Beam dynamics preparation studies for the crab cavity experiment in the SPS

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Many thanks to the SPS OP team

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Motivation

- The **crab cavity test** with proton beams will take place in the SPS in 2018
- Once the CC are installed only limited time for dedicated MDs will be available
- A good preparation is essential for an efficient testing in 2018

➔ The induced emittance growth , driven by phase jitter in the crab cavities (CC), one of the main concerns that needs to be addressed during the CC experiment

➔ Validation of the already existing instrumentation in the SPS that will be used during the CC experiment is of paramount importance!

HLLHC-UK collaboration

Outline

- Natural emittance growth studies in the SPS
- Machine Development studies plan for 2017
- Experimental results for this year
- Exploring the instrumentation for crabbing validation
- Summary

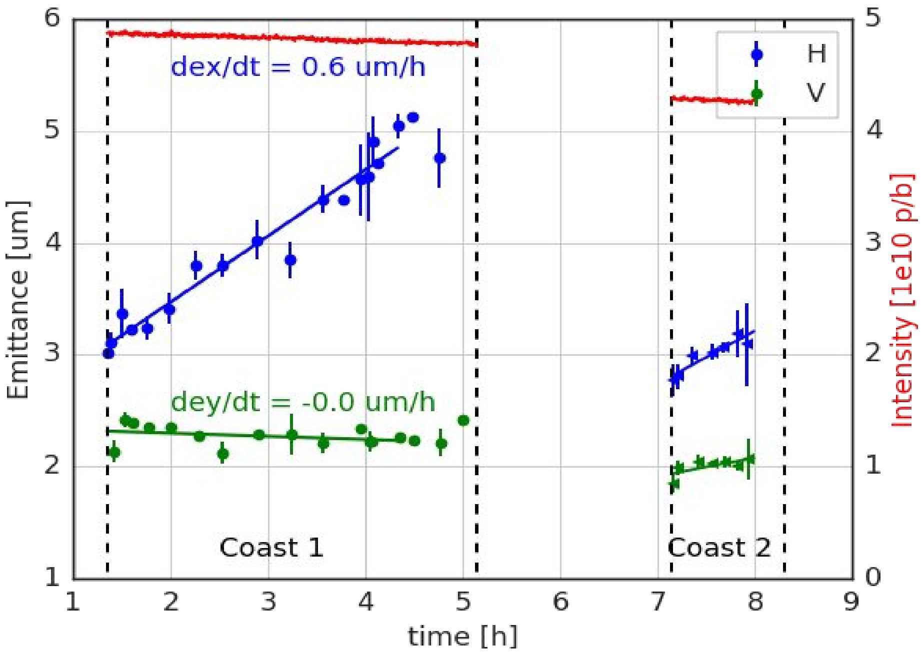
Natural emittance growth studies until 2012

	Unit	Sep 2010	Oct 2010	May 2011	July 2011
Energy	GeV	55	120	120	270
Qx,y	-	0.13/0.18	0.13/0.18	Several tunes	0.13/0.18
ξx,y		2-3	2	0.5	0.5
Intensity	$\times 10^{11}$	1.1	0.5	0.2	0.2
# Bunches	-	1	12	1	1
$\varepsilon_{x,y}$	μm	3.1/2.8	1.5-2.0	2.5	2.5
V_{RF}	MV	3.0	4.0 (1)	4.6 - 6.5	4.6 - 6.5

Energy [GeV]	Intensity [$\times 10^{11}$]	Qx/Qy	Voltage [MV]	$d\varepsilon_x/dt$ [/hr]	$d\varepsilon_y/dt$ [%/hr]	dεy/dt [μm/h]
55	1.0	0.13/0.18	3.0	140-370%	57%	1.6
120	0.5 (12b)	0.13/0.18	2.0-4.0	100-300%	40-90%	0.6-1.8
120	0.1	0.13-0.33	2.0-4.0	18%	17%	0.43
270	0.4	0.13/0.18	3.0	20-23%	14-24%	0.35-0.6

- **Different energy** coasts, primarily **single bunch** and **low intensity**
  - Distinguish between collective effects and natural emittance growth
- Best spots identified to be 120/270 GeV with 1-4 e10 ppb
  - The lowest emittance growth
  - Similar results in both planes
- Lower energies and higher intensities always gave worse results

Natural emittance growth studies in 2015 (after LS1)



- 2 MDs with coast beams in the SPS at 270 GeV took place in 2015
  - July and Oct 2015
- Different behavior observed for the natural emittance growth, with **different growth rates in the 2 planes**

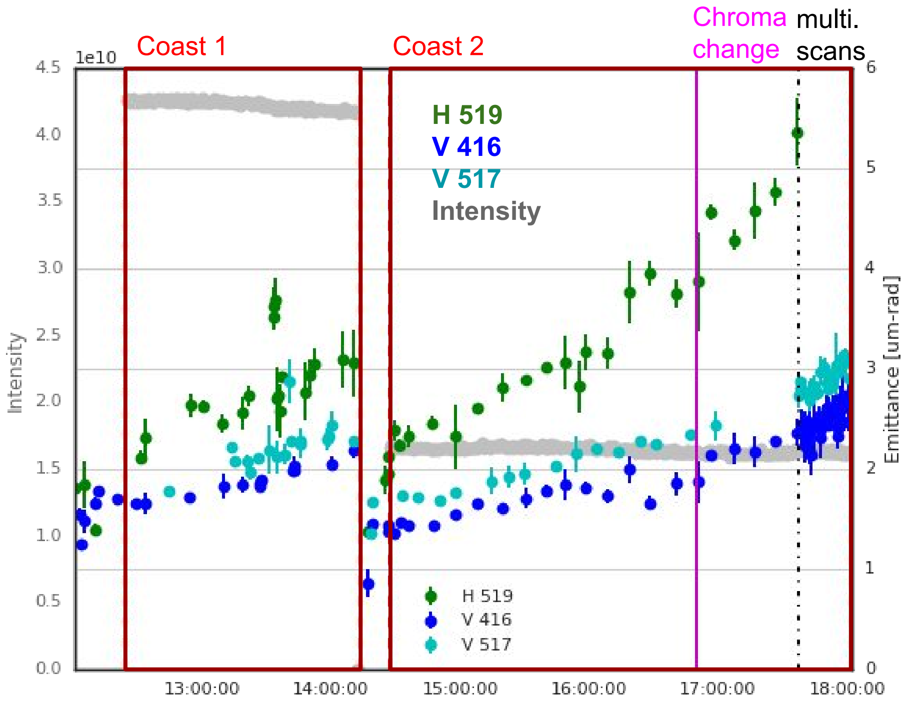
Emittance evolution in coast MD: 7 Dec. 2016

- 2 MDs took place in 2016
  - July and Dec 2016
- MD conditions for Dec. 2016:
  - Energy of 270 GeV
  - **Two different intensities**
    - Coast 1: 4.2e10
    - Coast 2: 1.6 e10
  - Chroma H/V: 0.5/1
  - Wire scanners used: 519H, 416V, 517V

➔ Chroma change by 2 units performed after 2 hours in coast 2

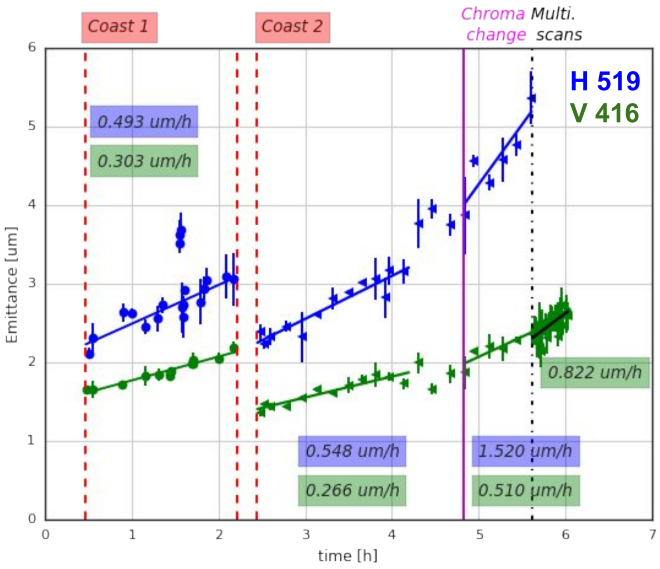
➔ **Multiple wire scans** performed the last 15 min. of the MD

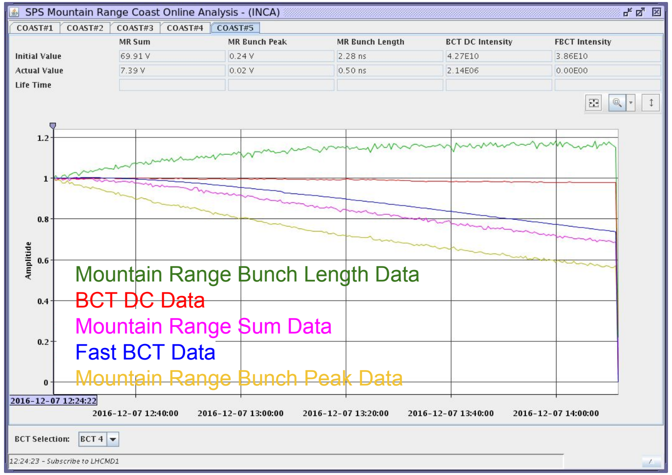
- ◆ Study the impact of the WS to the natural emittance growth



Emittance evolution along the MD

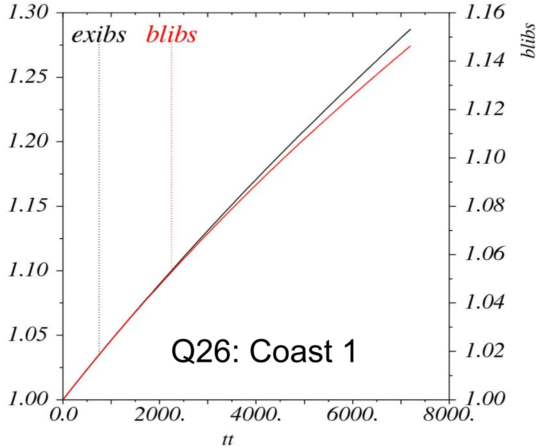
- Transverse plane
  - **Linear fit** applied for 4 different cases:
    - Coast 1
    - Coast 2 before chroma change and for same time-window as in coast 1
    - Coast 2 after chroma change
    - Coast 2 during the multiple WS
  - Clear **slope increase** after the **chroma change** in both planes
  - Slope increase during the multiple scans, however the spread is also large
- Longitudinal plane
  - Slow **off-bucket losses** observed
  - **Bunch length increase** by ~20% in 1.8h for coast 1 and ~10% in 1.8h for coast 2

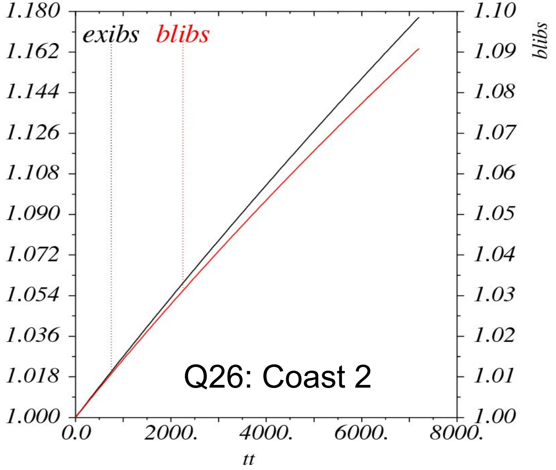




Emittance growth predictions due to intrabeam scattering (IBS)

- **IBS calculations** using the SPS lattice and the bunch characteristics during the MD
    - Coast 1:
        - H: 0.493um/h measured → 0.31um/h from ibs
        - L: ~20% measured in 1.8h → 14% from ibs
    - Coast 2:
        - H: 0.55um/h measured →0.186um/h from ibs
        - L: ~10% measured in 1.8h → 8% from ibs
- **Interesting notice: Correcting** the H plane from the ibs expectation → **H and V** have **similar growth**
- Similar calculations applied to all MDs of 2015 and 2016 with similar conclusions





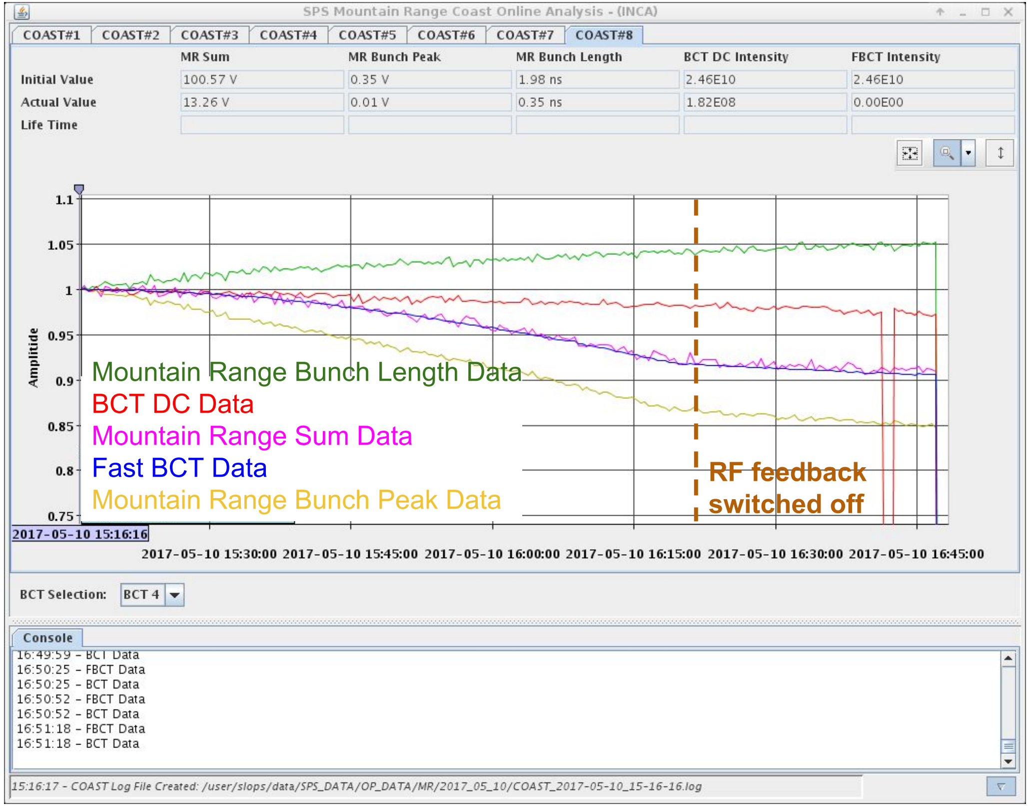
Studies plan for 2017

- Natural emittance evolution in coast
  - If possible one MD at the beginning of the year where the vacuum levels could be worse
    - At optimal conditions (low chroma and low intensity) to see if the situation for the emittance evolution is also worse
  - Commissioning and cross-calibrate the BGI monitors (similar with ion beams last year)
  - Repeat the WS multiple scans experiment of F. Roncarolo in a more systematic way
  - Systematic chroma scan
  - Different intensities
  - Effect of transverse damper: Identify the effect of the damper on the emittance evolution on coast without the CC
  - At the end of the year, dedicate few hours to degrade the vacuum levels and study the impact on the emittance evolution
  - vacuum and power supply monitoring during each MD and subsequent simulations

Studies plan for 2017

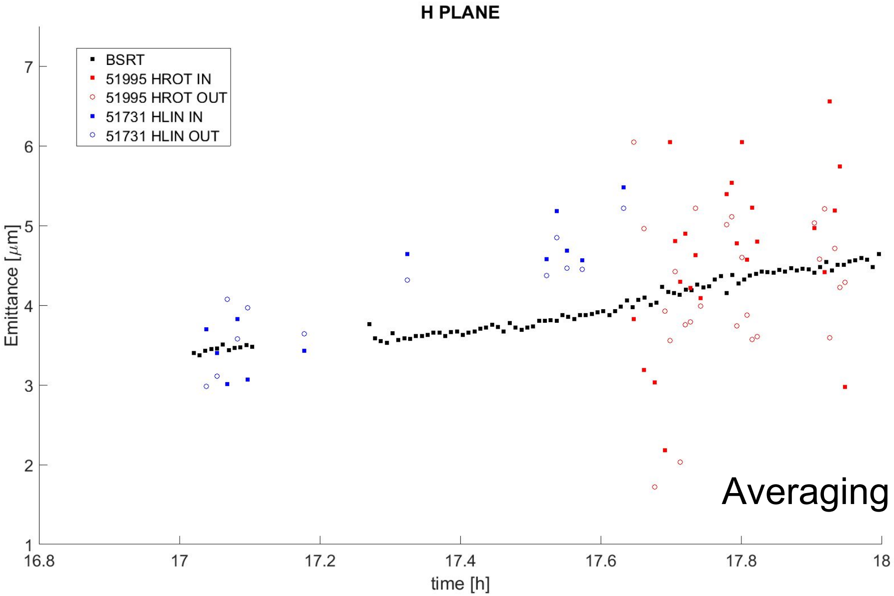
- Head - tail monitor
  - Study the accuracy of the monitor at different energies and intensities
  - Identify the minimum kick that can be measured
  - Simulations are currently in progress to use them as guideline (A. Alekou et al)
- Closed-orbit correction
  - In past MDs an rms orbit of 3-5mm. Verify if we can do better than this
  - Verify if the normal YASP can be used efficiently at 270 GeV
    - Is it more efficient to use the extraction kickers?
  - Identify the optimal kickers and the sensitivity of the BPMs around the crab loc
    a varying closed orbit in the cavity region to identify the electrical center.
- Collimation studies
  - Verify if the system works as it should (scrapers, BLMs, ...)
- Studies with shorter bunch length
  - look at effects of non-linearity of the RF curvature (the CC have an RF freq. of 400 MHz)

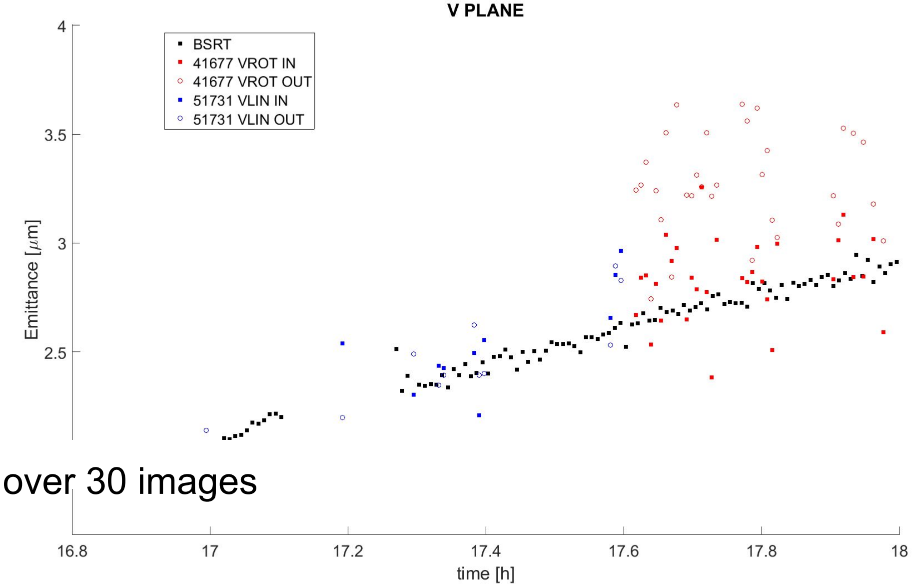
Experimental studies in 2017 - 10 May



- Not able to do any transverse emittance studies, due to “bad” transverse beam size profiles
  - Focus in the slow off-bucket losses
    - Very helpful input and participation of the RF group!
- **Source of off-bucket losses was identified → RF feedback**

Experimental studies in 2017 - 10 May



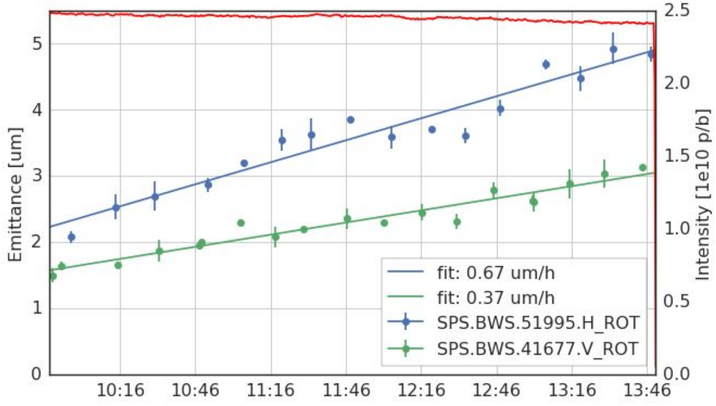


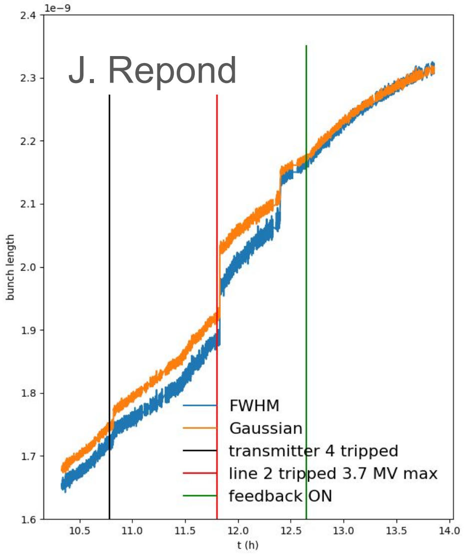
Averaging over 30 images

- BSRT calibration for the coast beams (many thanks to G. Trad)!!

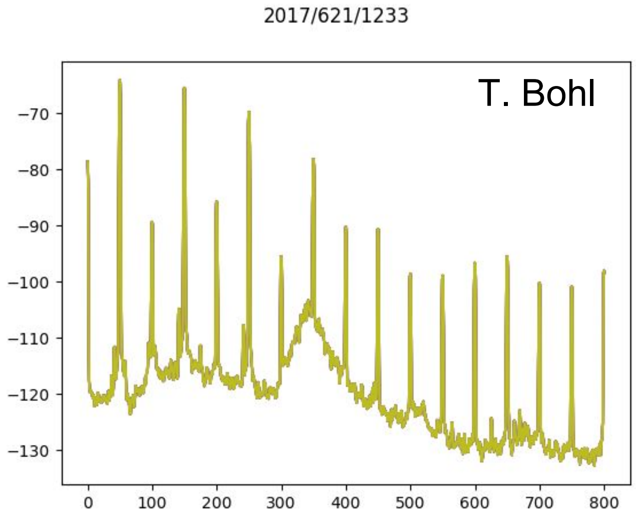
Experimental studies in 2017: 21 June

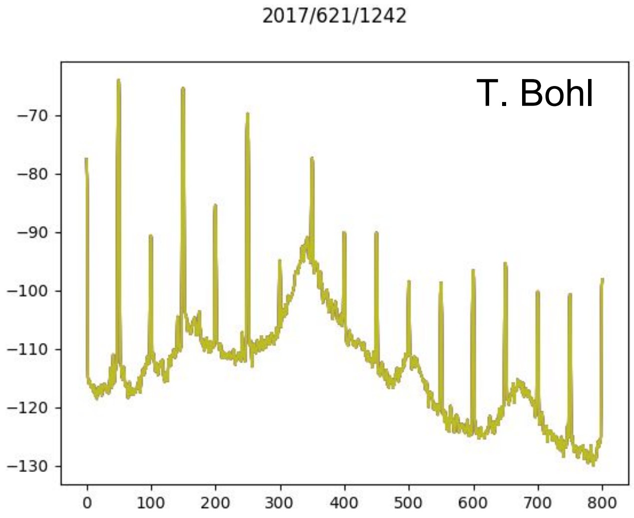
- 21 June: MD with coast at 270 GeV, low intensity and low chromaticity
  - The RF feedback was off for the first 2.5h and then switched on verifying that the off-bucket losses are caused by the RF feedback
  - Large growth in all planes observed
    - The RF system was not behaving very well during the MD
- 22 June:
  - Calibration studies for the Head Tail monitor at high intensity (T. Levens, T. Lefevre, M. Krupa)





Experimental studies in 2017: 21 June

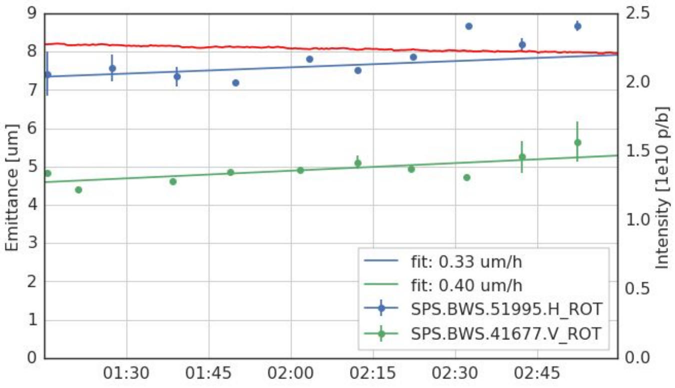


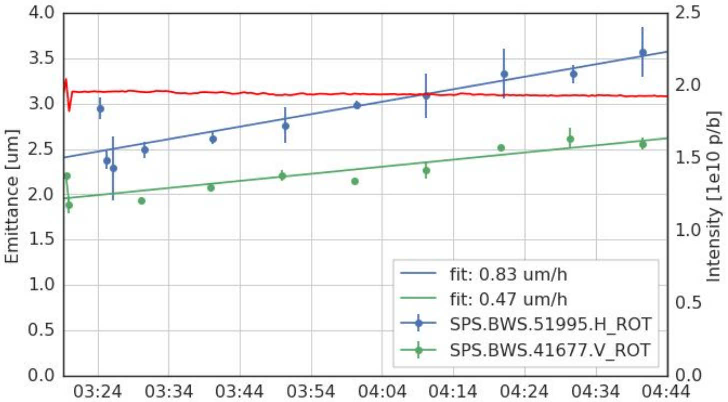


- Peak detected Schottky signals were also acquired with the RF feedack off and on in order to see if the spectrum is changing
- Very similar results for both cases

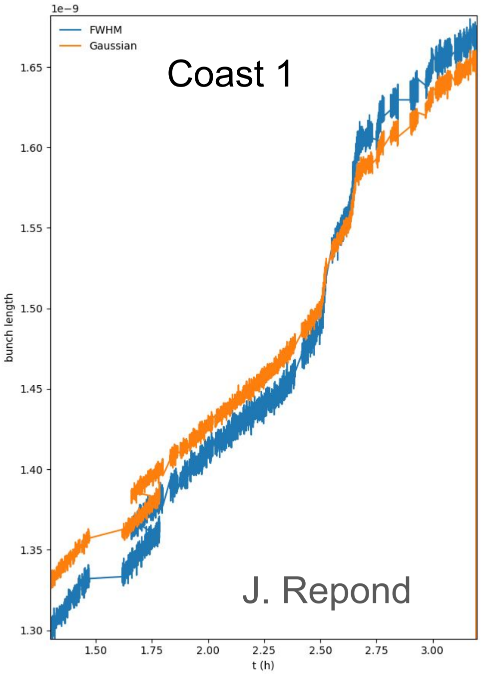
Experimental studies in 2017 - 4 July

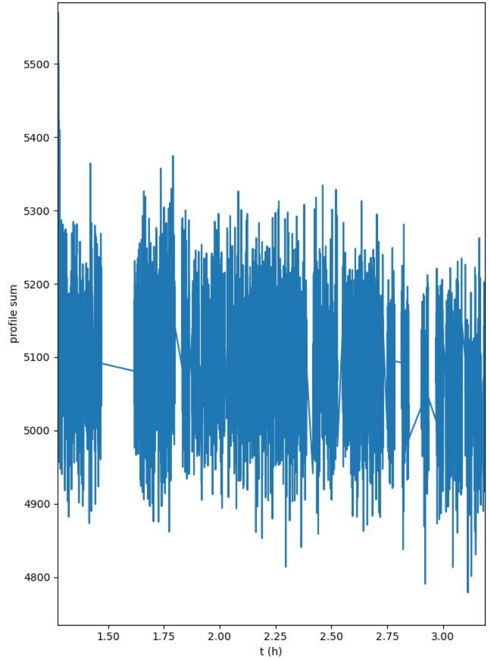
- The Q20 optics was tested!
- RF voltage of 5MV
- 2 coasts at low intensity and low chroma
  - Coast 1:
    - emit. H/V = 7.3 / 4.8 um
    - Nb=2.2e10ppb
    - σl = 1.7 ns
  - Coast 2:
    - emit. H/V = 2.5 / 2.0 um
    - Nb=2.2e10ppb
    - σl = 2 ns



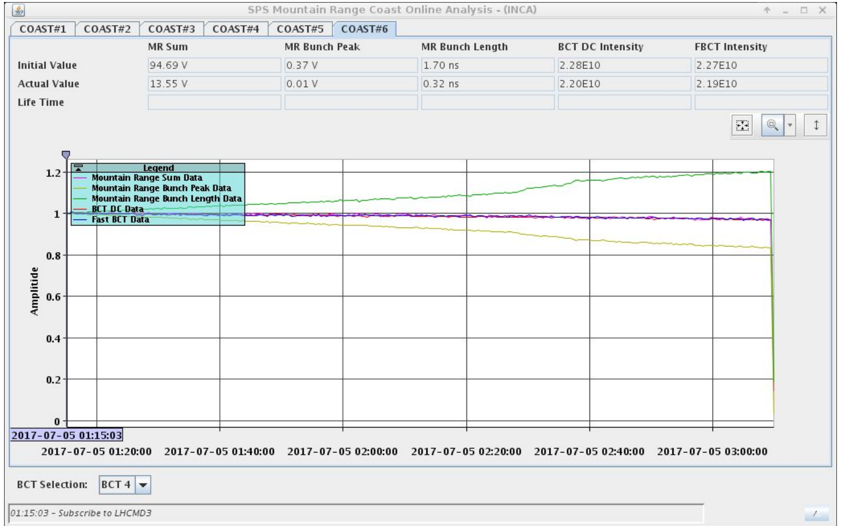


Experimental studies in 2017 - 4 July

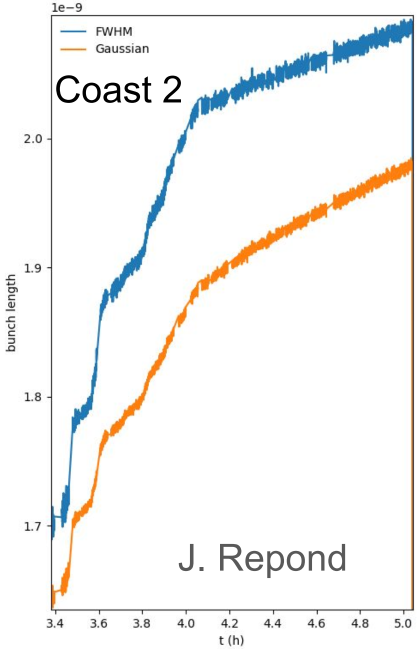


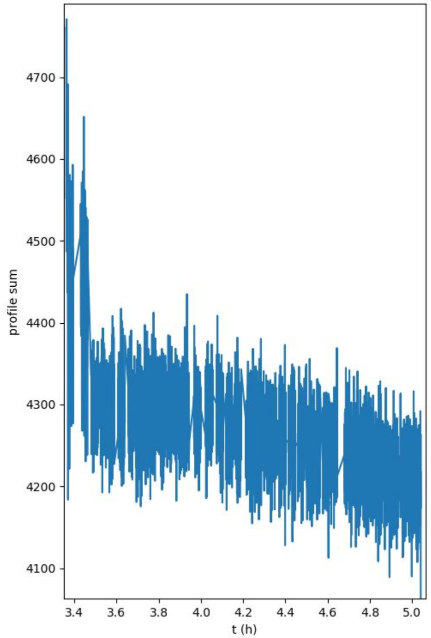


- Sudden jump in bunch length needs to be understood
- The effect is visible in the horizontal plane as well
- Analysis in progress

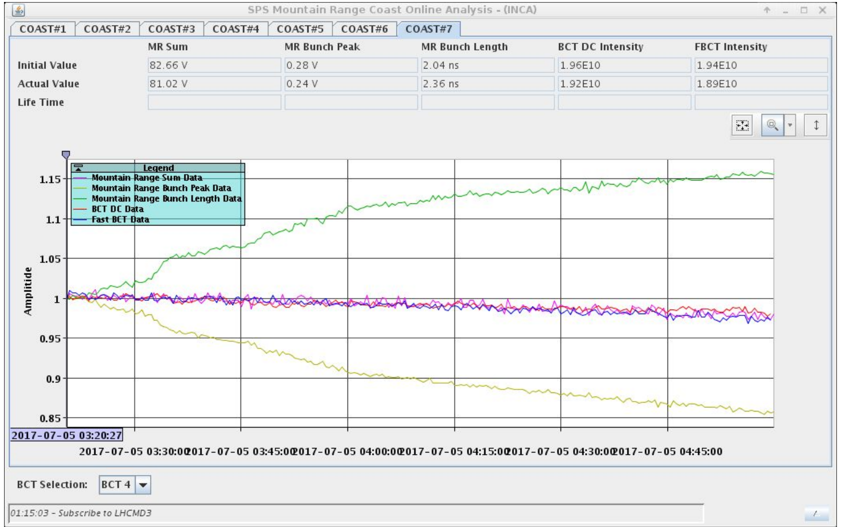


Experimental studies in 2017 - 4 July





- Sudden jumps in bunch length which starts earlier in time than coast 1
  - The bunch length is also larger
- Analysis in progress

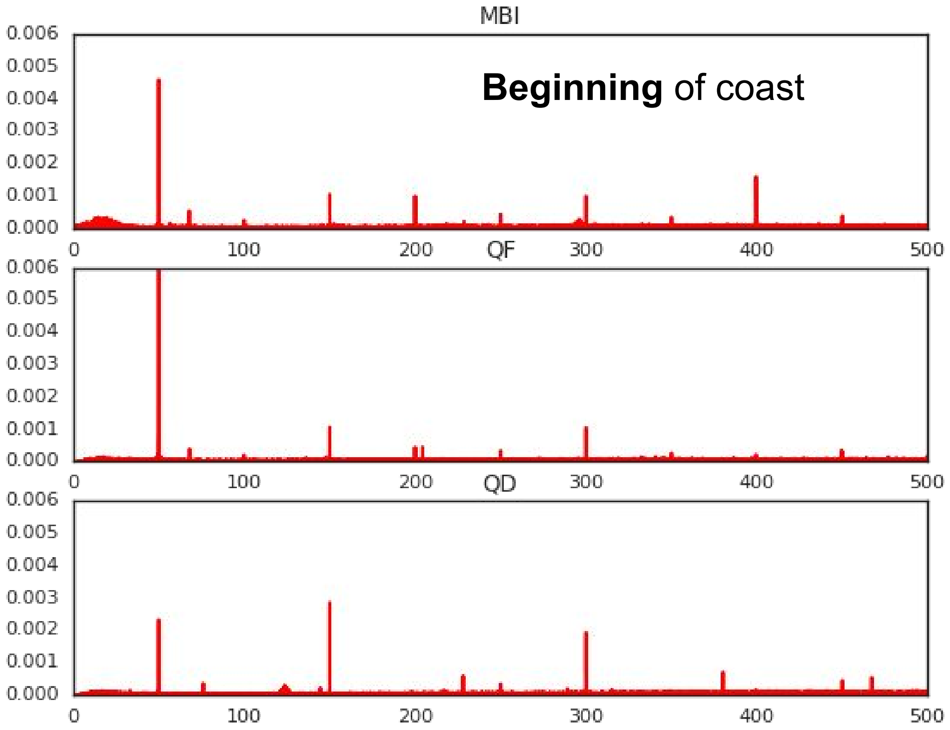


Experimental studies in 2017 - 4 July

- Calibration of the Head Tail monitor at low intensities (removing attenuators) (T. Levens, T. Lefevre, M. Krupa)
  - Very nice signals and promissing results
- BSRT profiles acquired by G. Trad

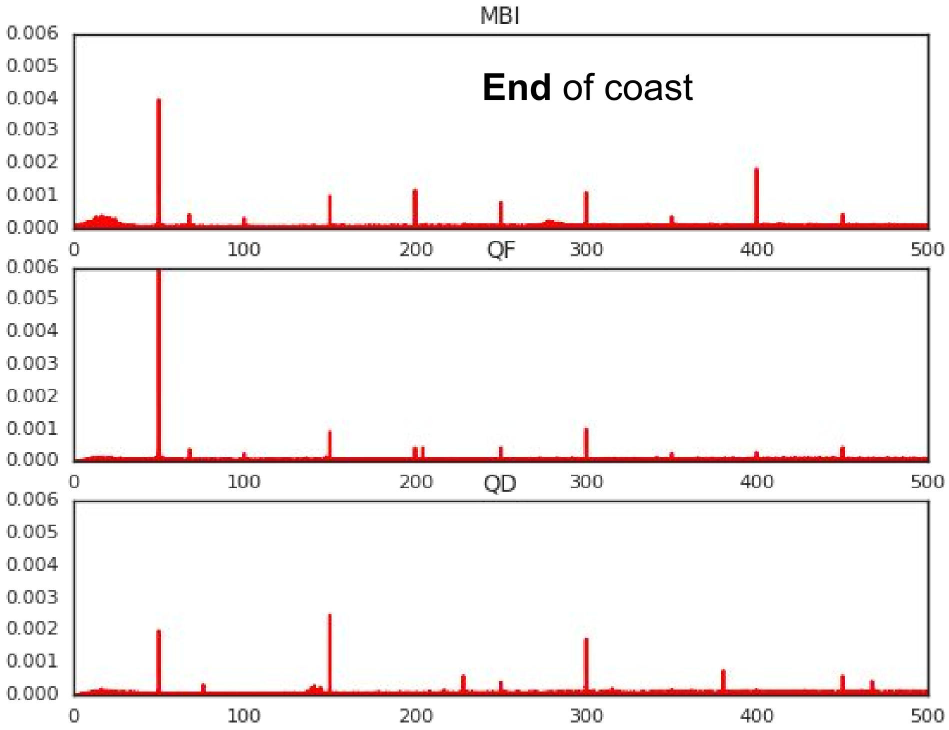
Power supply ripple

- Frequency spectrum of the power supply current for the MBI, QF and QD at the **beginning** of the coast
  - From 10 May MD
- 50Hz line is the main frequency and the higher harmonics of it are present



Power supply ripple

- Frequency spectrum of the power supply current for the MBI, QF and QD at the **end** of the coast
  - From 10 May MD
- 50Hz line is the main frequency and the higher harmonics of it are present
- Very similar to the one at the beginning
- Simulations are foreseen in order to estimate the impact on the emittance evolution
  - Technical student will start the 1st of Oct.



Summary table (Preliminary)

	Emit. H/V [μm]	Nb [1e10]	Chroma H/V	RF voltage [MV]	Bunch length [ns] / Long. emit. [eV. sec]	H/V growth [μm/h]	Bunch length growth	Time [h]	H growth corrected from IBS [μm/h]	Bunch length growth from IBS
July 2016	2.85/2.16	2.25	2.5/2.5	5.1	1.96/0.41	0.59/0.23	10%	1.6	0.45	3.3%
Dec. 2016 Coast1 Coast 2 ξ increase multi-scans	 2.23/1.61 2.25/1.41 4.0/1.98 -/2.3	 4.25 1.65	 0.5/1 0.5/1 2.5/3 2.5/3	2	 2.28/0.36 2.3/0.36 - -	 0.49/0.30 0.55/0.27 1.52/0.51 -/0.82	 20% 10% - -	 1.8 1.8 0.8 0.4	 0.183 0.364 - -	 14% 8% - -
May 2017										
June 2017	2.1/1.7	2.5	1/1.6	5	1.9/0.41	0.67/0.37	40%	4		
July 2017 Q20 Coast 1 Coast2	 7.3 / 4.8 2.5/2.0	 2.2 2.2	0.7/1.4	5	 1.7/0.33 2.0/0.45	 0.33/0.4 0.83/0.5	 20% 15%	 2 1.6	Negligible	

Summary table (Preliminary)

	Emit. H/V [µm]	Nb [1e10]	Chroma H/V	RF voltage [MV]	Bunch length [ns] / Long. emit. [eV. sec]	H/V growth [µm/h]	Bunch length growth	Time [h]	[illegible]	Bunch length growth from IBS
July 2016	2.85/2.16	2.25	2.5/2.5	5.1	1.96/0.41	0.59/[illegible]	[illegible]	1.6	0.45	3.3%
Dec. 2016 Coast1 Coast 2 ξ increase multi-scans	2.23/1.61 2.25/1.41 4.0/1.98 -/2.3	4.25 1.65	0.5/1 0.5/1 2.5/3 2.5/3	2	2.2[illegible]	[illegible] [illegible]27 [illegible]2/0.51 -/0.82	20% 10% - -	1.8 1.8 0.8 0.4	0.183 0.364 - -	14% 8% - -
May 2017										
June 2017	2.1/1.7	[illegible]	[illegible]	5	1.9/0.41	0.67/0.37	40%	4		
July 2017 Q20 Coast 1 Coast2	7.3 /[illegible] 2.5/2[illegible]	2.2 2.2	0.7/1.4	5	1.7/0.33 2.0/0.45	0.33/0.4 0.83/0.5	20% 15%	2 1.6	Negligible	

Preliminary table.
All the calculations need to be repeated taking into account the longitudinal plane correctly!

Current Conclusions

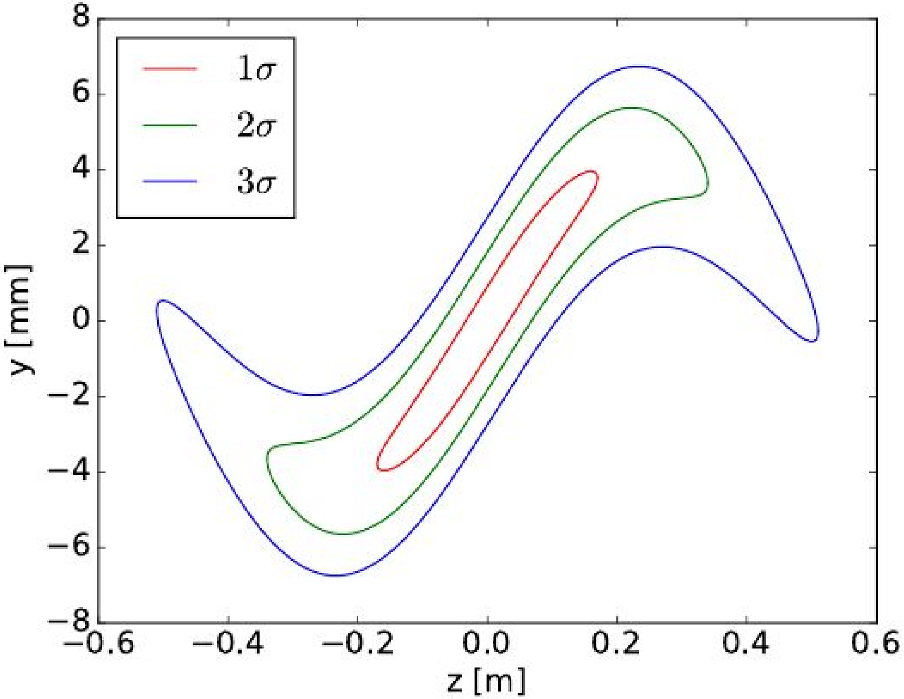
- Clear dependence of the emittance growth on the chromaticity
- Off-bucket losses correlated with the RF feedback
    - The effect was eliminated switching the RF feedback off
- IBS seems to play a role. Correcting the IBS part the growth in the two planes tend to become similar

Next studies in dedicated MDs

- Systematic chromaticity scan in order to define optimal chroma settings in both plane
- Linear WS multi-scan to verify dependence on the number of scans
- Vacuum degradation and emittance evolution correlation

Thank you for your attention!

Instrumentation validation for measuring the crabbing



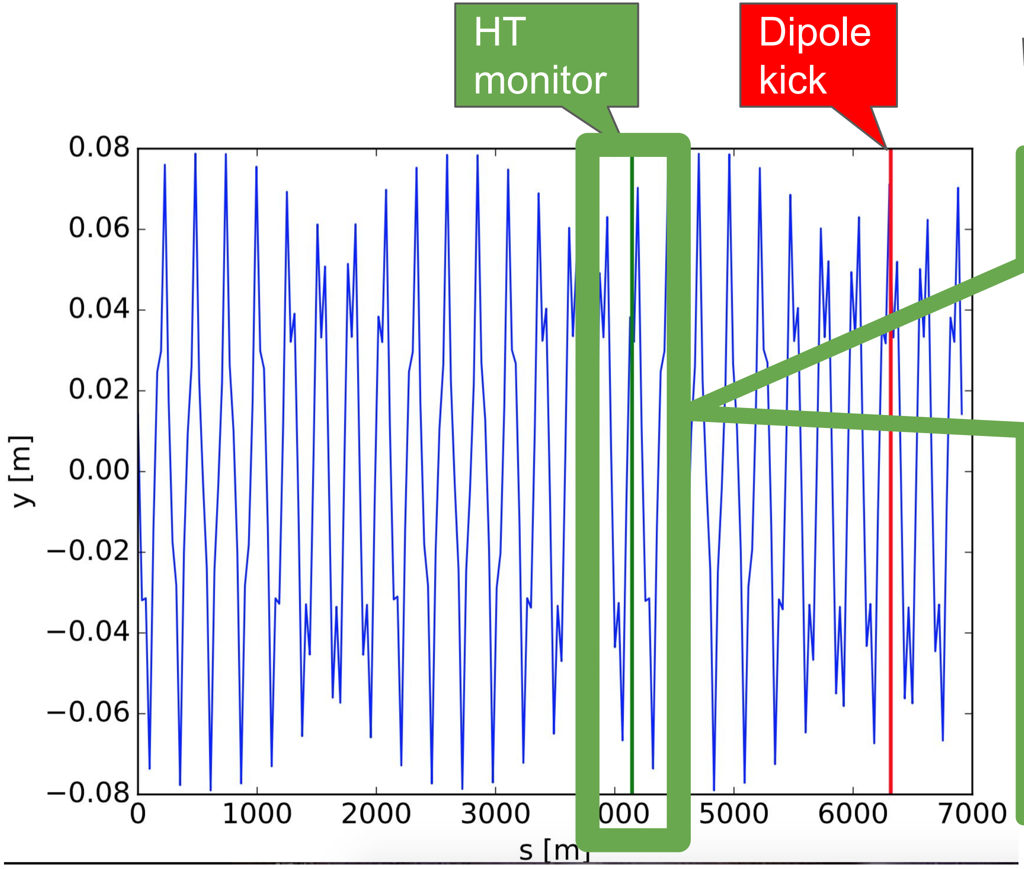
The bunch profile of the crabbed beam at the HT monitor location (55GeV, V=6.8MV)

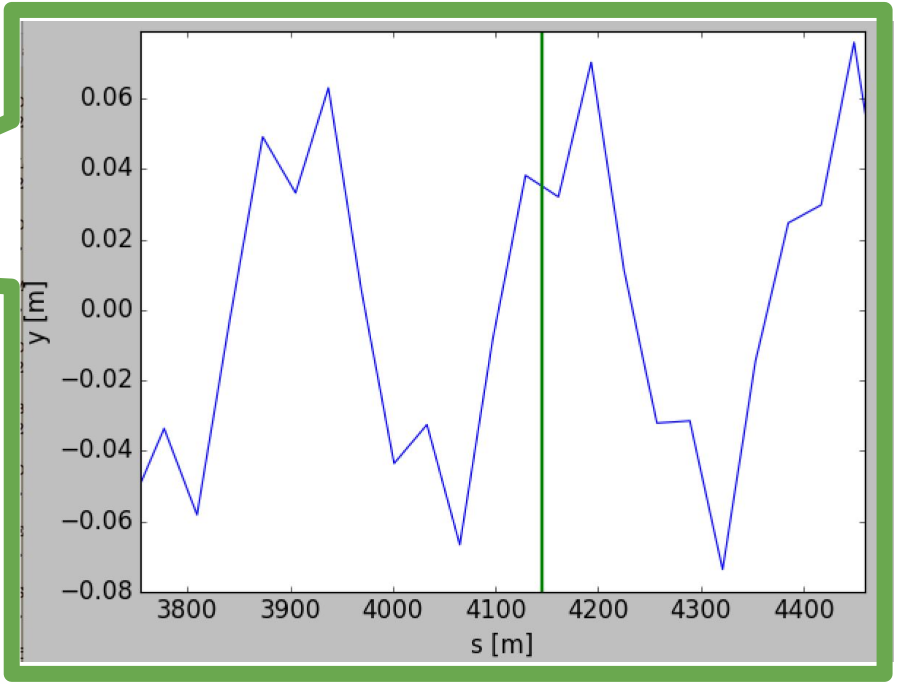
- The most sensitive instrument available in the SPS that we can use to measure the kick of the crab cavity is the Heat-Tail monitor
- It has been used mainly to detect instabilities → Large intra-bunch motion
- Preparation studies are in progress to prove that it can be used to measure the crabbing of the bunch

A. Alekou

CO deformation due to dipole error compatible with the CC kick

V CC kick simulated with a V dipole kick of 1 mrad
WP: 26.13, 26.18





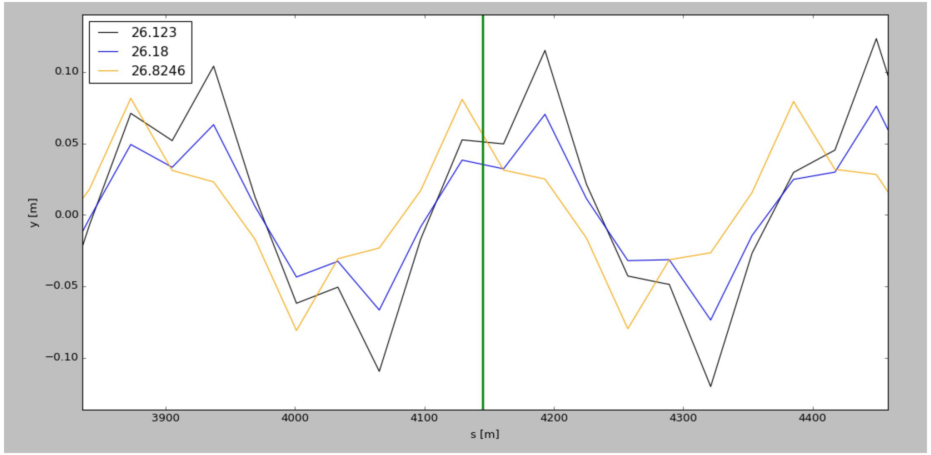
A. Alekou

Head-Tail (HT) monitor reading

- We would like to have a **good y-reading at HT monitor position**
- For higher y-signal at HT we could physically move the HT (only if absolutely necessary, to be avoided), or change the SPS WP

Impact of the SPS working point

- Can increase overall y-CO and therefore the CO at the HT monitor location
- Changes ph-Advance between HT and kick, HT can be at crest of wave

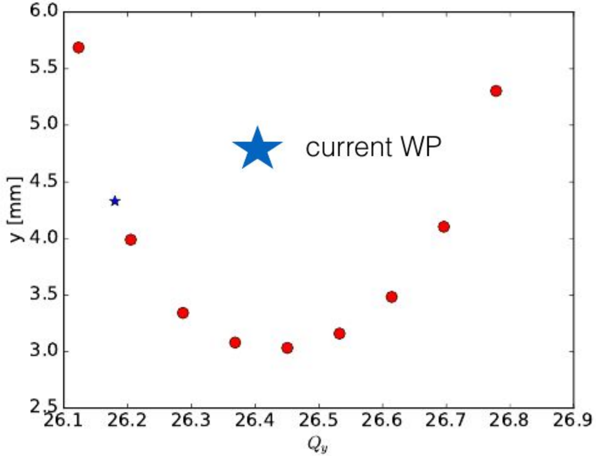


$$z(s) = \frac{\theta}{2} \frac{\sqrt{\beta(s)}\sqrt{\beta(s_k)}}{\sin \pi Q} \cos\left(\left|\Phi(s) - \Phi(s_k)\right| - \pi Q\right)$$

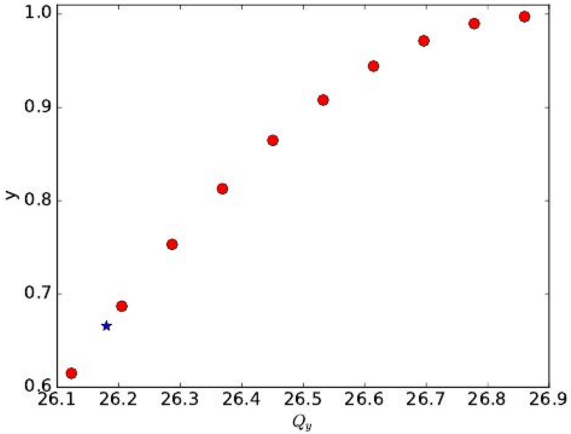
A. Alekou

Head-Tail monitor reading with respect to WP change

y-amplitude at HT monitor



normalised y-amplitude at HT monitor
y_norm=(y@HT/ymax)*√(βmax/β@HT)

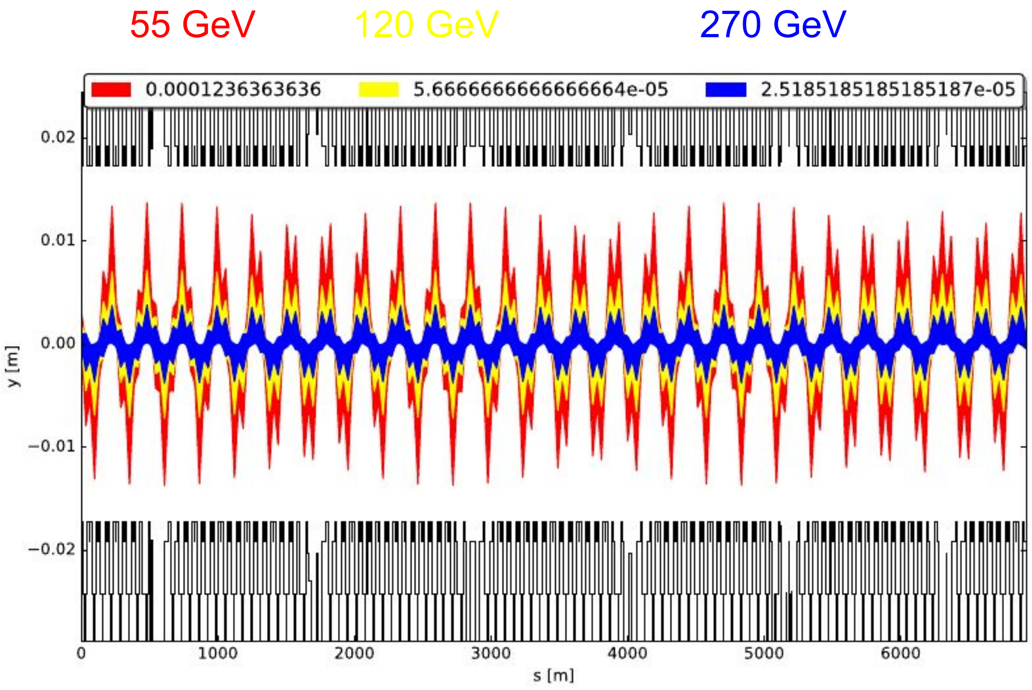


- 30% “loss” of reading does not justify WP change or change of HT monitor location.
- In contact with the BI group (T. Lefevre, T. Levens et al) to study HT limitations
  - First parallel MD already took place the 22nd of June and next one foreseen for the 4th of July

A. Alekou

Aperture limitation vs kick size vs energy

V=6.8MV

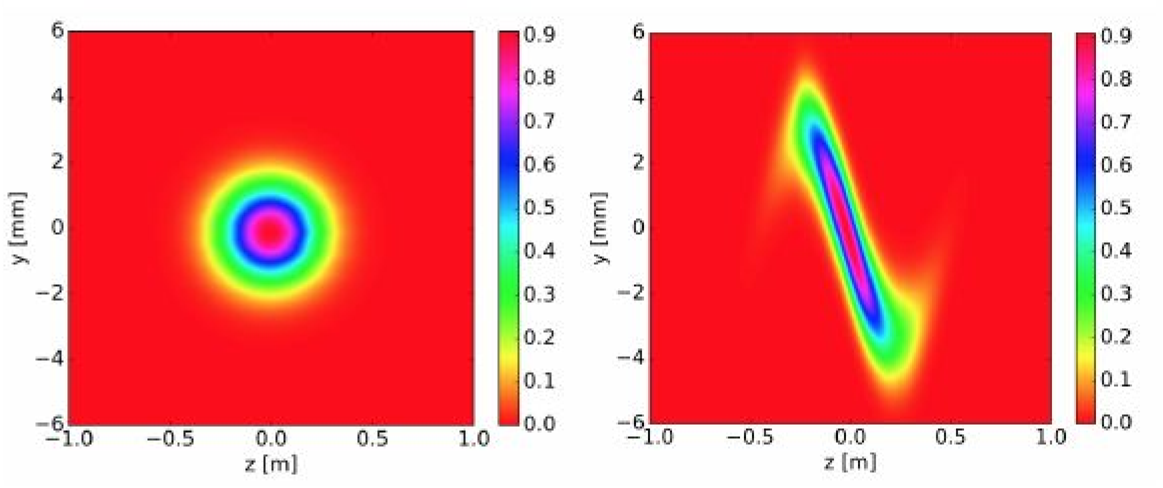


Energy [GeV]	Kick [mrad]
55	0.1236
120	0.0567
270	0.0252

Conclusion: for max V (6.8 MV), nominal WP, at 55, 120, 270 GeV, there is no aperture limitation.

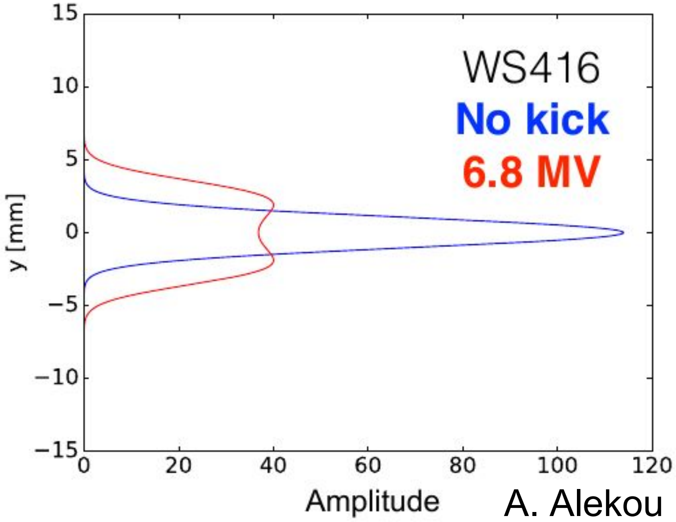
A. Alekou

Using the Wire scanners to measure the crabbing



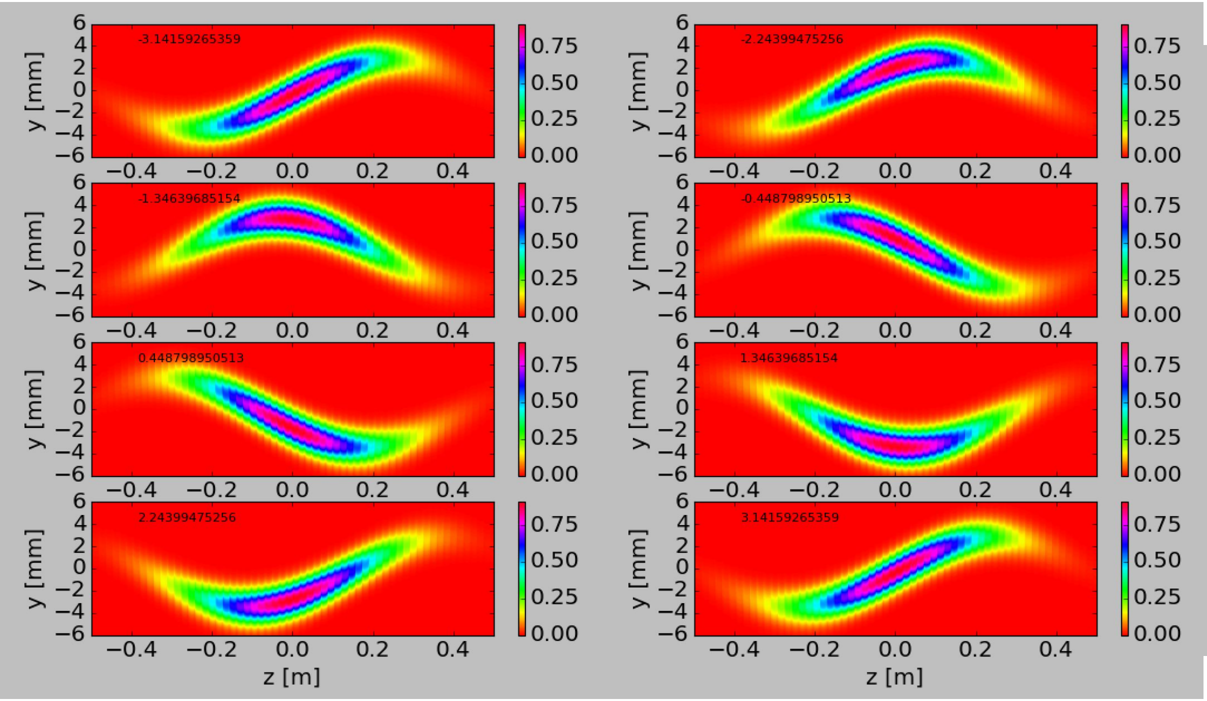
2D gaussian beam in y and z, without (left) and with a kick corresponding to 6.8 MV (right).

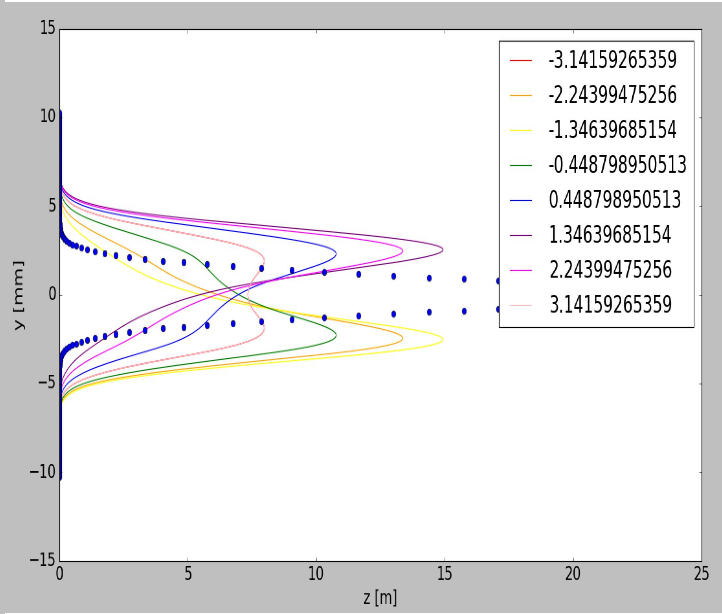
- An alternative approach is under investigation → Use the Wire scanners to measure the effect of the CC on the bunch profile



A. Alekou

Impact of the CC phase on the bunch profile at the WS location





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