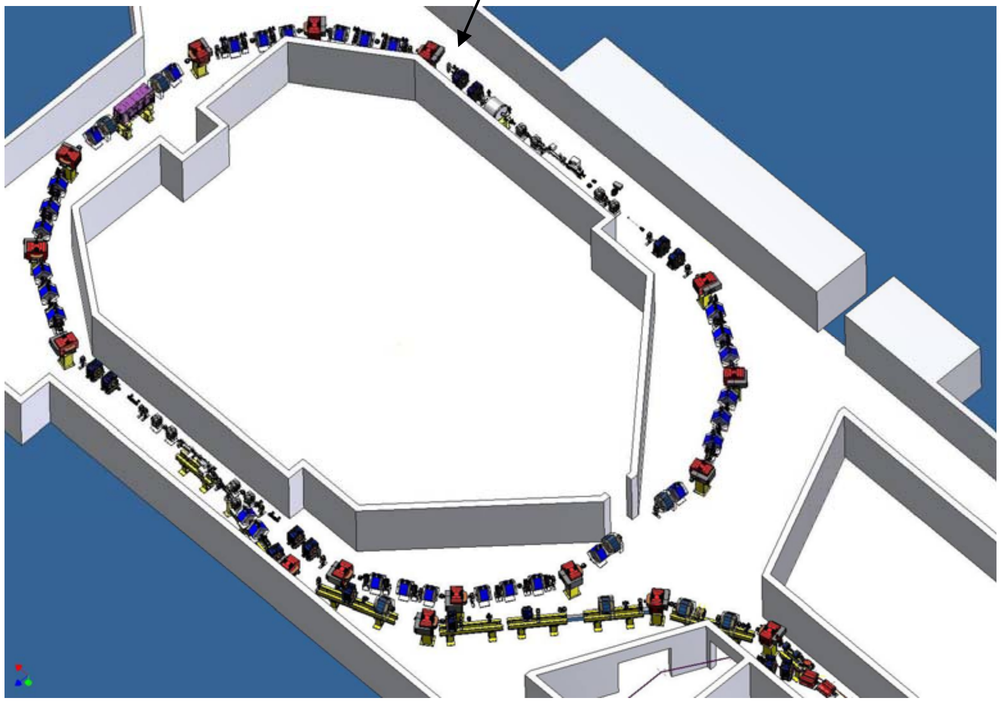
- Dispersion is measured with „line scaling” technique
  - All magnetic elements are scaled by some small factor
    - This makes the beam energy mismatched to the line setup
  - Easier for us comparing to energy change
  - Allows to measure dispersion section-wise, starting at any given element
  - More about it in the next talk by Simona

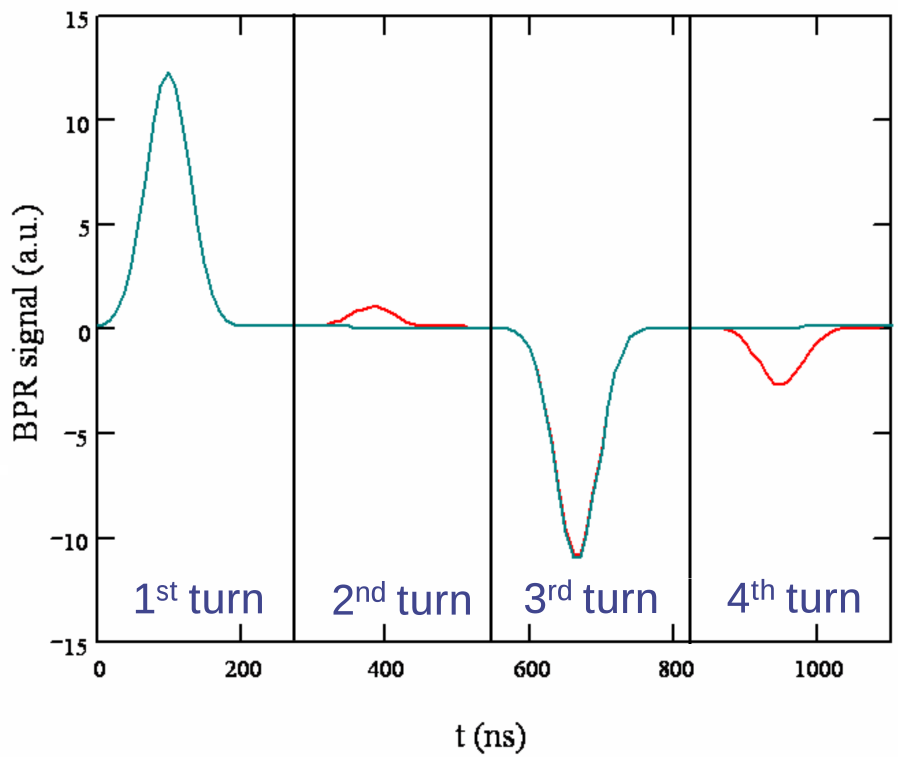


Measurement of the ring length

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





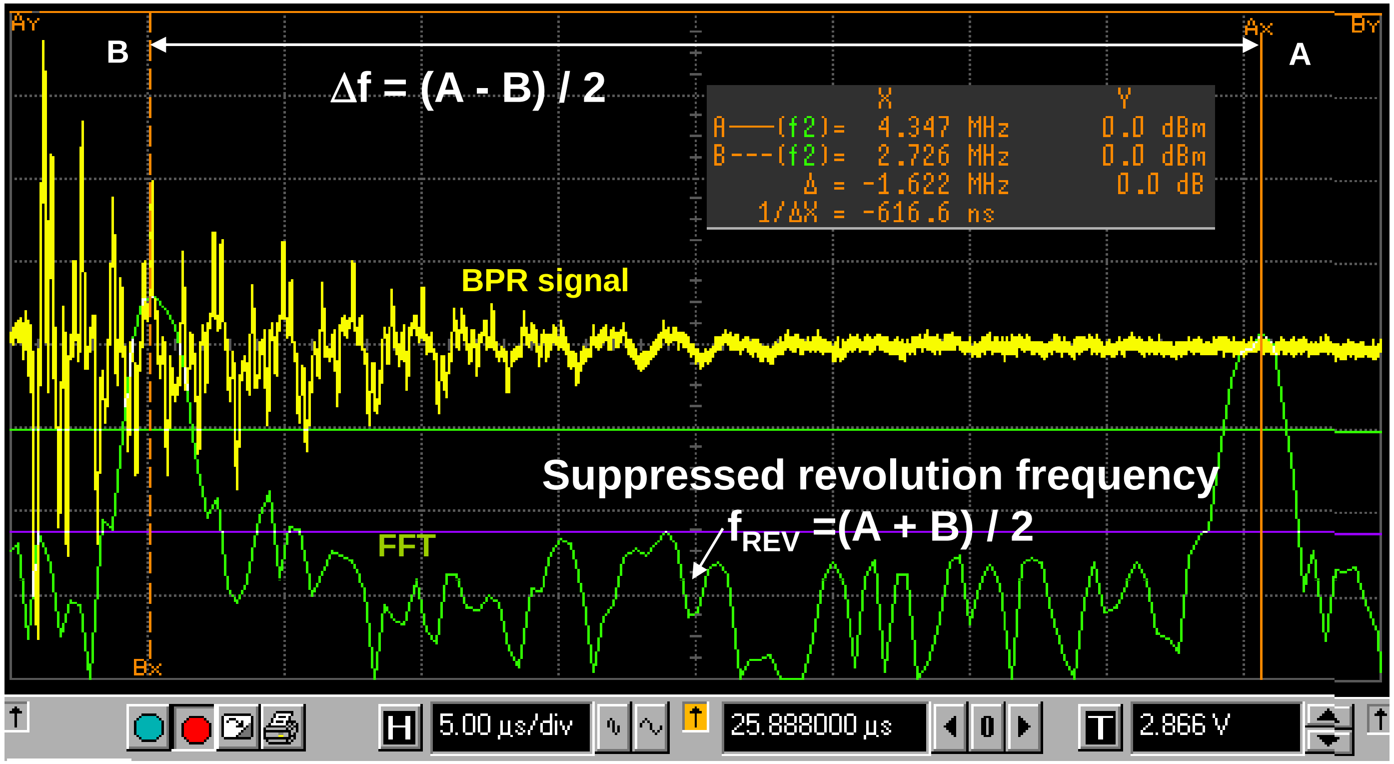
Simulated signal

Combination factor 4

Combination factor 4 with + 5° error

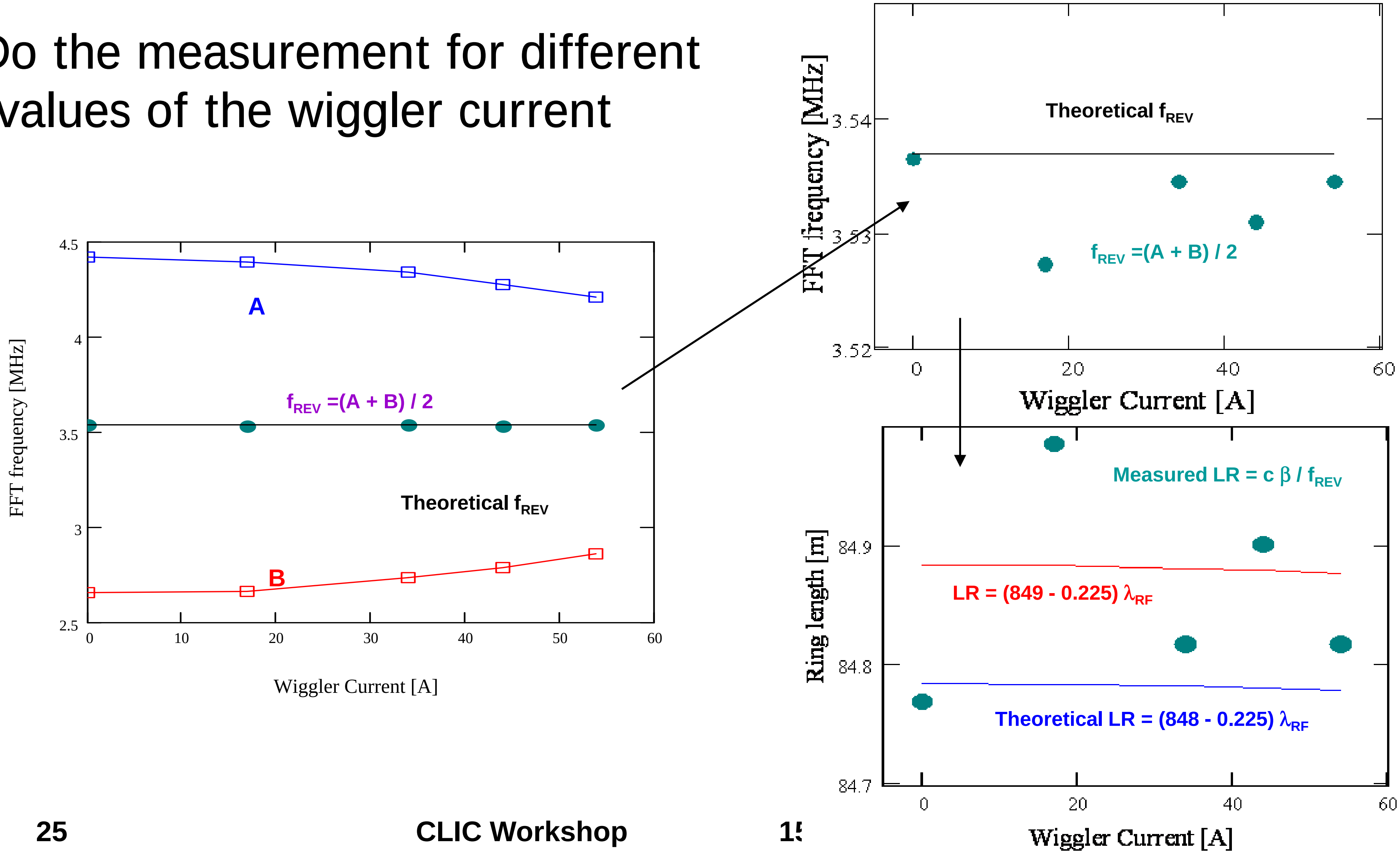
BPR measurement

- 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 $1/CF\ \lambda_{RF}$

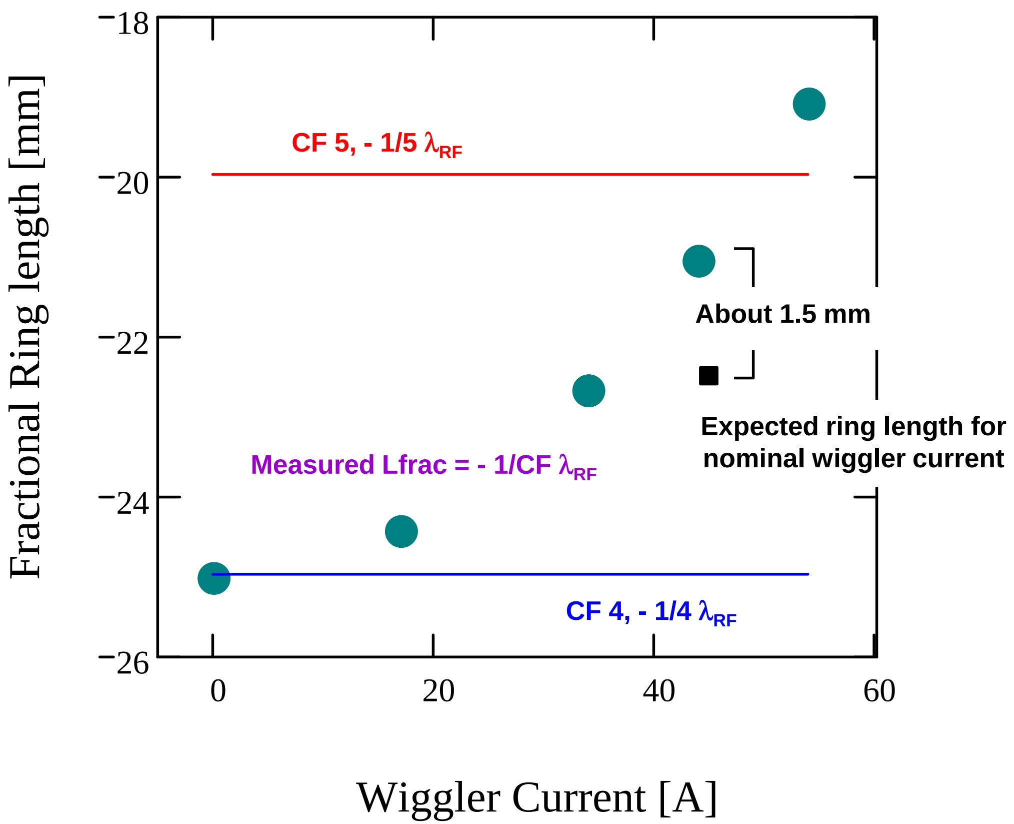


BPR measurement: f_{rev}

Do the measurement for different values of the wiggler current

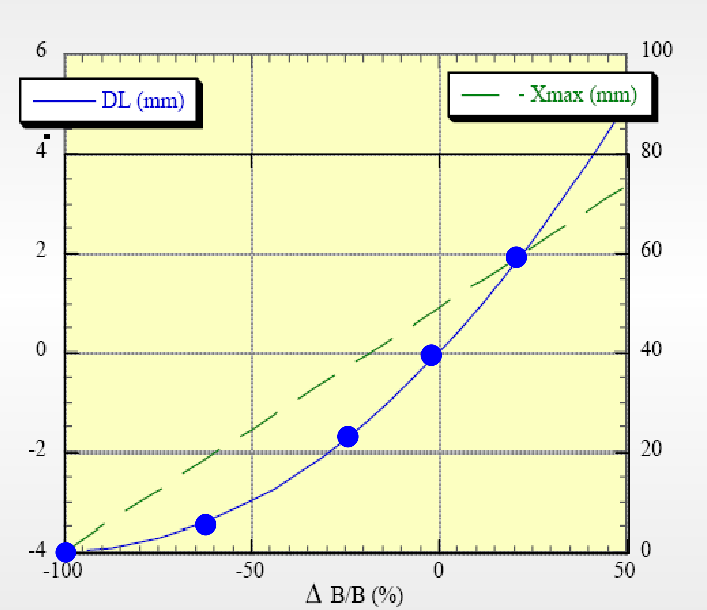


BPR measurement: Δf



expected —

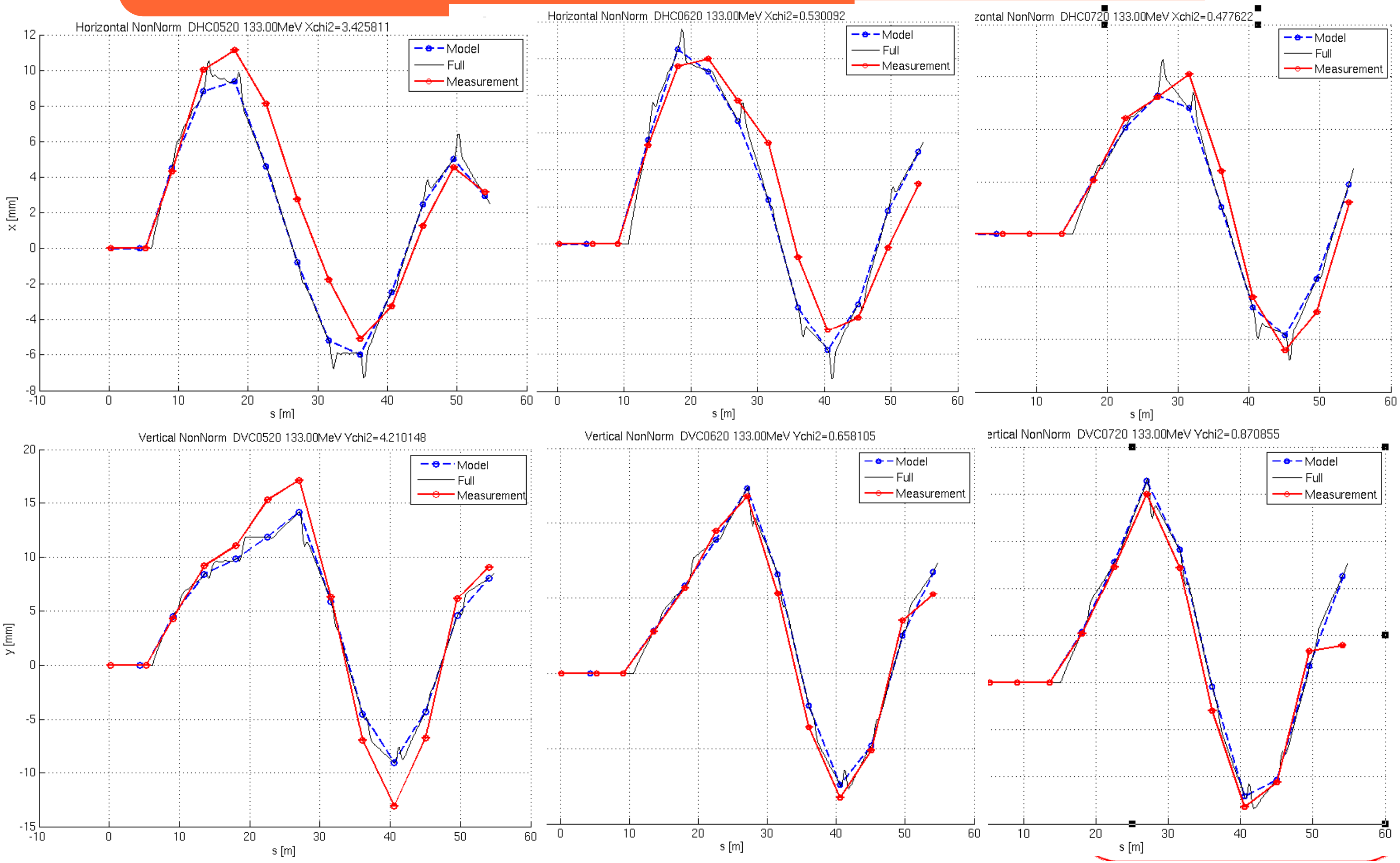
measured ●



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

C. Biscari

Linac Model Validation
Current Status and Remaining Problems

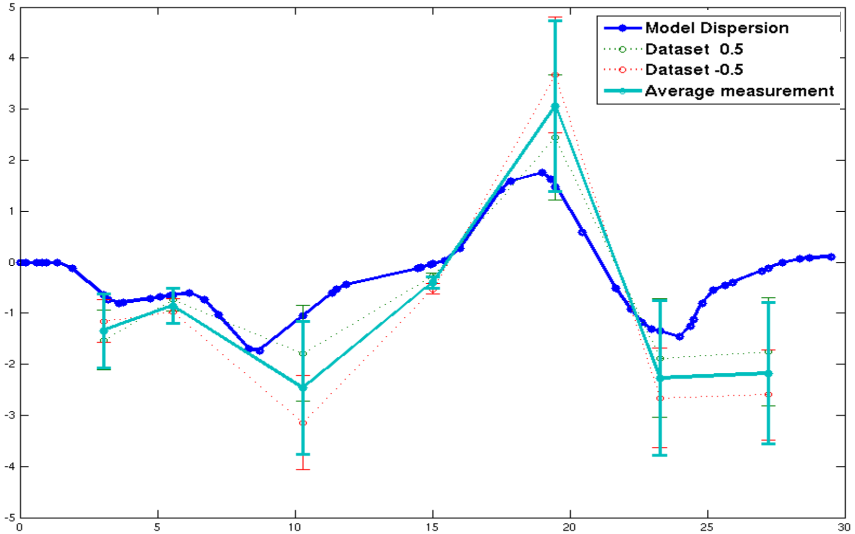


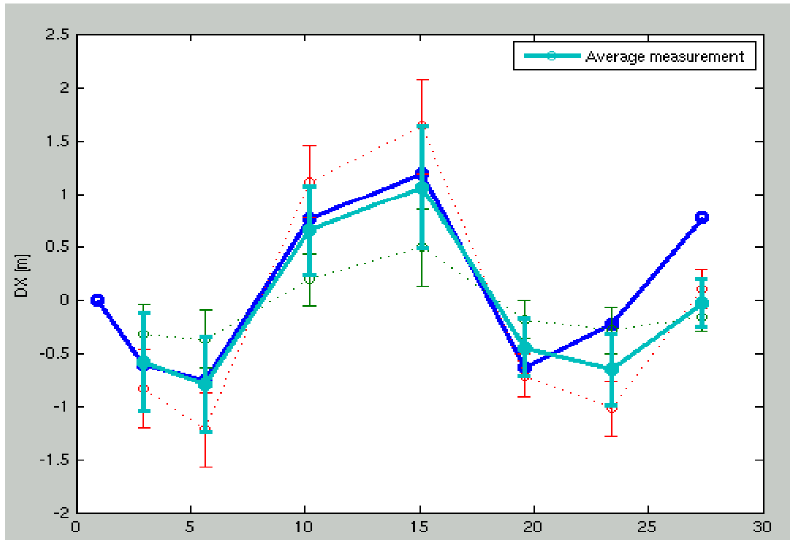
Linac Model Validation
Current Status and Remaining Problems

- There is some optics error in the area of girder 7 and 8
  - We see it as phase slippage in response matrix
  - But also when we rematch the linac, the twiss parameters measured afterwards are very close
- The magnetic fields on the pole surfaces where verified and are consistent with all the other magnets of this family
- More work is needed to nail down the problem
  - Additional data, for example response matrix with different quad families off, would certainly help
  - However, in principle we have already sufficient data to be able to find it with off-line analysis and systematic analysis should reveal the problem

TL1 Model Validation Discovered Bugs

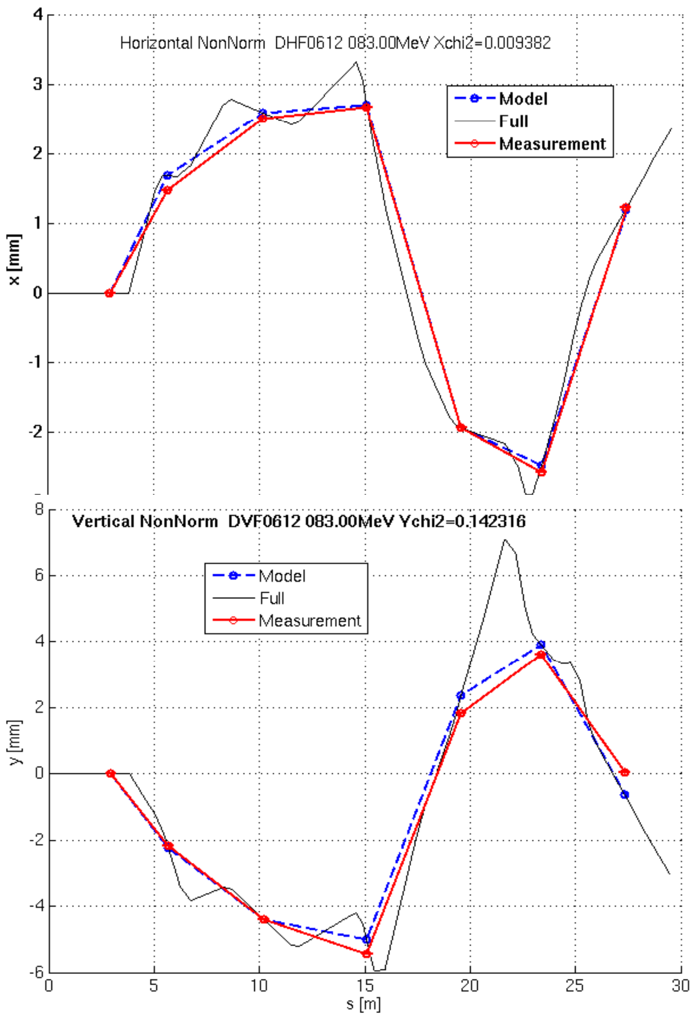
- The measured dispersion pattern in TL1 always was showing slight (just outside the error-bar) but systematic discrepancy at the last BPM
- Finally with the high precision response matrix measurement we found
  - wrong current to gradient coefficient for CT.QDF0720
  - Wrong drift length because of the same variable name used in CR

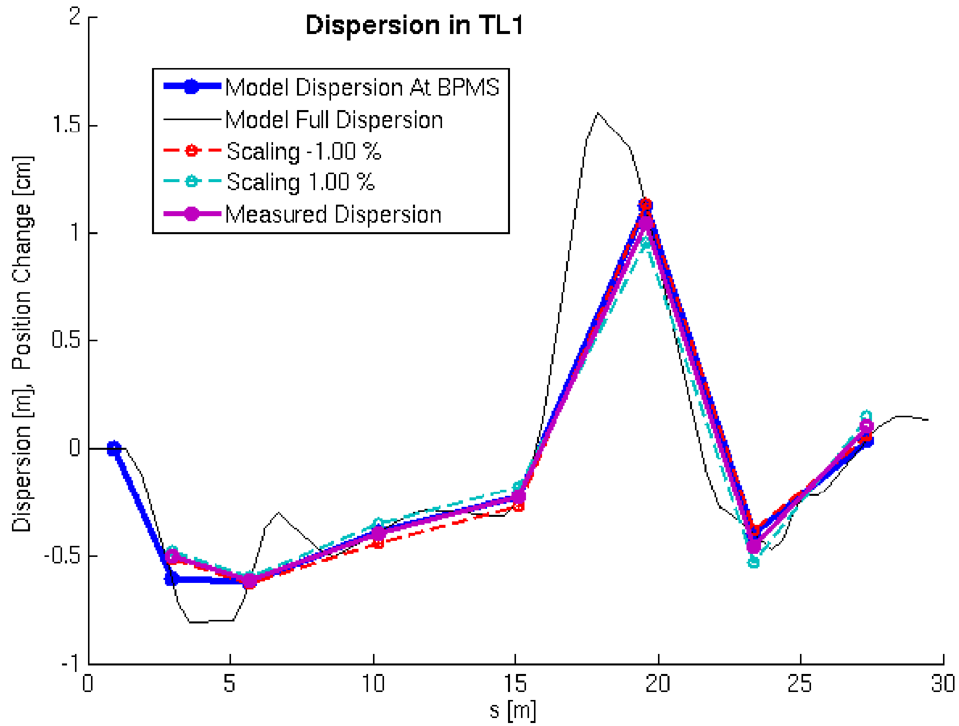




TL1 Model Validation
Current Status and Remaining Problems

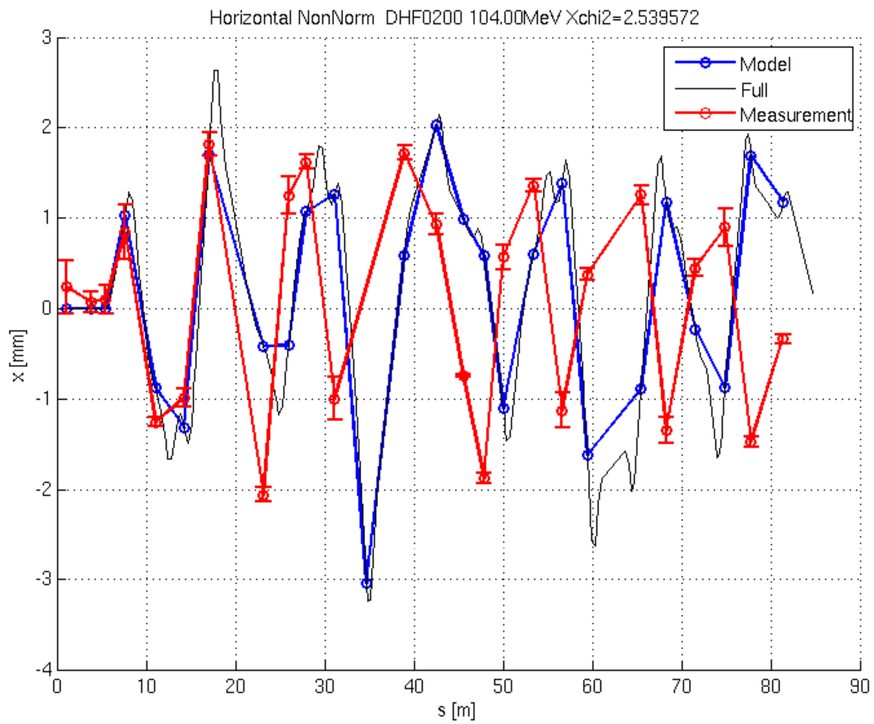
- We consider TL1 commissioned and its model quite well validated, although some small discrepancies remain





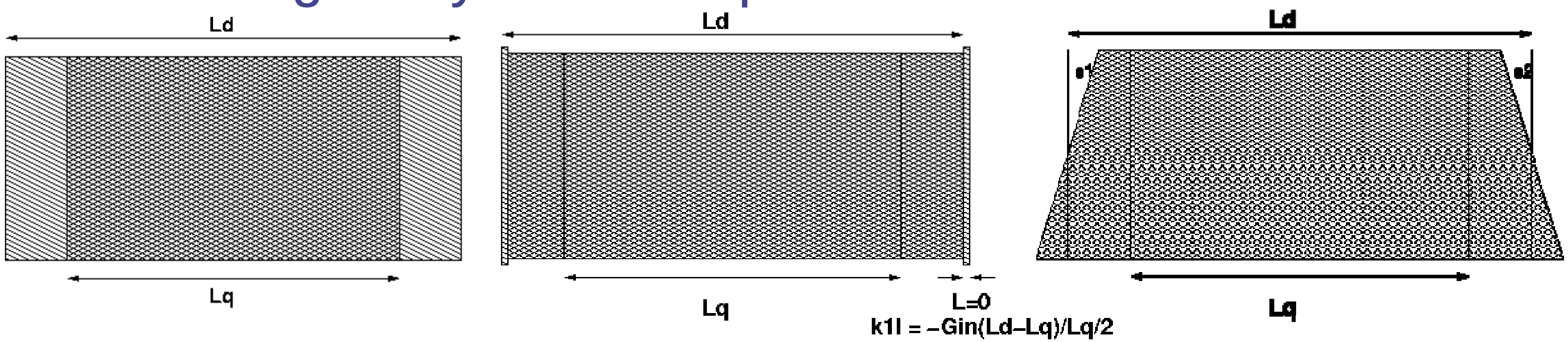
CR Model Validation Discovered Bugs

- Already in 2007 we found
  - Cross-cabled control units for quadrupole's power converters
  - Wrong current to gradient coefficient for J type quads
- Further higher precision measurements were needed to nail down the remaining discrepancies



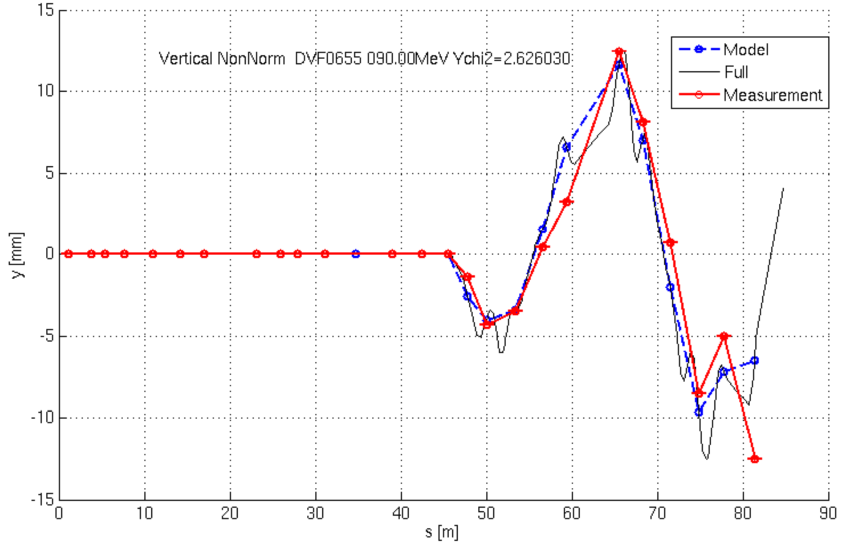
CR Model Validation
Discovered Bugs

- Insufficiently precise modeling of combined function magnets for magnetic lengths for quadrupolar component is shorter then for dipolar one
  - We inherited the model of those magnets from EPA in which the 3rd way of the magnet modeling was chosen
    - However EPA had 16 of them in the ring, and CR has 12
    - Although all parameters were scaled accordingly and it should work for CR equally well as for EPA
- The modeling with the straight forward (1st) way give slightly better results
- Lowering k1 by 10% compares better with the model



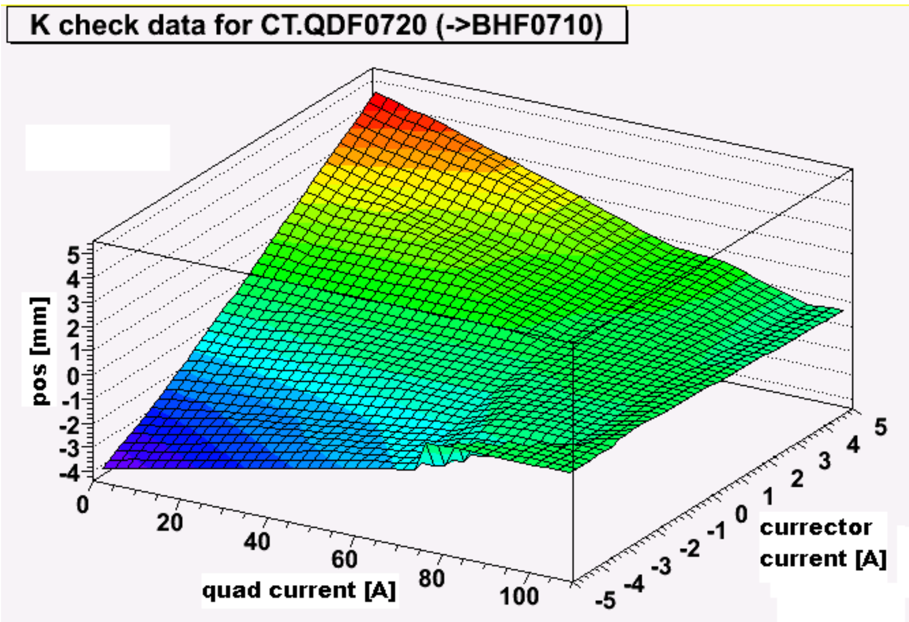
CR Model Validation
Current Status and Remaining Problems

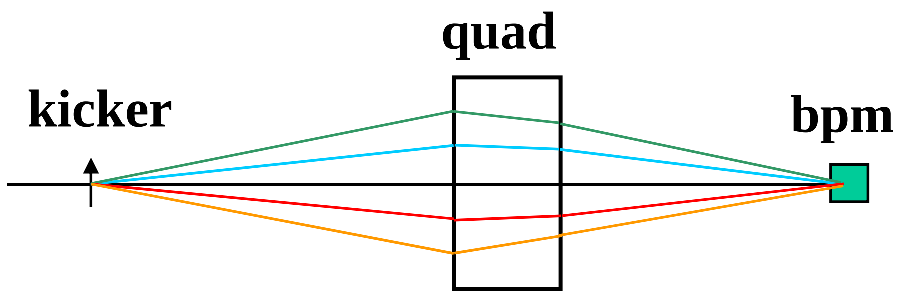
- Response matrix
  - Lowering 10% quadrupolar strength for combined function magnets gives better agreement between the model and RM data for the second half of CR
  - But the first half still does not agree well
    - Presumably we have more than one optics error
    - Hopefully now machine will be more stable so we can get large range of high quality measurements with the constant conditions



K1 measurement

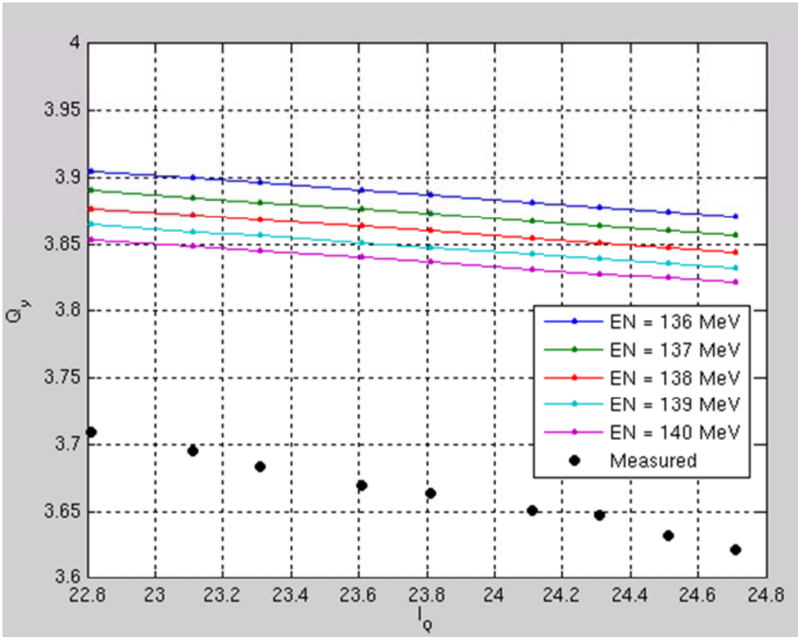
- We have attempted to measure fucusing strength of combined function magnets
  - We look for the magnet current that gives 180 phase advance between kicker and bpm
    - Knowing energy and distances we get k1
- Unfortunately when we did it the gun was still unstable and the result was not precise enough

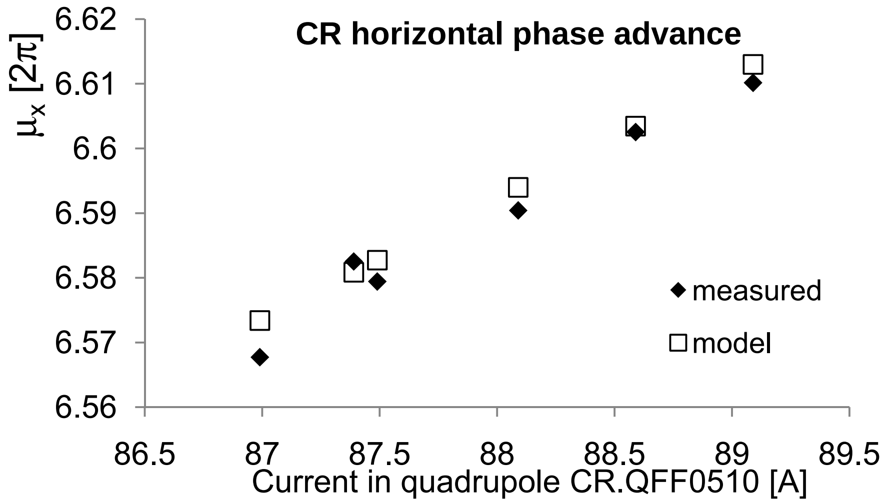


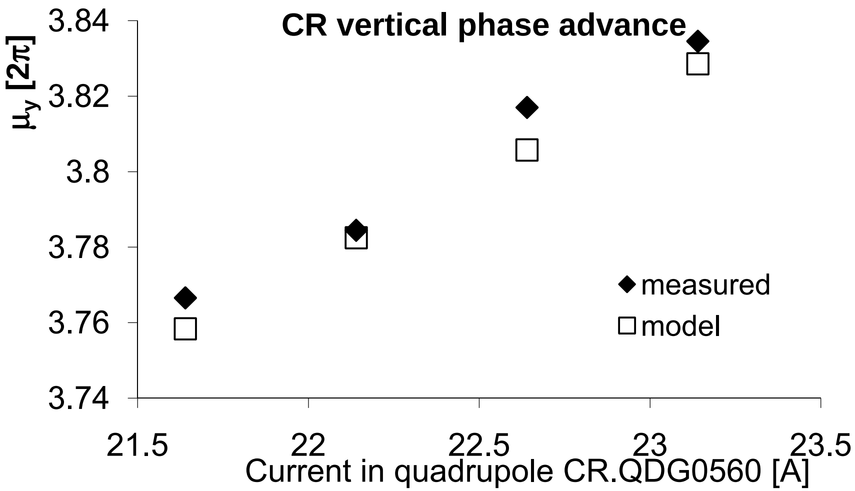


CR Model Validation
Tune measurements

- Tune measurements
  - We see discrepancy with the model

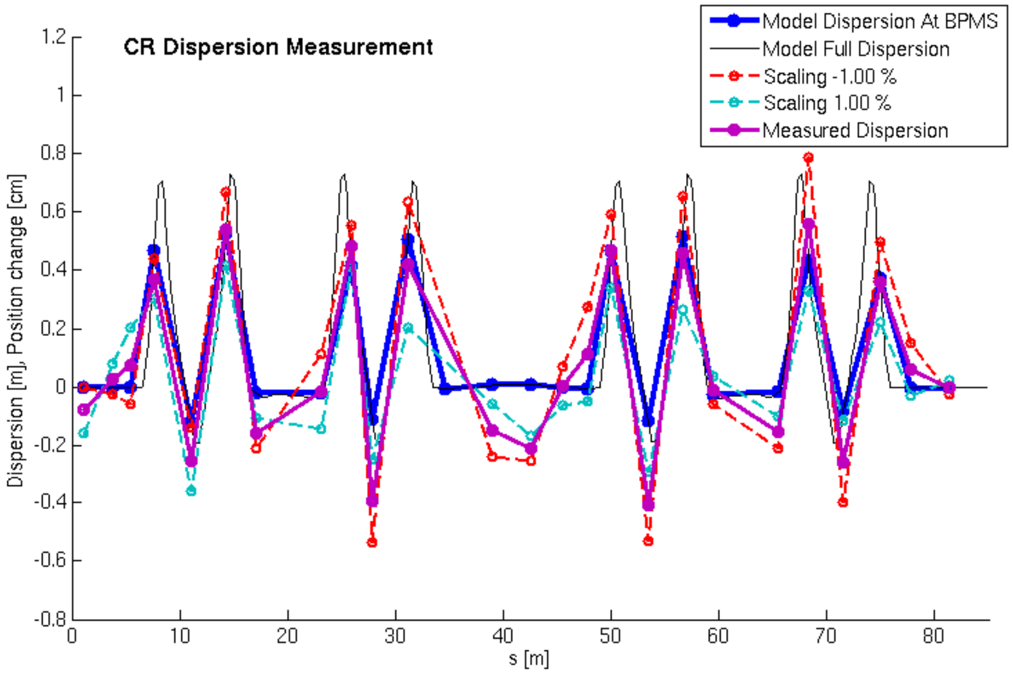




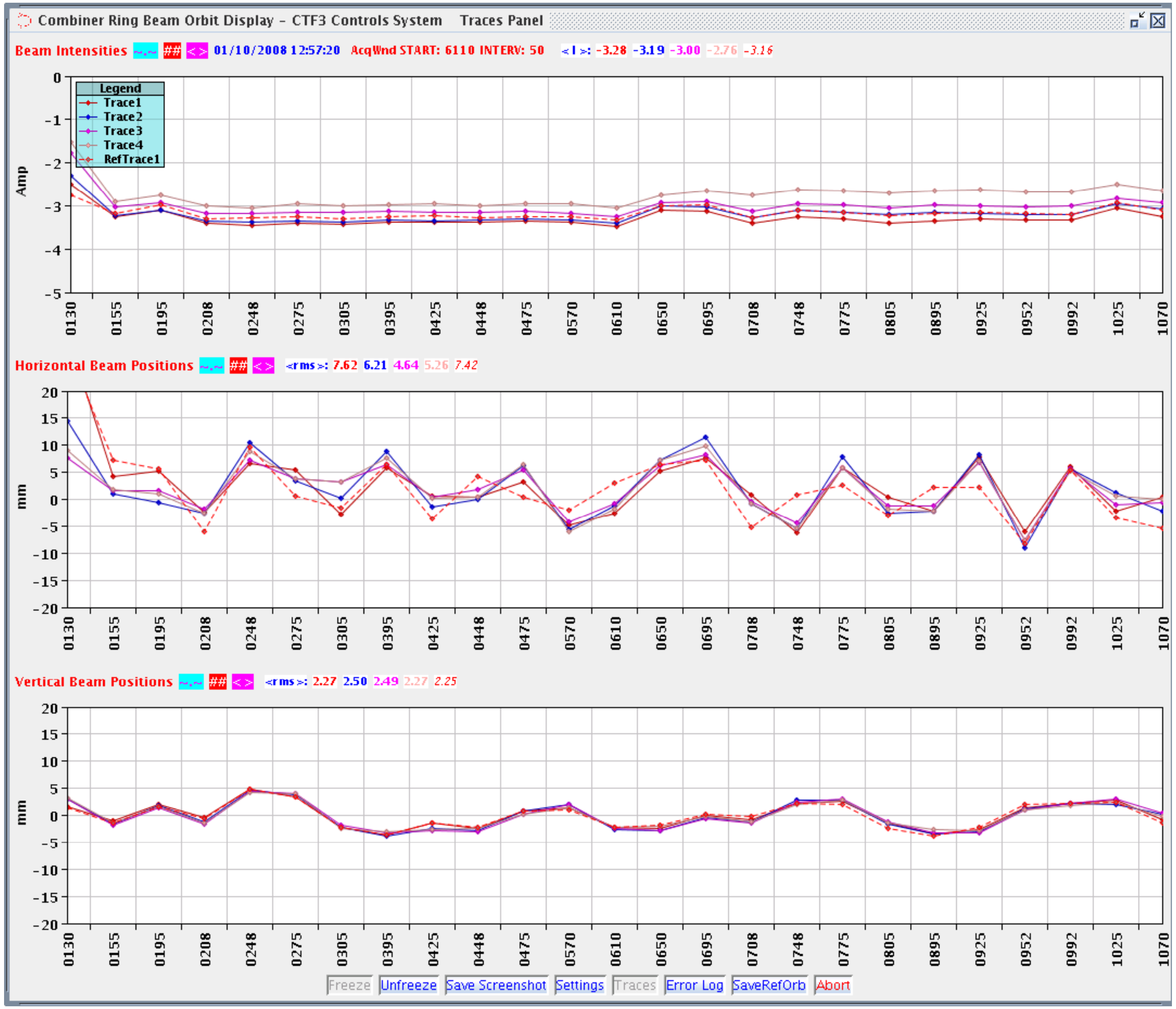


CR Model Validation
Current Status and Remaining Problems

- Dispersion measurements
  - Close, but not enough

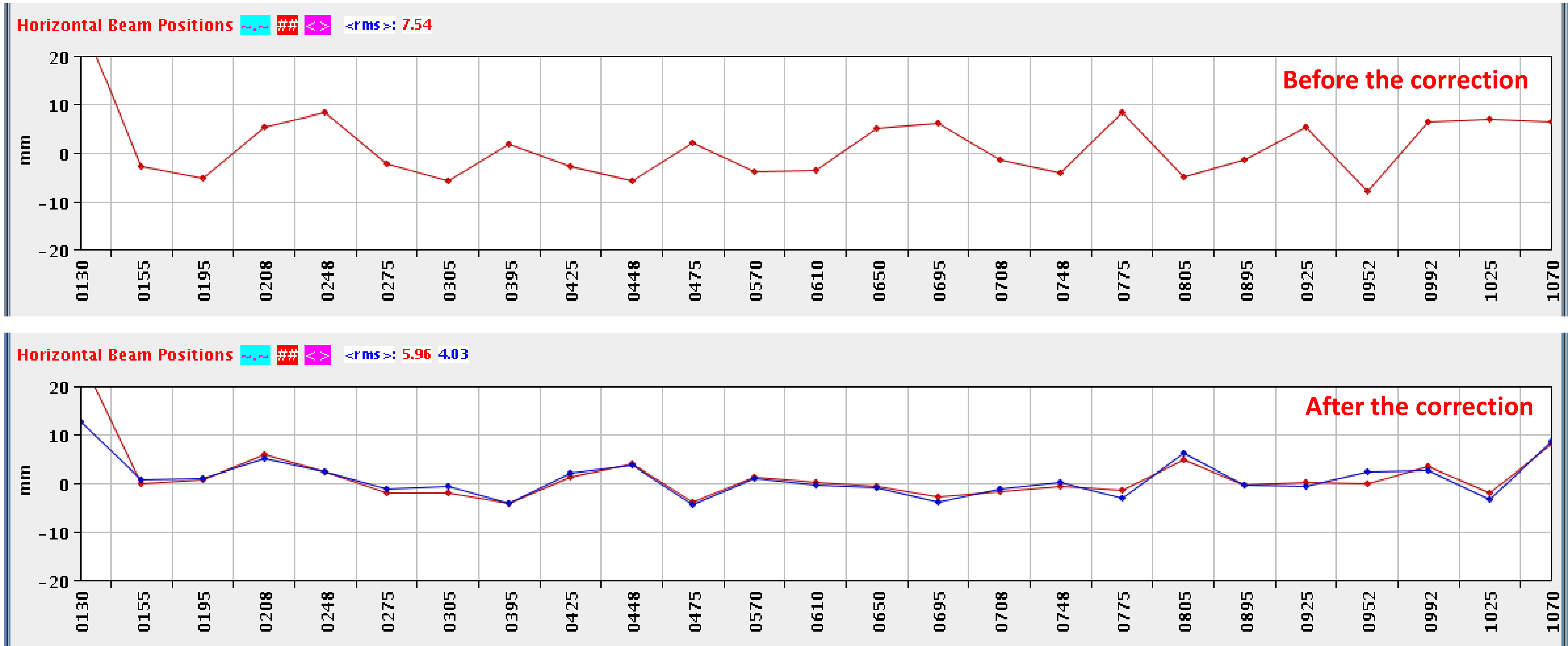


CR Orbit Closure



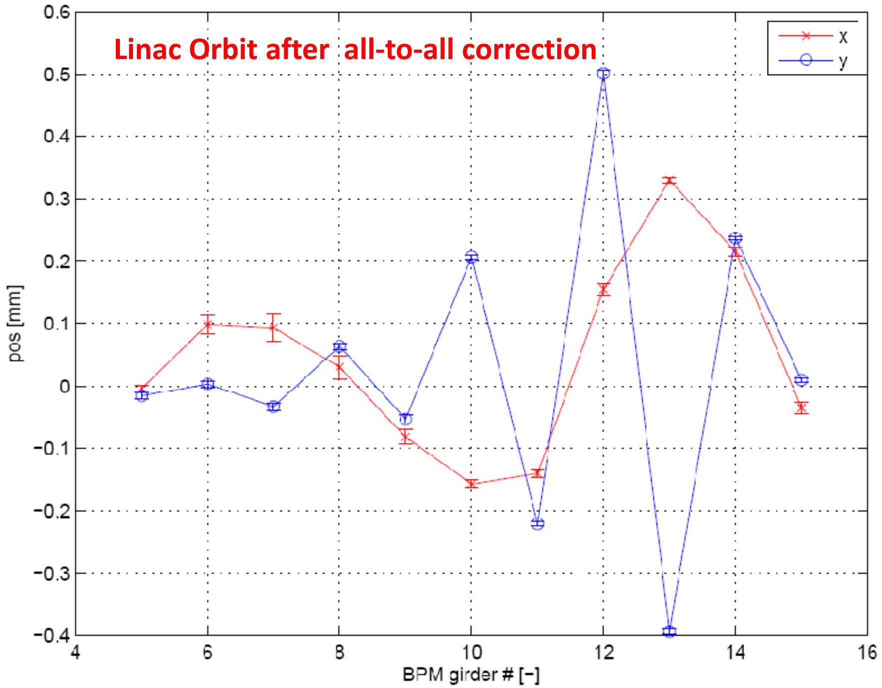
Orbit corrections

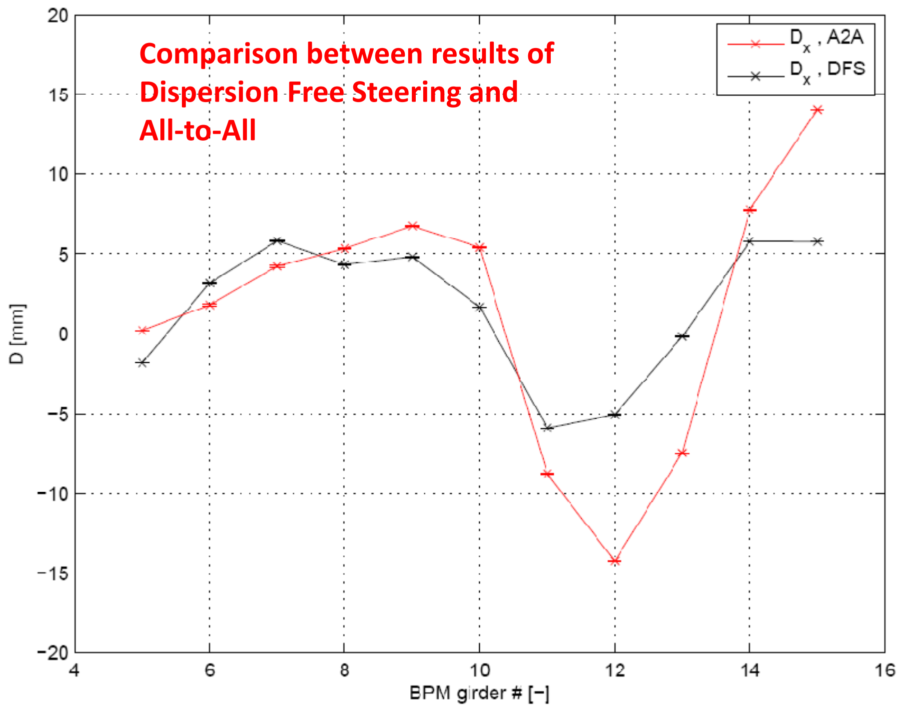
- Successful application of orbit correction in CR
  - See the next talk for more details



Steering Algorithms

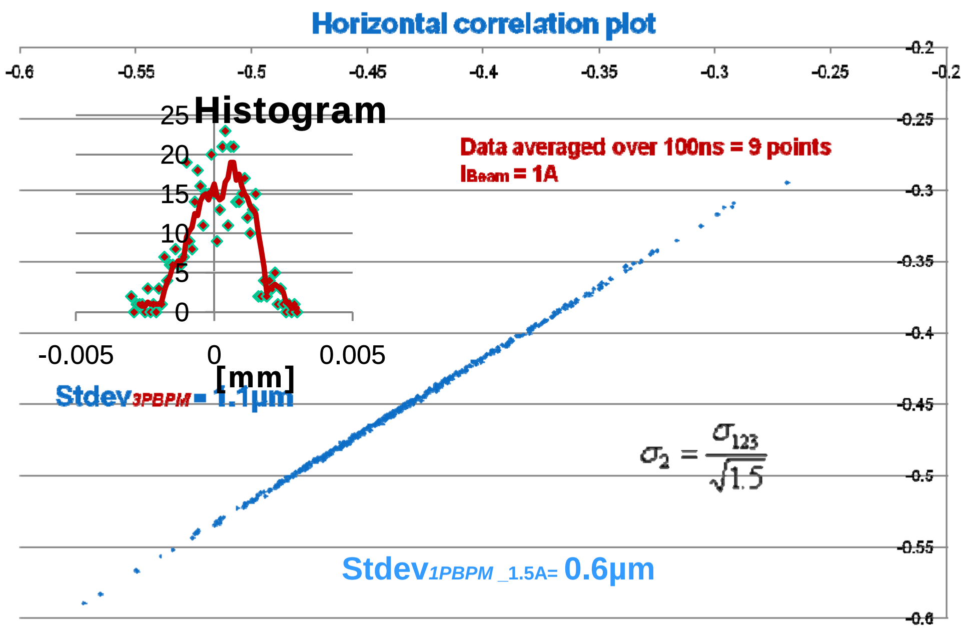
- We have successfully, but not without problems applied following steering techniques
  - dispersion free
  - one-to-one
  - all-to-all

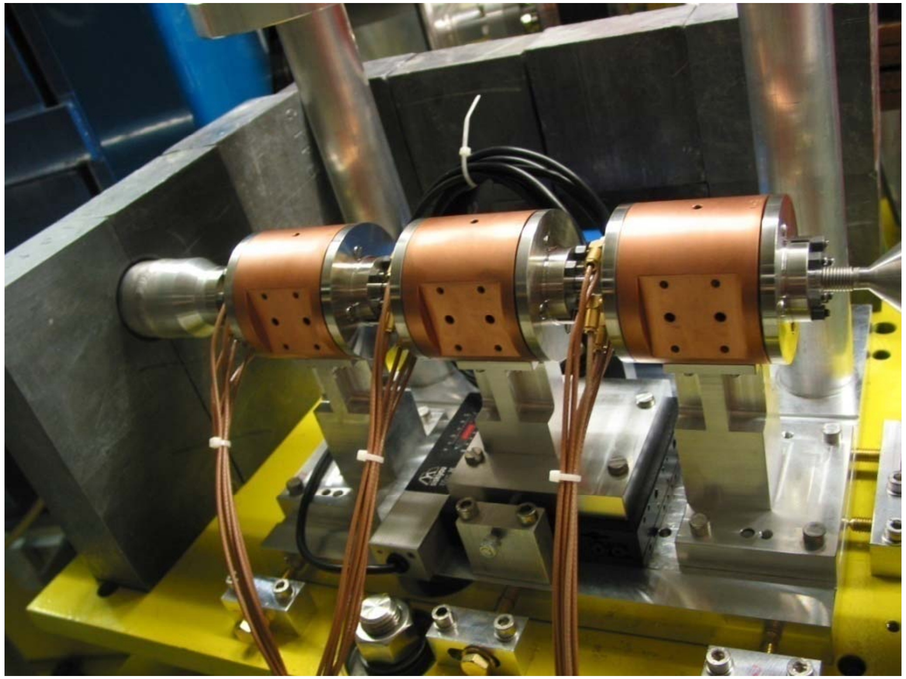




EuroTeV BPMs

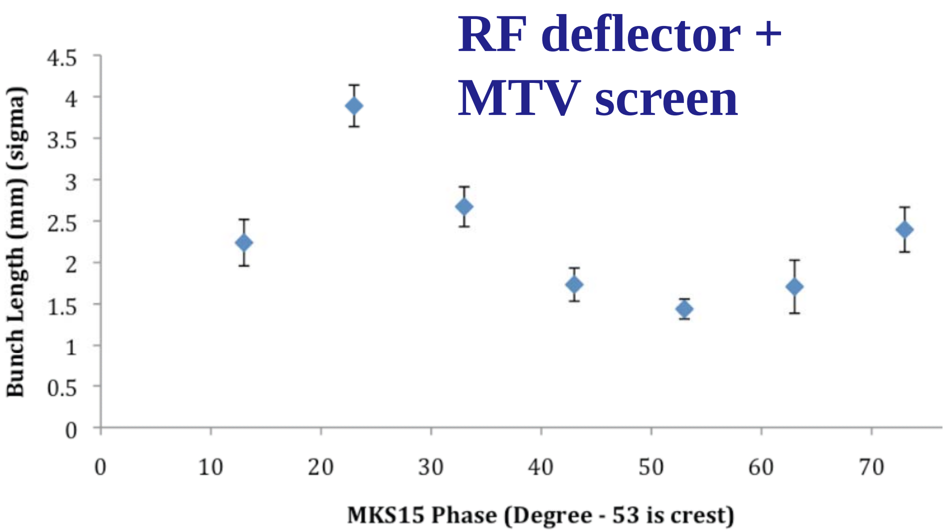
- We have tested the new high precision BPMs
- We have already tried during previous year however, we could not get full transmission thru 2nd and 3rd bpm
  - Turned out to be a hardware problem
- We have installed standard BPM after the tested triplet
- Measurements successfully repeated this year
  - See Lars talk at 4PM for the detailed results

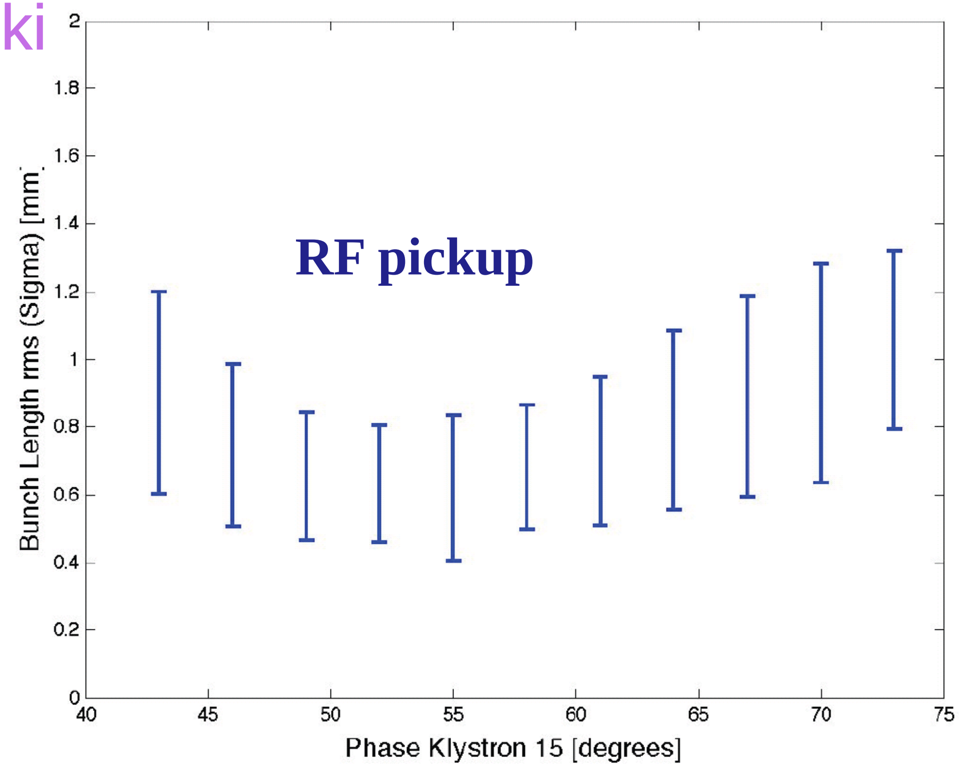




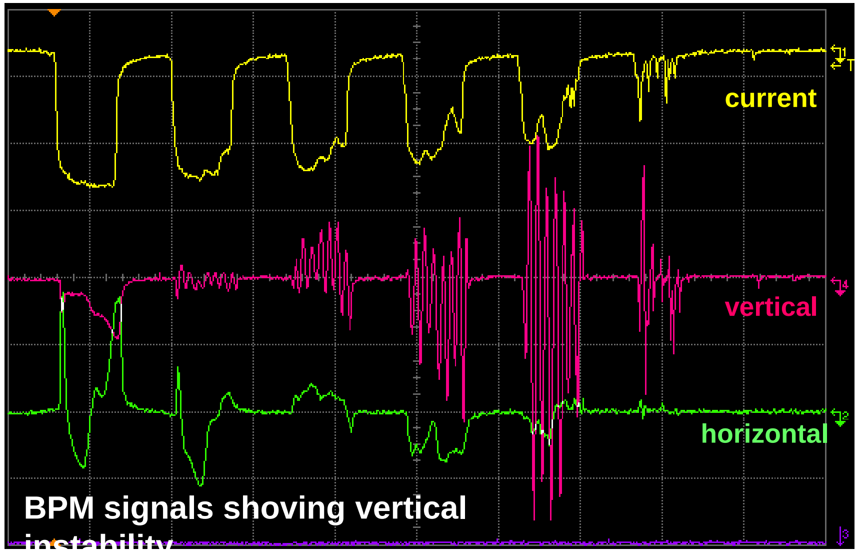
Bunch length measurements

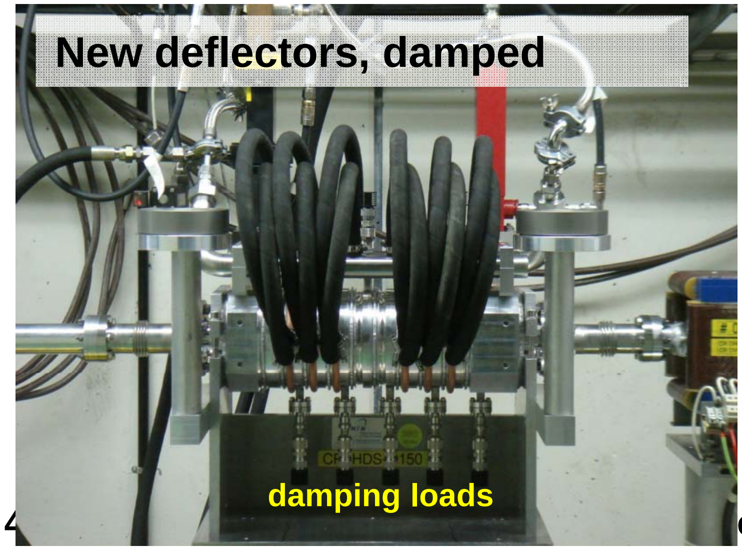
- We have two methods to measure the bunch length
  - Standard way with RF deflector and MTV screen
  - Novel non-destructive RF pickup
- Up to now the results are factor 2 different
  - See talk of Anna Dabrowski for further explanations





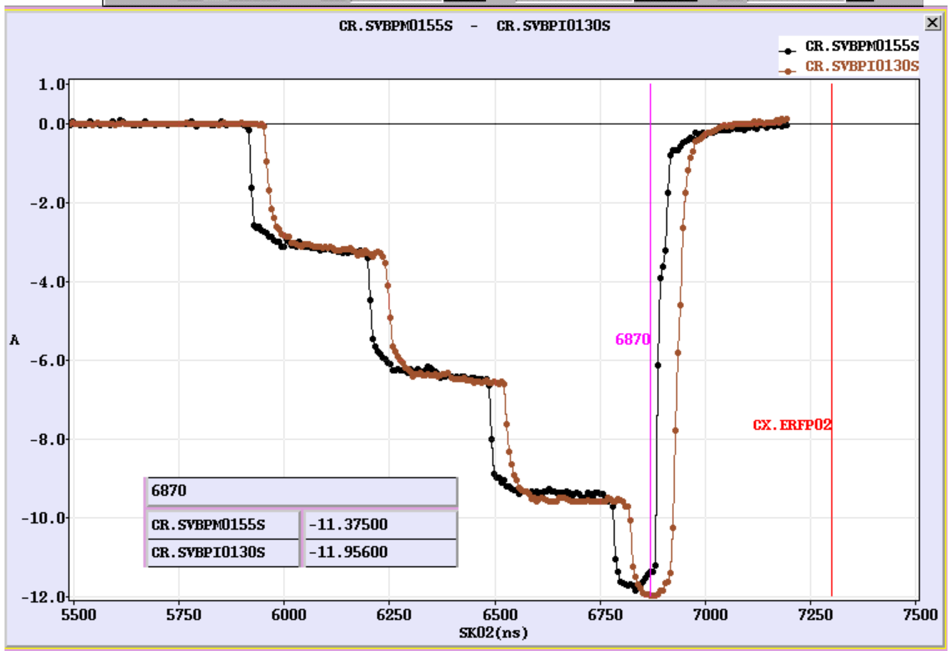
Combiner Ring Commissioning Instability Solved





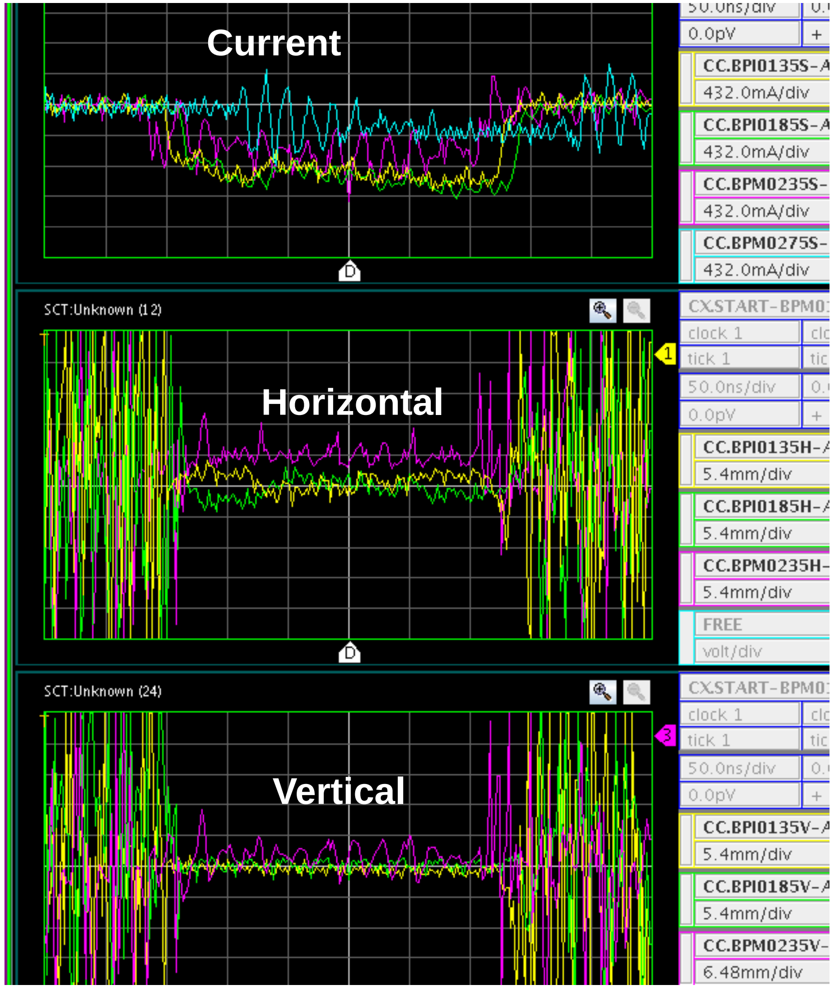
Combiner Ring Commissioning

- We solved many of the problems of which the most important was the instability
  - New deflectors were installed mid of September
  - Gun seems to be stable now
- This brought immediate effect in form of the full recombination factor 4
- Now all the measurements are much easier to do and much more precise
  - Tune measurements
  - Orbit corrections
- Still the model does not describe the ring optics precisely enough



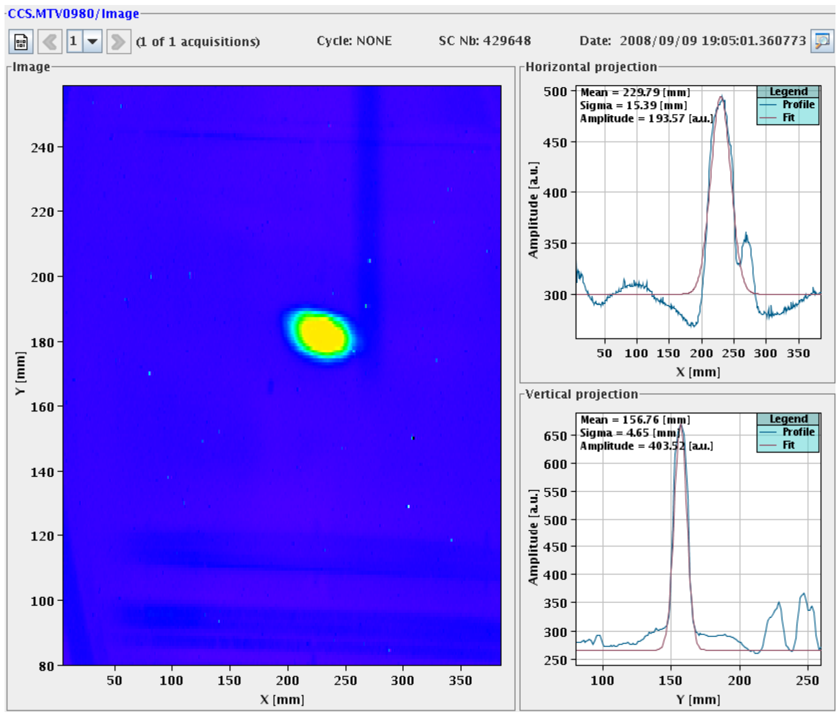
TL2 and TBTS Commissioning

- Strip-line kicker works well
- BPMs based on the new LAPP electronics work, but
  - 30ns time jitter
  - Big problems with OASIS viewer
    - The traces are digitized in-situ and analog signals are not available and we have to use this application to get them
  - Constant improvement in making them stably operational
- The beam setup was very difficult



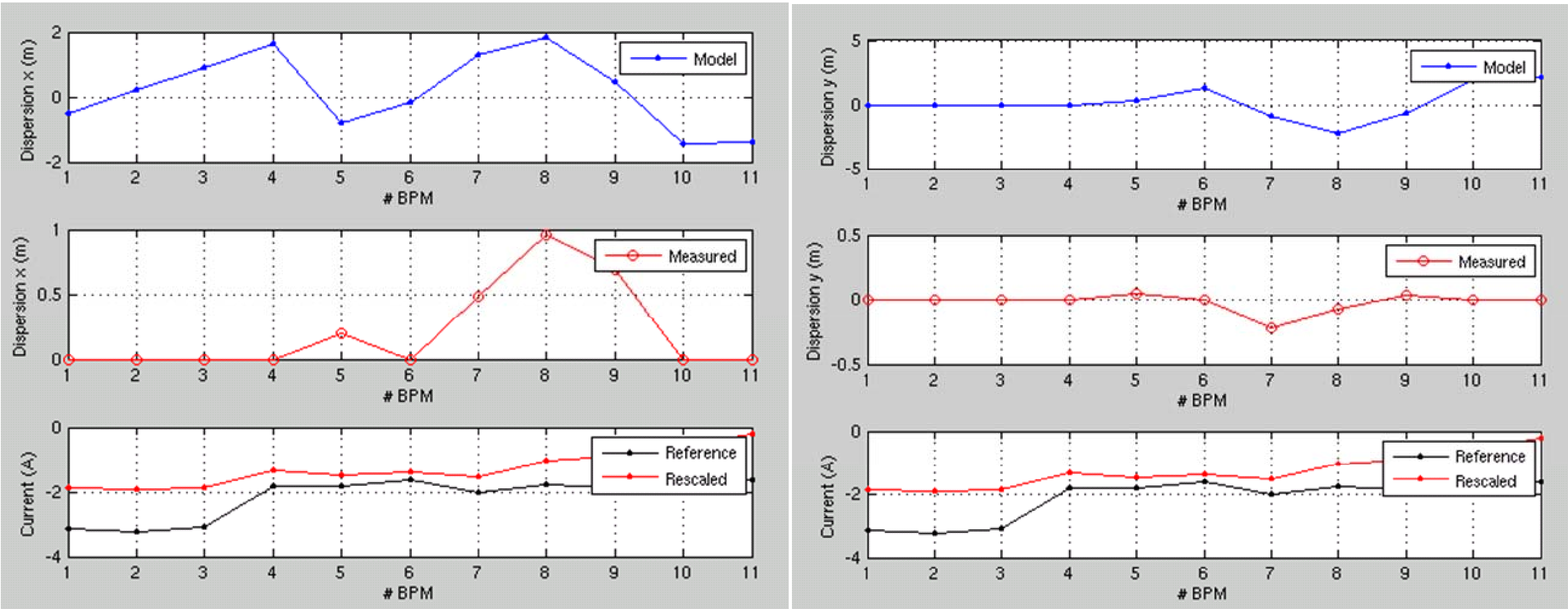
TL2 and TBTS Commissioning

- After long fight we have managed to transport the beam till the end of TBTS, however, with 50% current loss
  - We have some problem with the optics, which is not diagnosed yet
    - Either incoming CR beam is terribly mismatched
      - Rather doubtful since the beam is able to circulate for tens of turns in CR
    - There is some optics error in TL2 itself, but it is difficult to diagnose not having
      - Full transmission
      - Fully operational beam monitors



TL2 and TBTS Commissioning

- We have attempted to do some optics measurements, but they were not very successful mainly due to losses along the line
  - One have to get somehow full transmission and only then try optics measurements



Conclusions

- Up to now, 2008 runs go relatively smoothly without any major disasters like
  - Vacuum leaks (2 in 2007)
  - Klystrons down for good (2 in 2007)
- It seems the problem with the unstable gun disappeared for now
  - But we are not really sure we have found the core of the problem and that it disappeared for good
- New RF deflectors installed in the Combiner Ring two weeks ago
  - It is confirmed now that there is no sign of the instability now
  - Immediately managed to get recombination factor 4
  - There is serious chance to finish its commissioning soon

Conclusions

- The gun
  - Find and repair the problem that makes unstable
  - Consolidation program needs to be completed
- Linac
  - Establish stable & documented working point
  - Stability studies
  - Diagnostic consolidation
- TL1
  - Optics measurements and model validation
- Delay Loop
  - Beam optics measurements
  - Re-establish the recombination

Conclusions

- Finish the commissioning of CR
  - Perform set of optics measurements
    - Model still not validated – Optics errors still present
  - Validate the machine model
  - Tune and β function dependence of vertical instability
    - Problem disappeared with the new deflectors
- Commissioning
  - TL2
  - TBTS
  - TBL
  - CALIFES
- Test new devices and techniques
  - EuroTeV BPMs
  - Bunch length measurement with RF pickup
  - Transient compensation
  - Dispersion Free Steering and other automatic algorithms

End

Conclusions

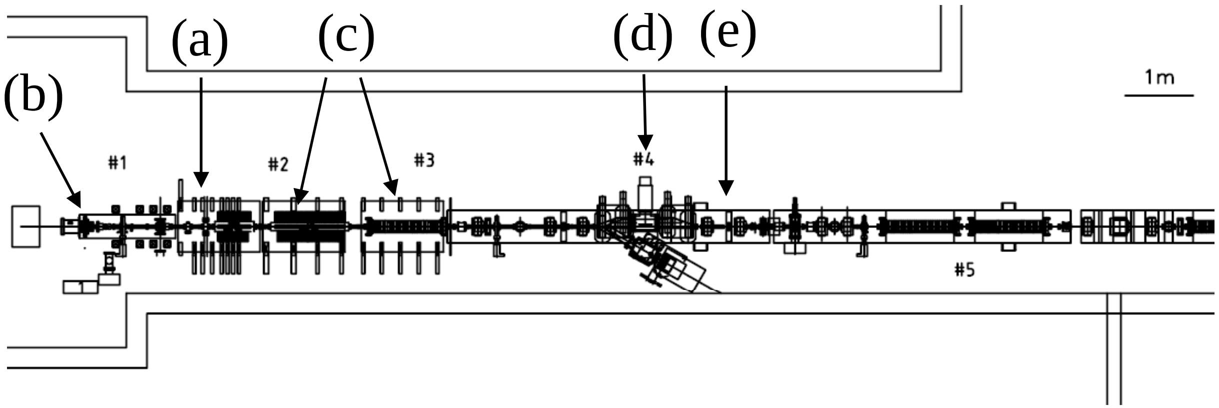
Backup Slides

- BACKUP

Beam setup procedure
Linac to girder 4

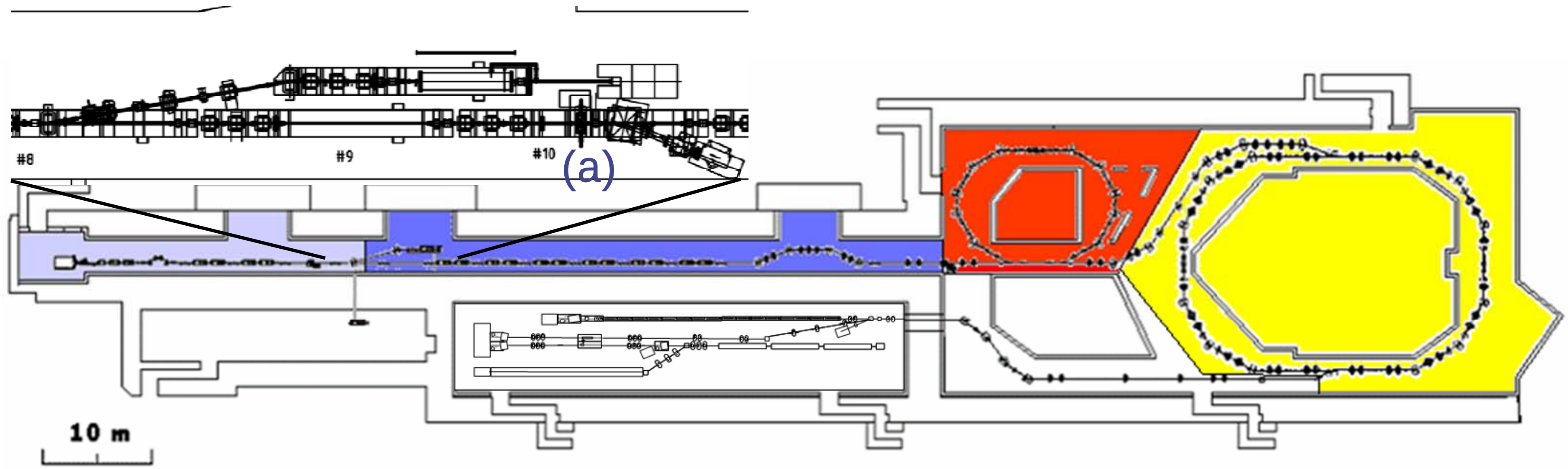
- We start with 3GHz (more stable) beam
  - Traveling Wave Tubes (TWTs) off (a)
- Adjust
  - The gun (b)
  - Phases of klystrons 2 and 3 (c)
  - The compressor chicane (d)
    - Current in bends
    - The slit gap

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



Beam setup procedure
Linac to girder 10

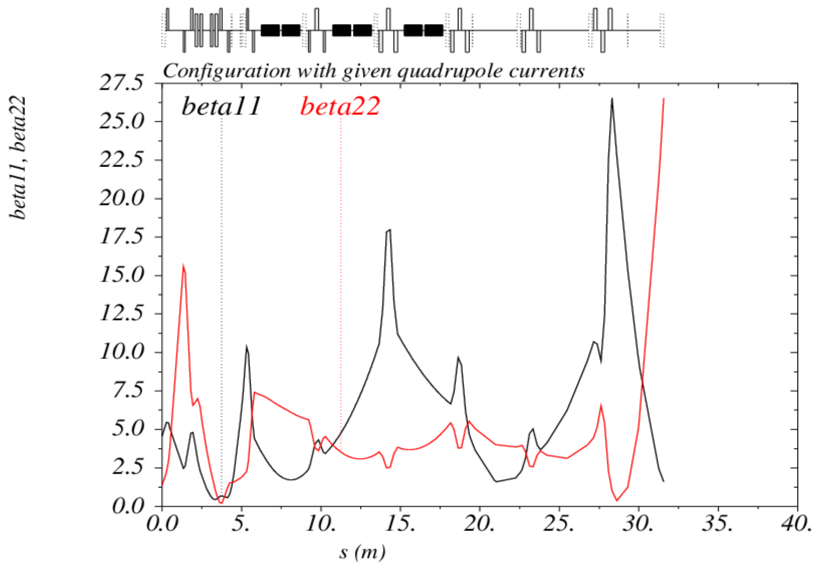
- Adjust the phase of MKS05
- Get somehow the beam up to spectrometer 10 (a)
  - Usually by scaling up and down all the quadruples together
- Beam measurements at spectrometer 10
  - Energy with the slit dump
    - Vary the bend current to get maximum signal
    - Having current-momentum coefficient 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

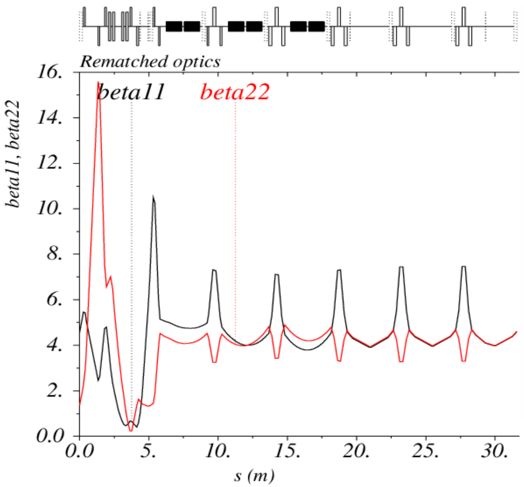
- Having
  - The energy profile along the whole linac
    - Having input power to each of the accelerating structures and knowing beam current one calculates acceleration in each cavity
  - Twiss parameters at certain location

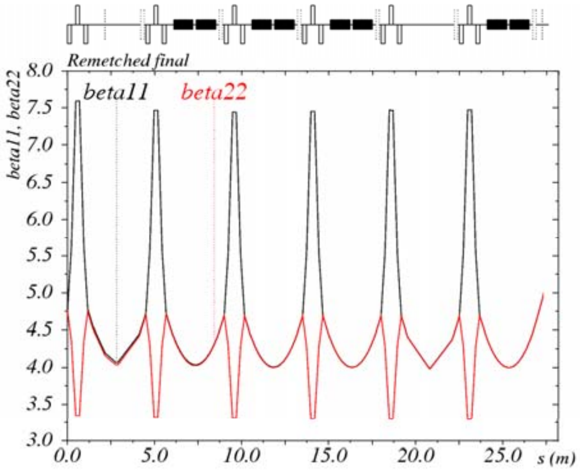
  we can calculate the optics along the machine
- We have the design optics however the exact magnet setting depends on
  - Beam provided by the injector
  - Energy profile that depends on the klystrons power

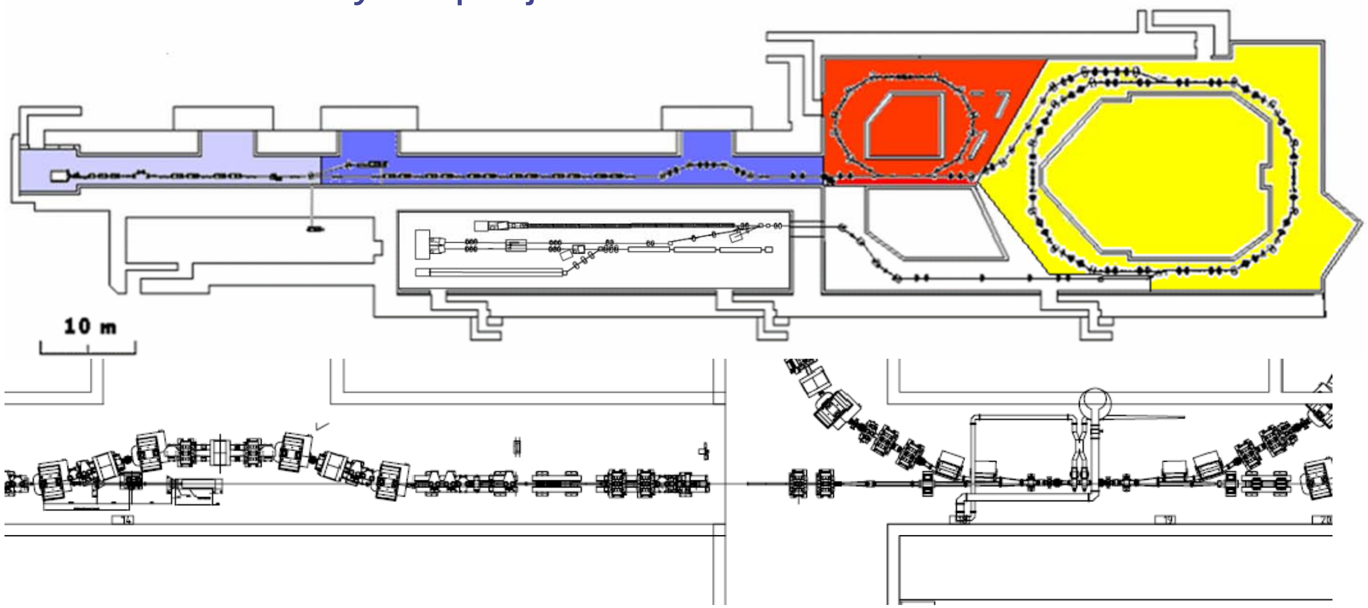


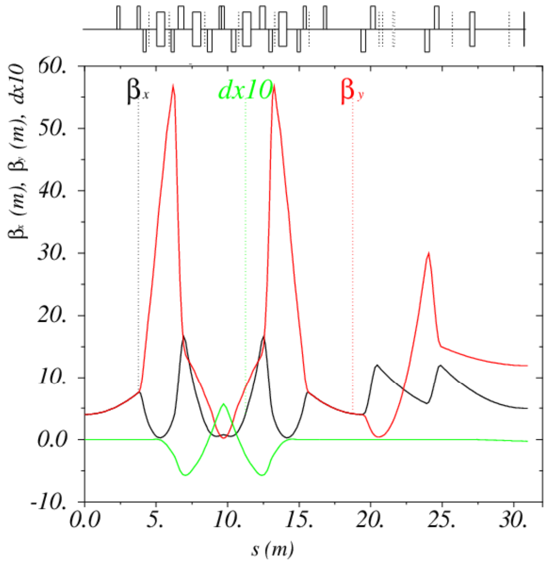
Beam setup procedure
Linac rematch

- 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



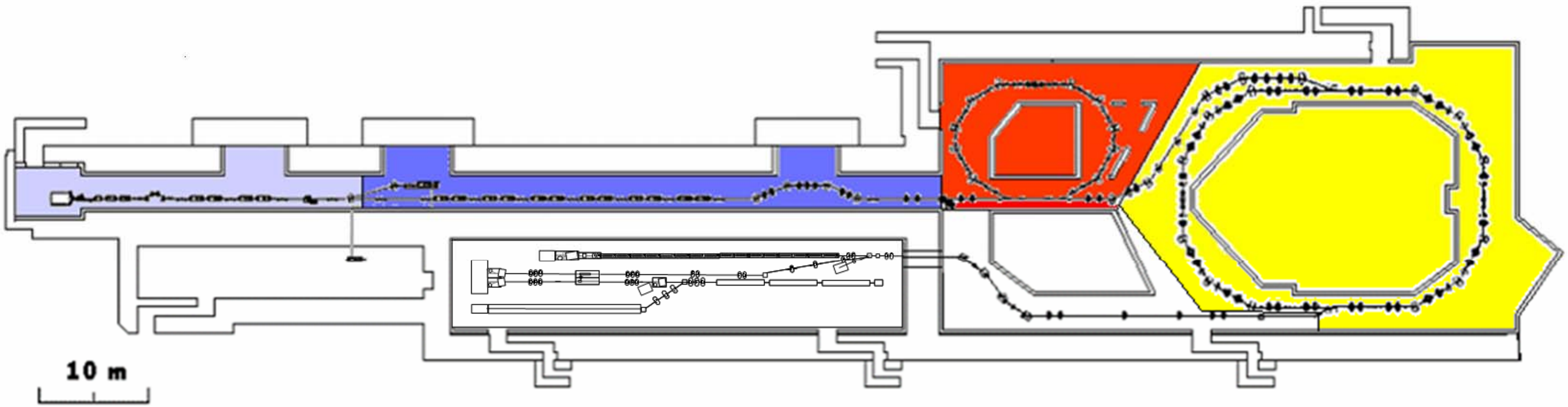






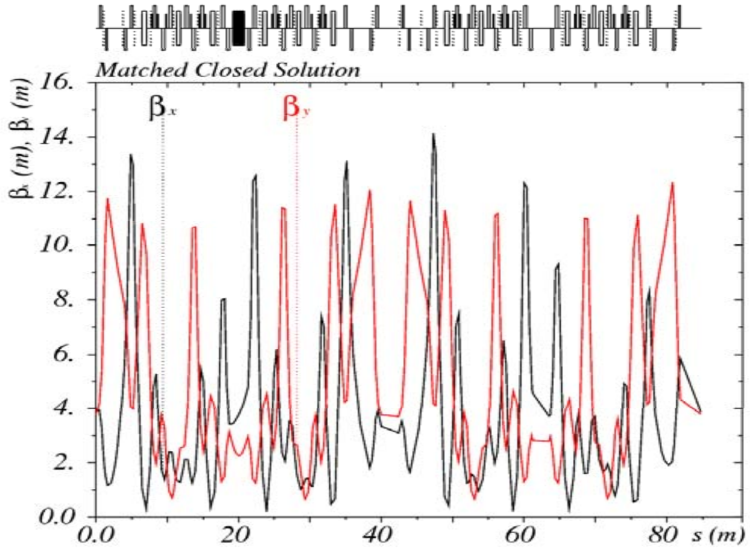
Beam setup procedure
Optics Verification

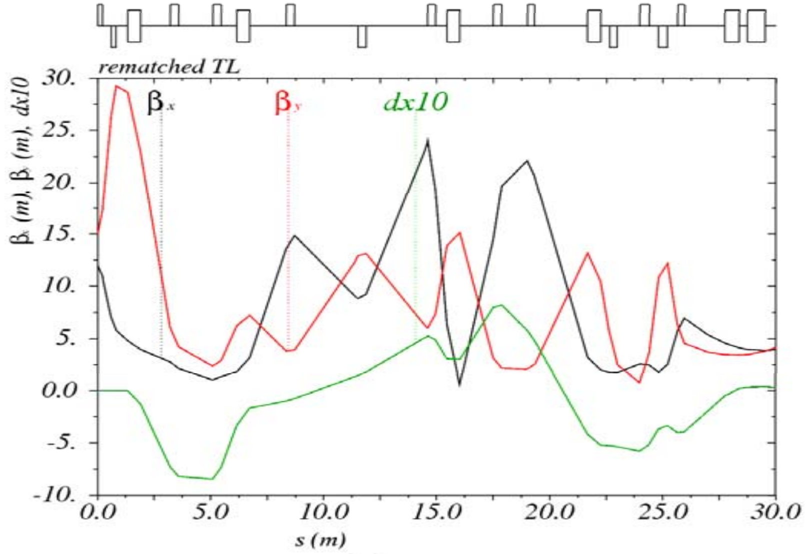
- Perform quad-scans at
  - Spectrometer 10
    - To verify the rematch
  - Beginning of TL1
- Depending on the obtained results rematch whole or part of the linac
- Check if the obtained energy agrees with the bends settings

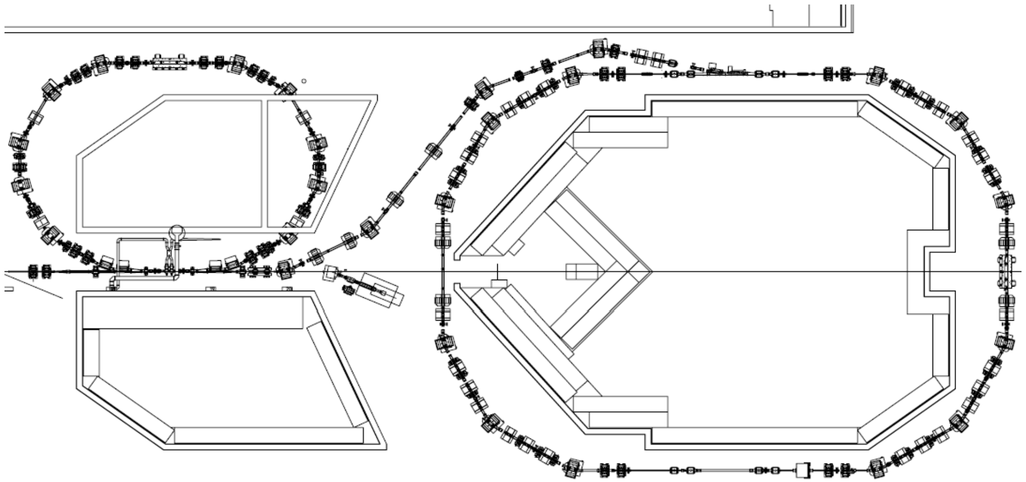


TL1 and CR optics

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

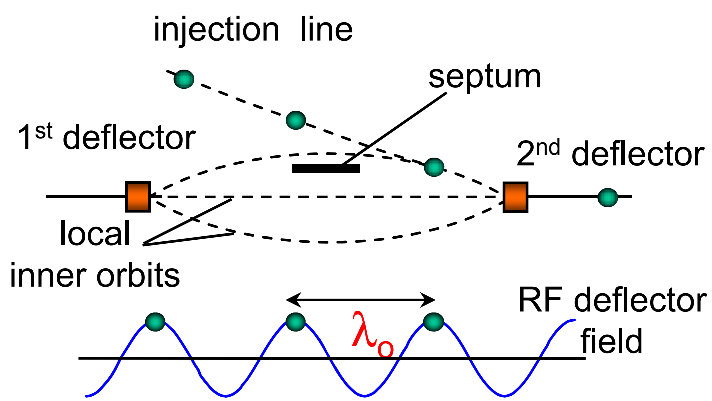


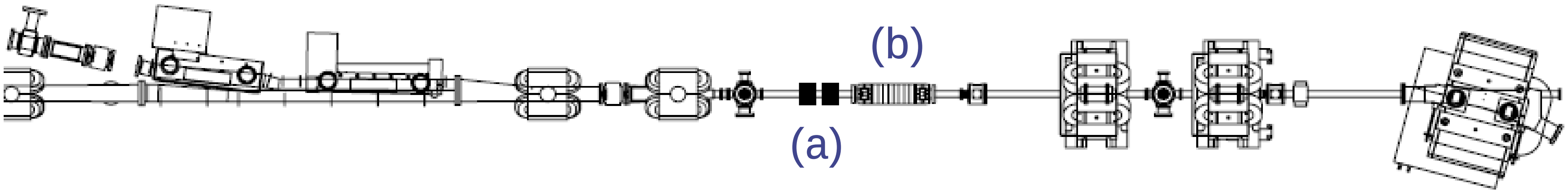




Beam setup procedure
CR Injection

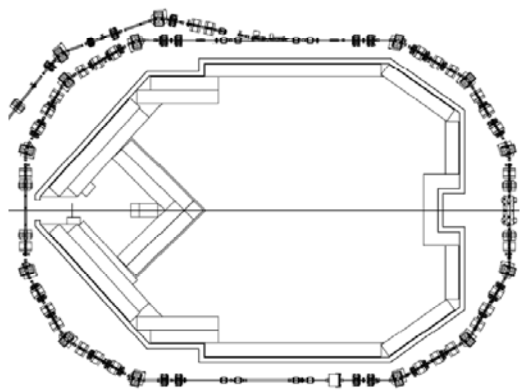
- We start with static magnetic injection using two horizontal correctors (a)
  - It allows for only one turn in CR
- Setup the septa and the orbit
- Switch to the injection with the RF deflector (b)
  - It is an iterative procedure that involves the following steps
    - Set RF power (amplitude)
    - 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

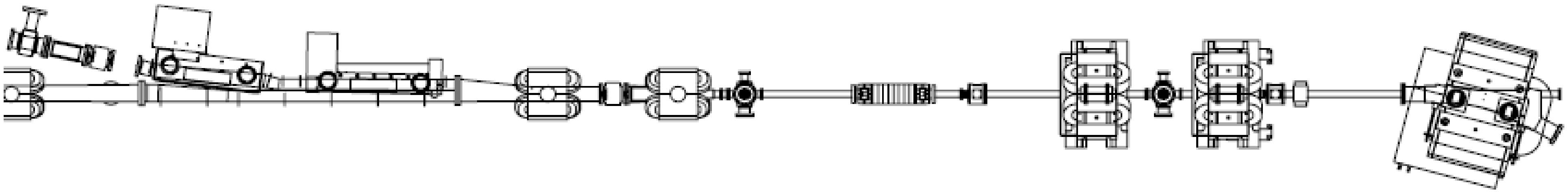




Beam setup procedure
CR Injection

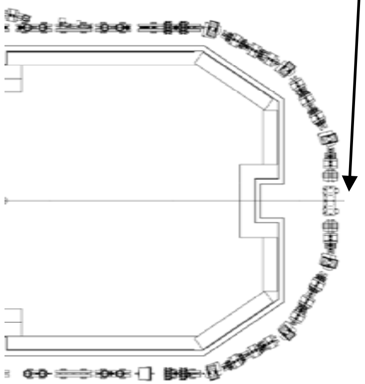
- To setup a good injection and orbit
  - Short train is injected (~140ns)
  - RF is switched off just after the last bunch is injected
- It allows for long lasting beam circulation in the ring
  - Then it is easier to find a closed orbit
  - It makes possible to apply orbit correction procedures more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

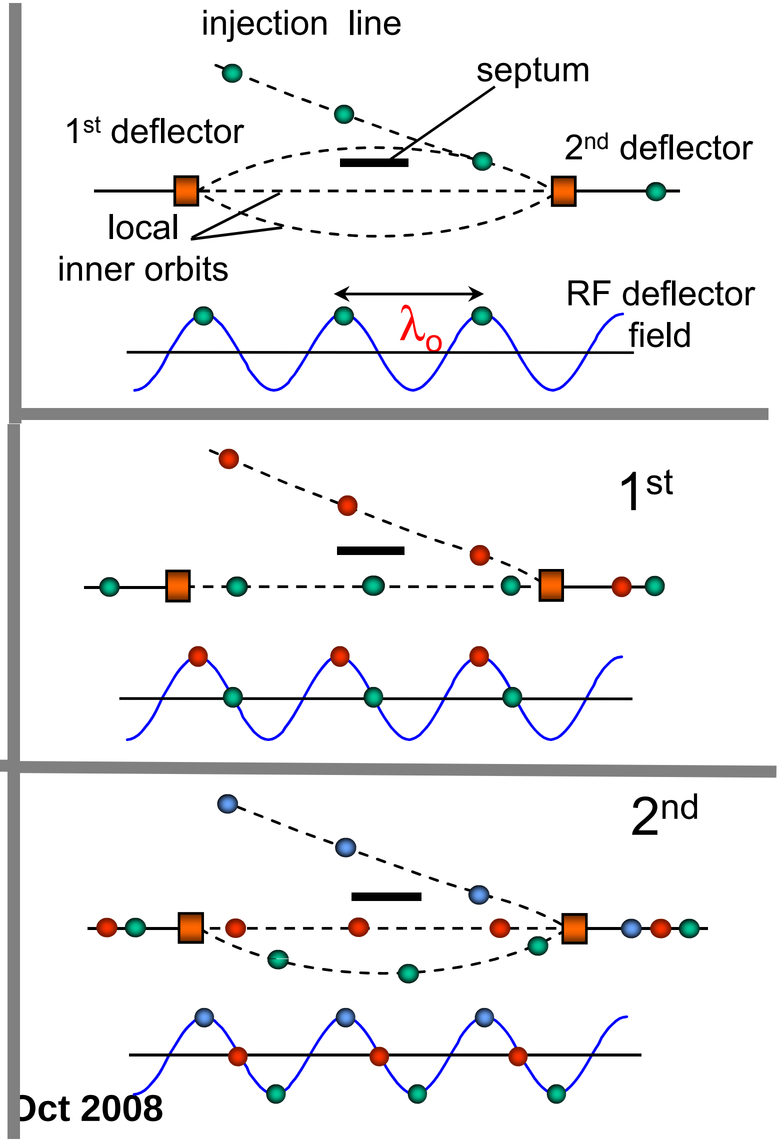


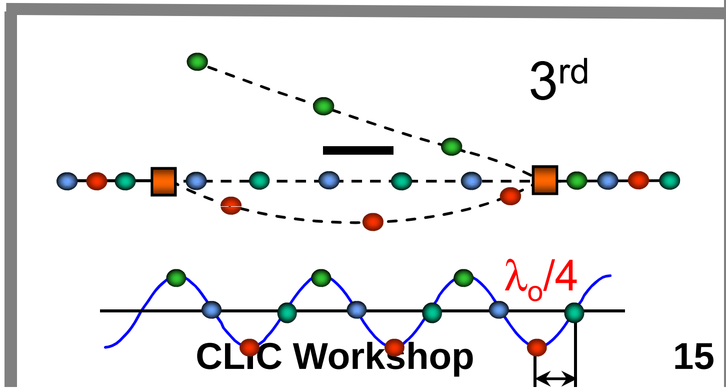


Orbit length in CR

- The orbit must have the length $C_r = (n_t \;\; \tfrac{1}{4})\,\lambda$ *(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!

Schedule 2008 v1

30 GHz → *DL & CR* →

	Apr					May				Jun			
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	31	7	14	21	28	5	Whit. 12	19	26	2	9	16	23
Tu													
We							Today						
Th													
Fr													
Sa	Open Days												
Su													

RUN 1

Installation: TL2, CALIFES, TBTS, new deflectors

DL, CR, TL2 → *TBTS* *CALIFES* →

	Jul					Aug				Sep			
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	30	7	14	21	28	4	11	18	25	1	8	15	22
Tu													
We													
Th											Jeune G.		
Fr													
Sa													
Su													

RUN 2

Installation: tail clipper

Delayed 2 weeks ?

Linac only

Linac, Ring area, (CLEX)

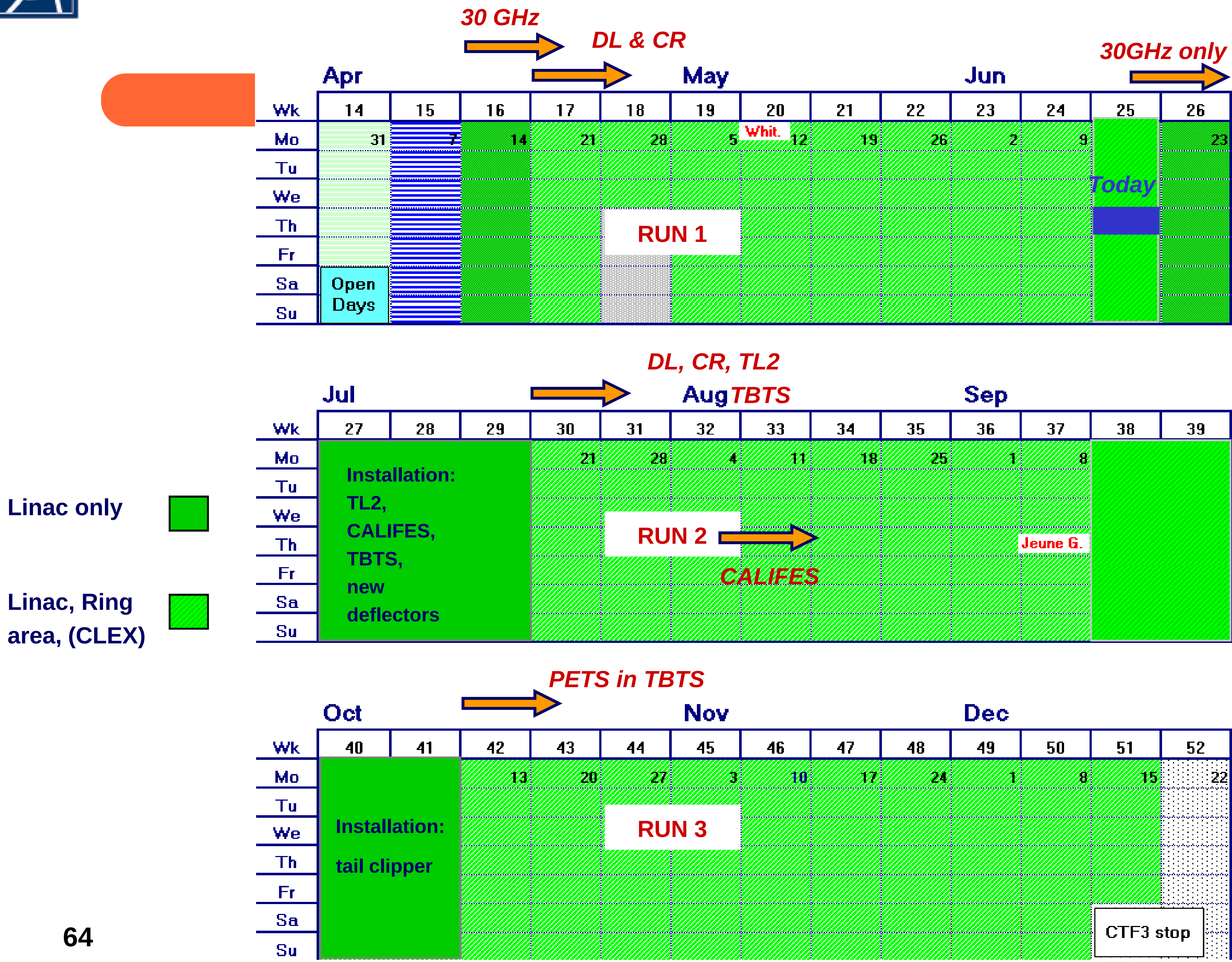
PETS in TBTS →

	Oct					Nov				Dec			
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	29	6	13	20	27	3	10	17	24	1	8	15	22
Tu													
We													
Th													
Fr													
Sa													
Su													

RUN 3

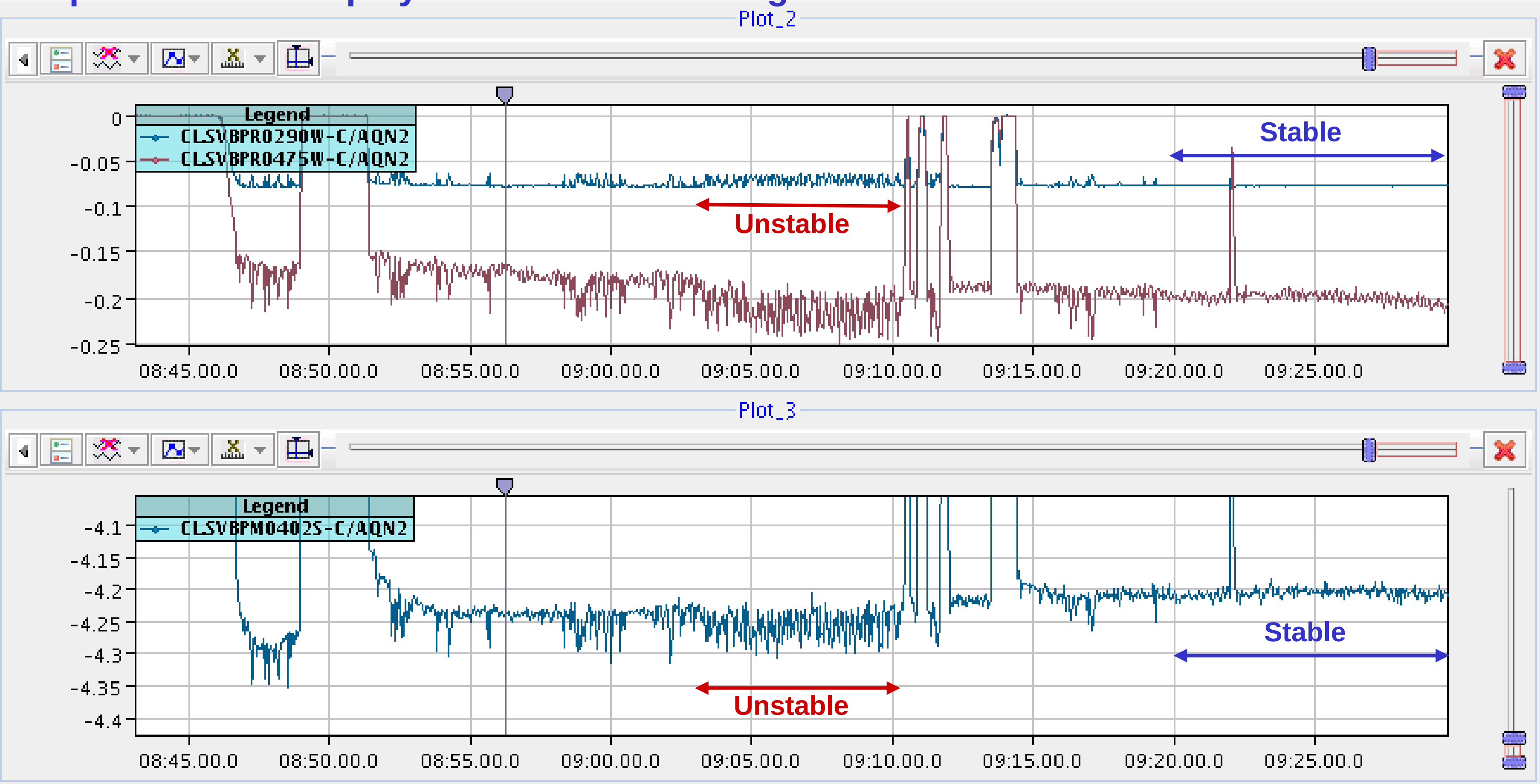
CTF3 stop

Schedule 2008 v2

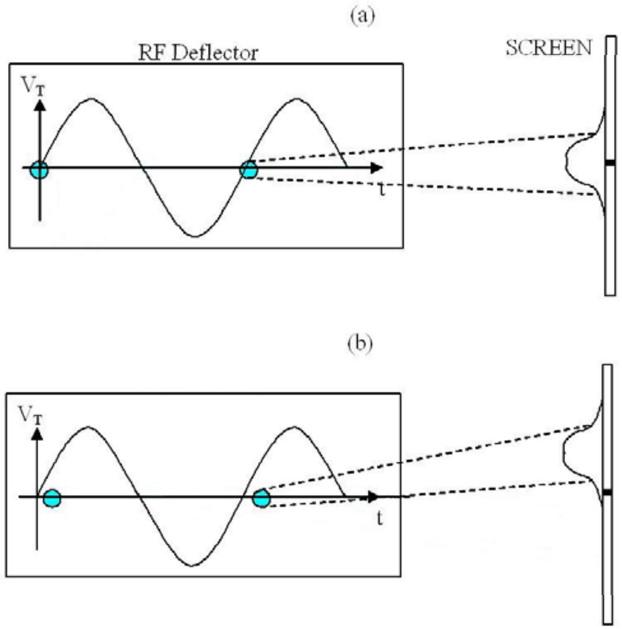


Gun HV stability

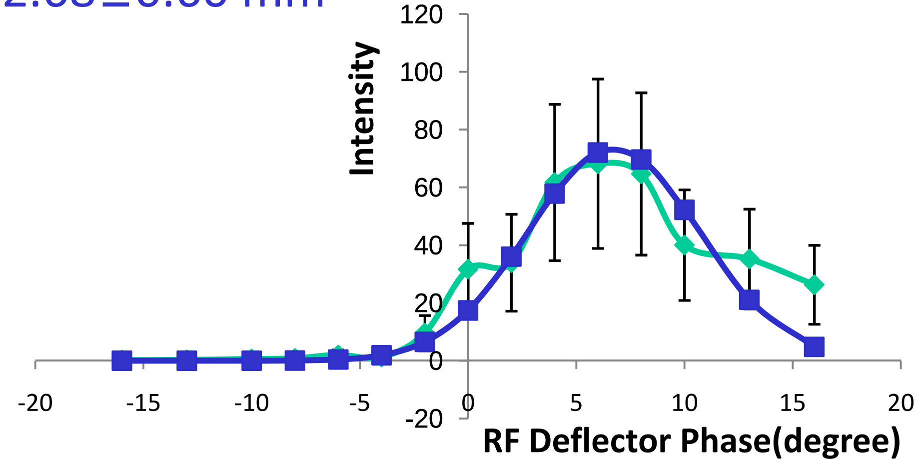
It must be the Gun HV instability since 0290 is only after buncher, whichs phase does not play a role for bunch length

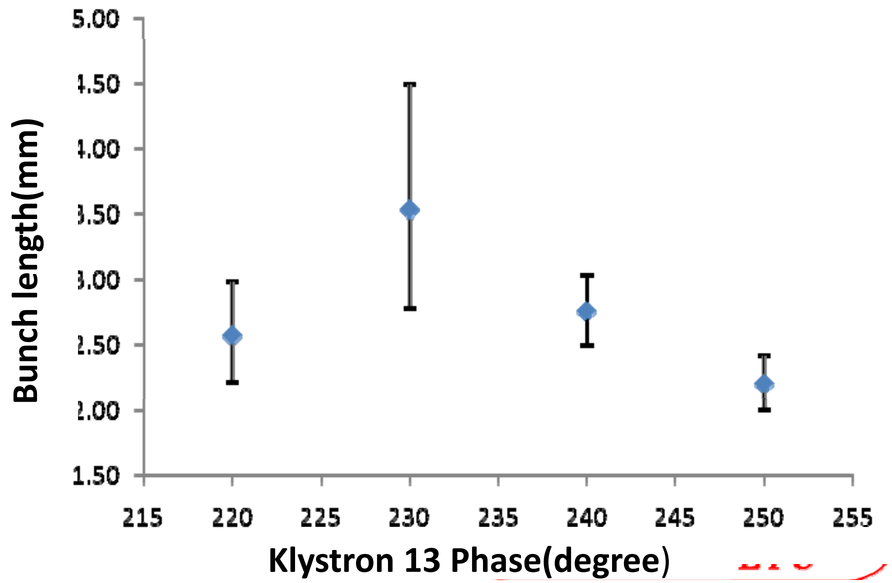


Bunch length



$l_b = 2.68 \pm 0.60$ 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

Machine setup – 2nd slide
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
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