Observation of Collective Effects
during Positron and Electron Operation at PETRA III.

Three-Way Meeting, Aug. 1-2, 2013

Argonne National Laboratory.




Rainer Wanzenberg
DESY

Aug. 1, 2013

HELMHOLTZ
ASSOCIATION

DESY

Outline

- Introduction
  - PETRA III (History, Parameter)
  - Emittance Diagnostics
- Operation with e+
  - Electron Cloud Effects
- Operation with e-
  - Ion Effects
  - Single Bunch Effects (TMCI)
- Test Runs at Low Energy (3 GeV) and Low Emittance
  - Intra Beam Scattering / Emittance Growth

PETRA - History

The PETRA ring was built in 1976 as an electron – positron collider and was operated from 1978 to 1986 in this collider mode.

From 1988 to 2007 PETRA II was used as a preaccelerator for the HERA lepton hadron collider ring.

2007 – 2008: The PETRA ring was converted into a synchrotron light facility.

e+ operation (2009 – 2012)

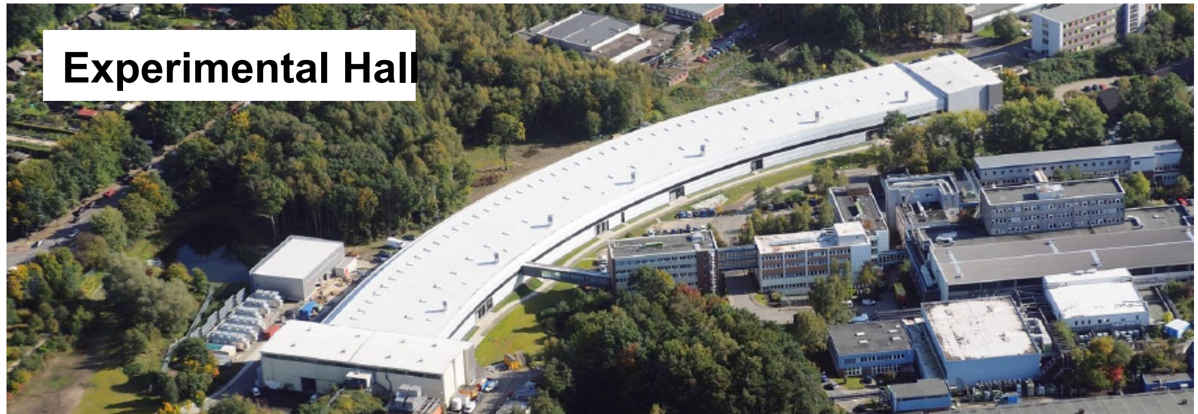
2009 commissioning with beam
2010 "friendly users",
first indication of electron cloud effects,
40 x 4 = 160 / 60 x 4 = 240 Bunches
2011 regular user operation
60 x 4 = 240 / 240 x 1 Bunches (32 ns)
2012 regular user operation
240 x 1 / 320 x 1 Bunches

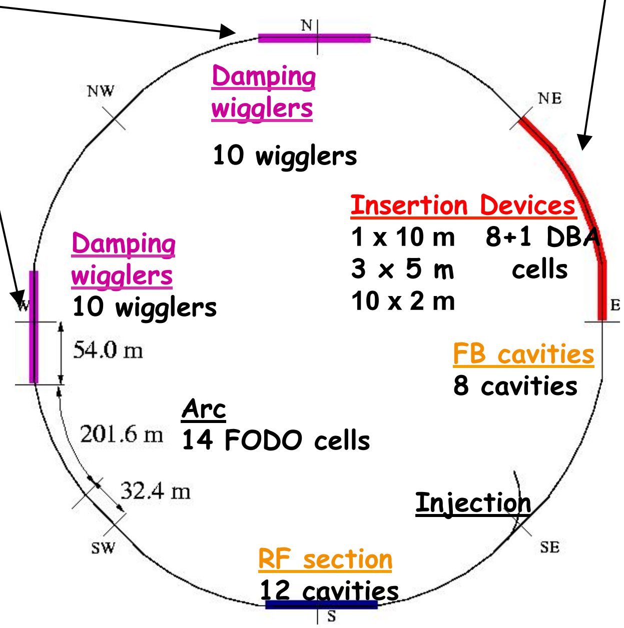
e- operation (started Jan 2013)

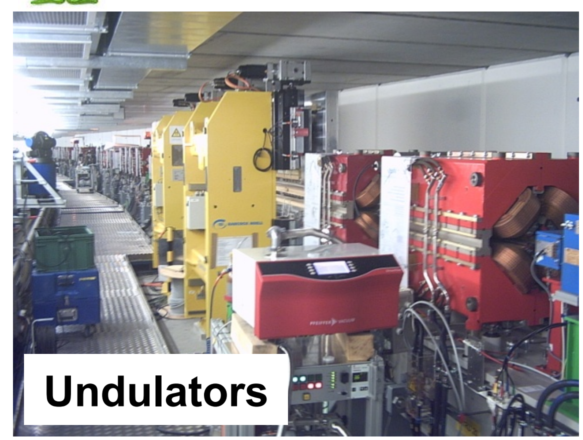
2013 regular user operation
480 and 960 bunches (design)

PETRA III - Overview

Parameter	PETRA III
Energy / GeV	6
Circumference /m	2304
Total current / mA	100
Emittance (horz. / vert.) /nm	1 / 0.01

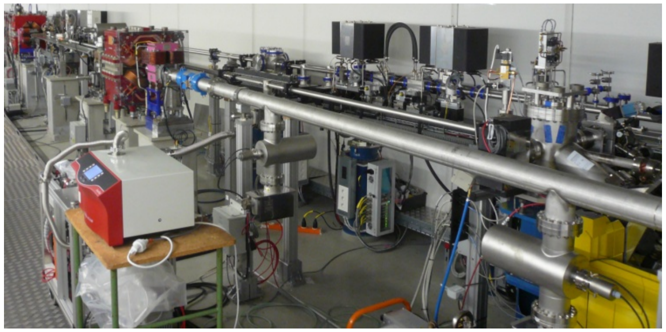


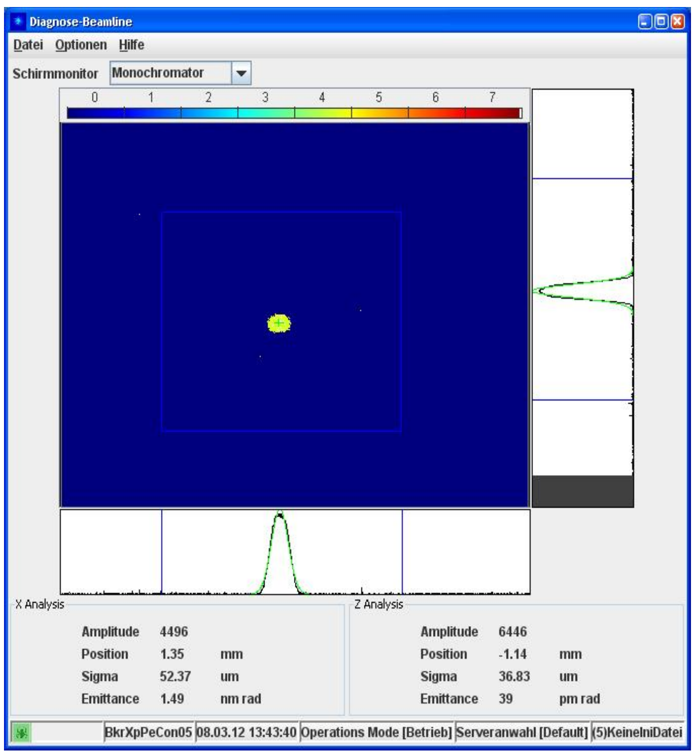




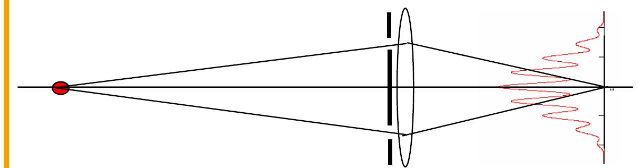
PETRA III Emittance Diagnostics

Diagnostic Beam Line (Exp. Hall)

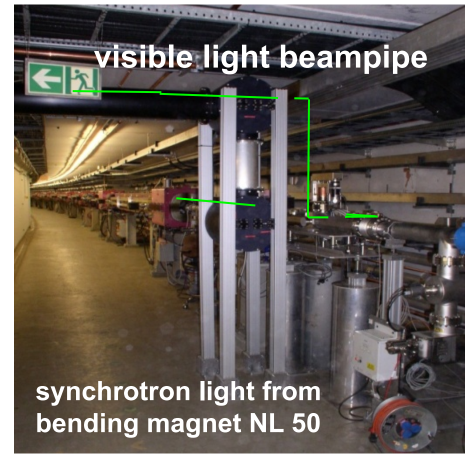


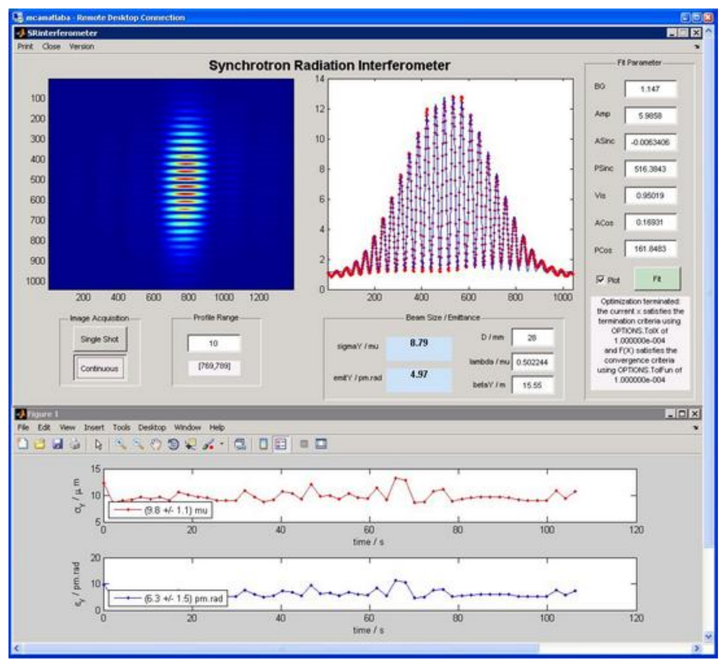


Interferometric beam size measurements (North)



Reference:
PETRA III
G. Kube, DIPAC'07, EPAC'08
ATF - KEK
H.Hanyo et al., Proc. of PAC99 (1999), 2143
T. Naito and T. Mitsuhashi, Phys. Rev. ST Accel. Beams 9 (2006) 122802





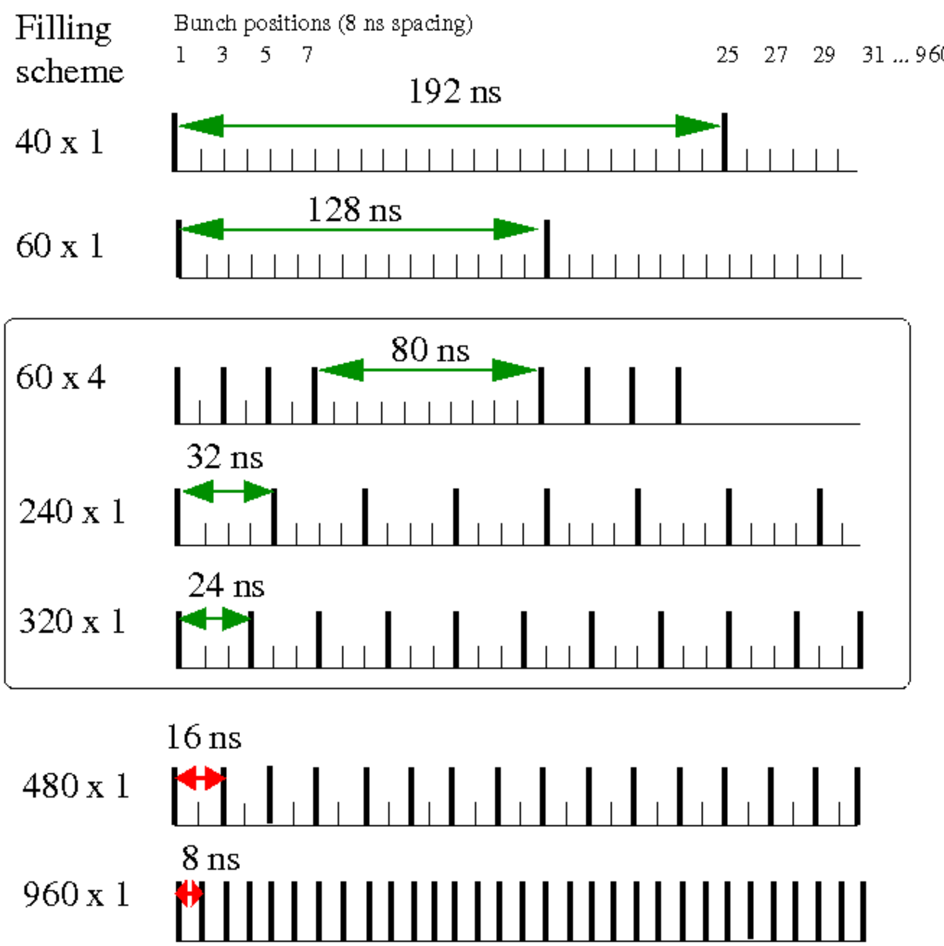
60 x 4 bunches, 100 mA
Vert. Emittance

~ 5 pm rad

(March 8, 2012)

PETRA III – Parameters, Filling patterns

Design Parameter	PETRA III	
Energy / GeV	6	
Circumference /m	2304	
RF Frequency / MHz	500	
RF harmonic number	3840	
RF Voltage / MV	20	
Momentum compaction	1.22×10^{-3}	
Synchrotron tune	0.049	
Total current / mA	100	
Number of bunches	**960**	**40**
Bunch population / 10^{10}	**0.25**	**12**
Bunch separation / ns	**8**	**192**
Emittance (horz. / vert.) /nm	**1** / 0.01	
Bunch length / mm	12	
Damping time H/V/L / ms	16 / 16 / 8	



achieved: e+ 80 mA: 40 bunches; 100 mA : 60, 240, 320 bunches

e- 100 mA: 40, 60, 480, 960 bunches

Electron clouds

Broad band resonator model
+ coasting beam model *)
threshold density:

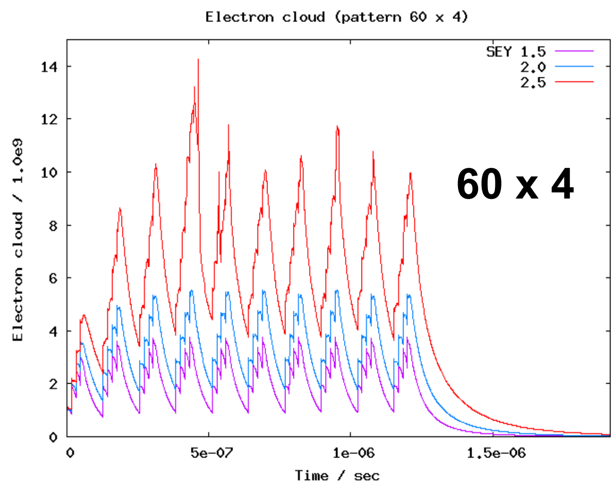
$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_e\sigma_z/c}{KQ\sqrt{3}r_e\beta L}$$

Q ~ 5 < K

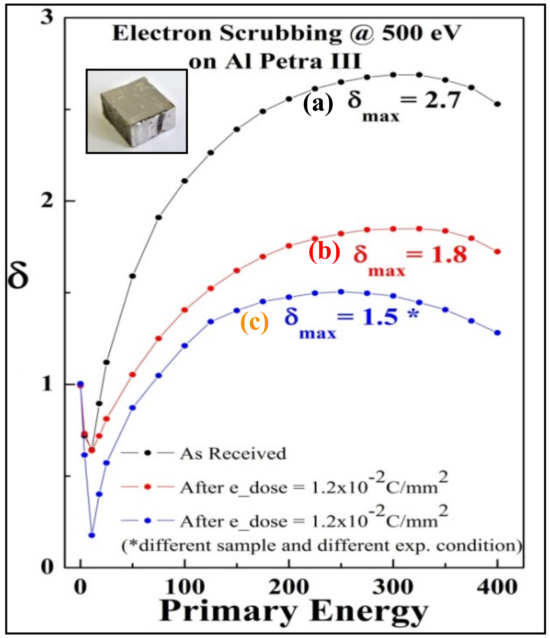
(L = circumference of the ring)

	$K \sim \omega_e\sigma_z/c.$
PETRA III:	**~ 1.4 x 10^{12} m^{-3}**

Electron cloud build-up simulations ECLOUD code (CERN) *)**



Dipole Vacuum chamber **), SEY = 2.7 as received



Al, 80 mm x 40 mm

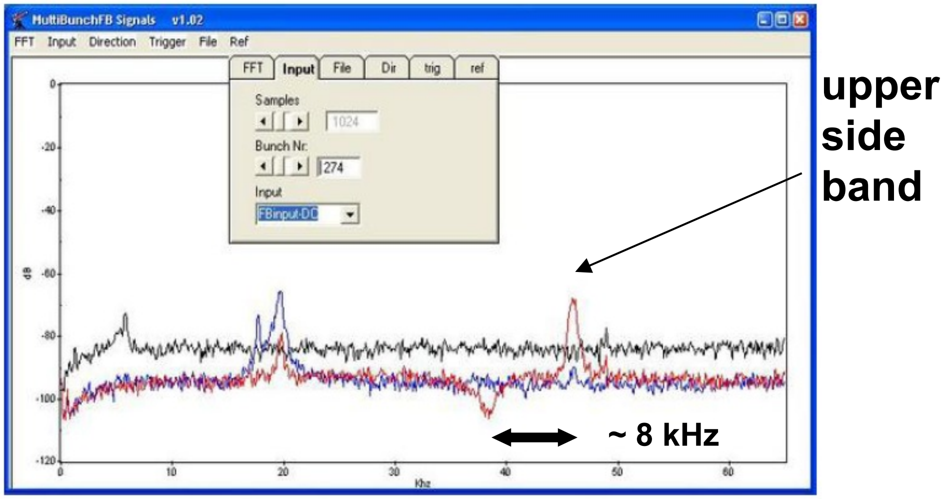
*) K. Ohmi: Electron Cloud Effect in Damping Rings of Linear Colliders, "ECLOUD'04"

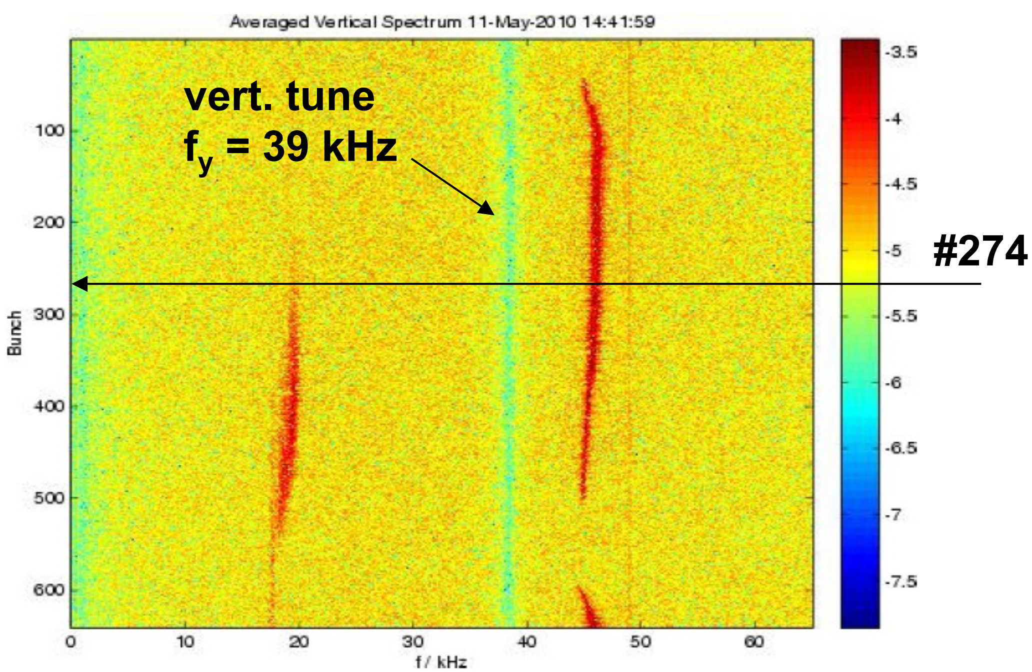
**) D.R. Grosso et al: Secondary Electron Yield of Al Samples from the Dipole chamber of PETRA III, IPAC'11

***) G. Rumolo, F. Zimmermann, CERN-SL-Note-2002-016

Vertical emittance blow up (640 bunches, 2010)

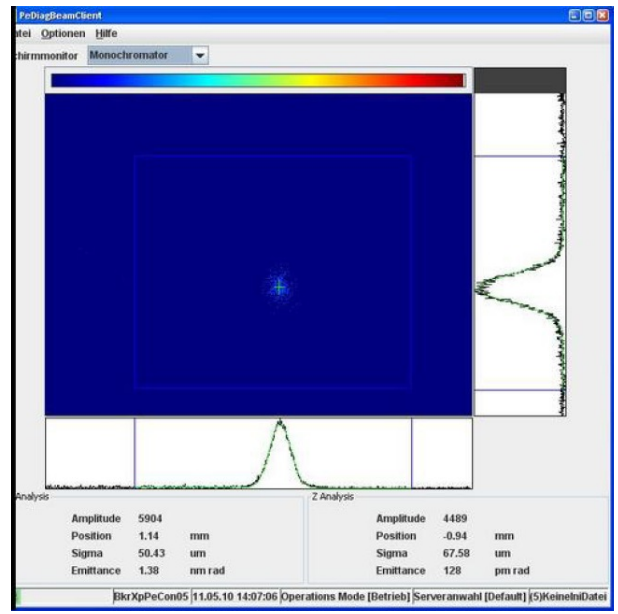
Tune spectrum, bunch position #274





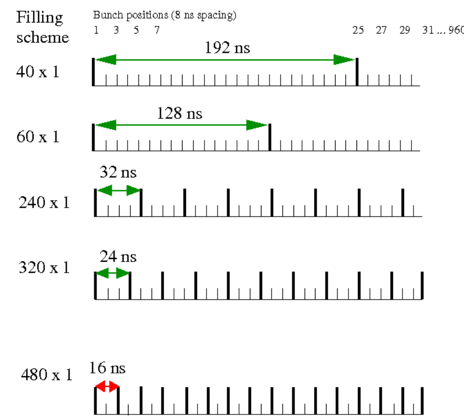
640 bunches, 8 ns bunch spacing + gap
639 x 8 ns = 5112 ns, gap 2568 ns,
total current 65 mA

Measured Emittance on May 11, 2010
Horz. 1.38 nm
Vert. 128 pm
(Average, all bunches)



Operation with e+ in 2012 / Understanding of eclouds

Conditioning (integrated beam current)
May 2010 → May 2011 → Dec. 2011 → April 2012 → Dec. 2012
133 Ah → 577 Ah → 980 Ah → 1050 Ah → 1520 Ah
Dedicated Scubbing Runs: March 3-4 and 10-11, 2012



User runs with 240 (32 ns) and 320 (24 ns) bunches.

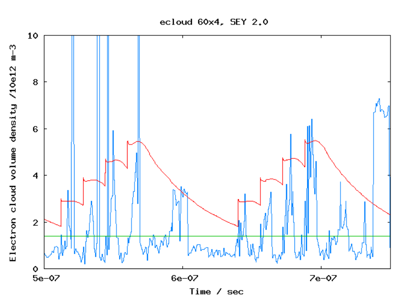
<u>Understanding of the Ecloud effects at PETRA III:</u>

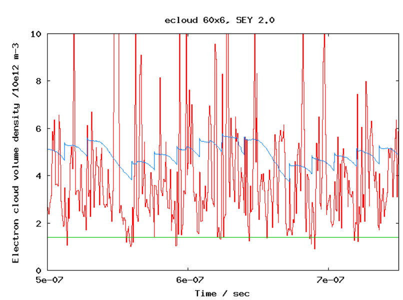
1) Investigation of the surface chemical state of the Al alloy

(CNR, LNF-INFN, R. Cimino, R. Larciprete et al. Phys Rev. STAB **16**, 051003 (2013))
After scrubbing SEY 1.5 … 1.8, but scrubbing is not permanent, Al has a chemical propensity towards oxygen, the Al surface binds O atoms and the SEY is increased, **no** significant build-up of a graphitic layer

2) Simulation of ecloud build-up for different filling patterns

(workshop ECLOUD'12)
Comparing the central e- density for different filling patterns (60x4 vs. 80x4) indicates that a SEY of ~ 2.0 is consistent with the observations based on the estimates for the instability threshold.

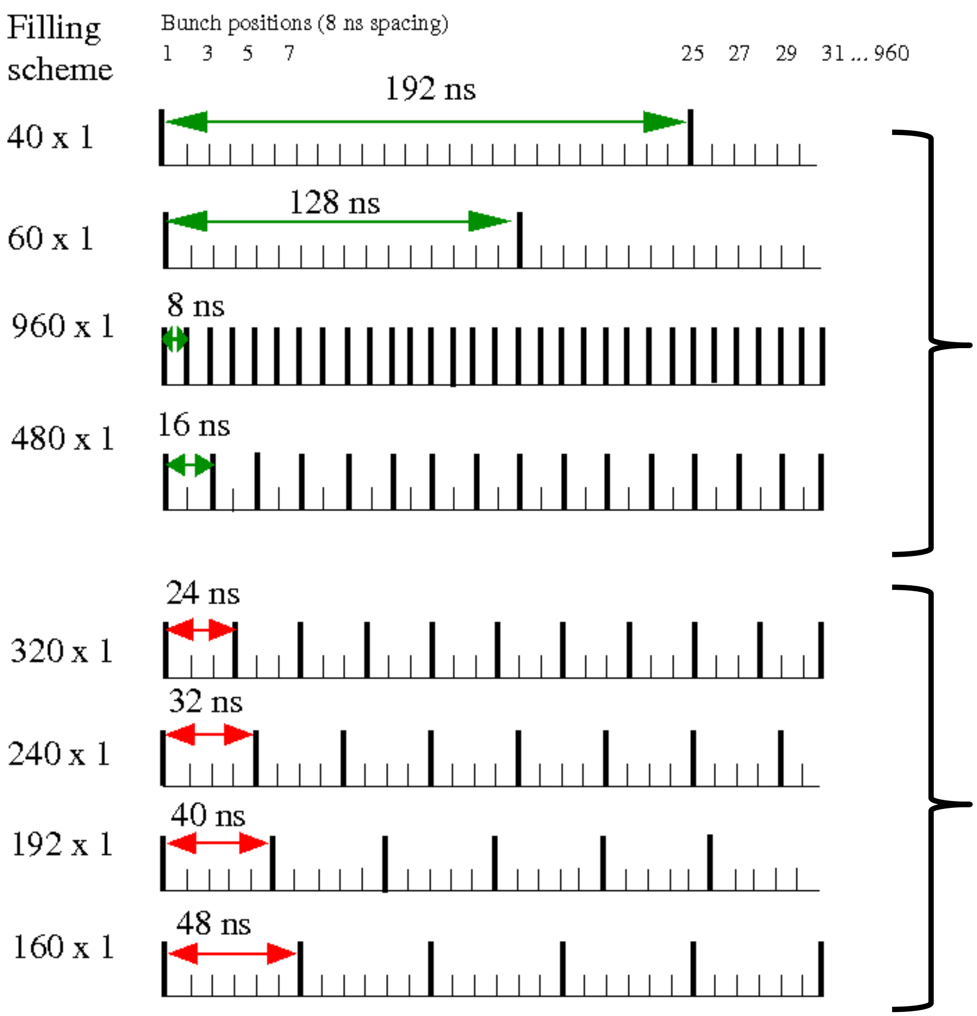




Open issues:
Strong fluctuations of the simulated
Central density
Primary photoelectron density is
not well known

Operation with Electrons in 2013, Ion effects

Filling schemes without a clearing gap



critical ion mass (classical ion trapping)

$$A > A_c = N_b\, L_b\, \frac{r_p}{2\,\sigma_y\,(\sigma_x + \sigma_y)}$$

N_b :	A_c				
960:	1	240:	16	120:	66
480:	4	192:	26		
320:	9	160:	37		

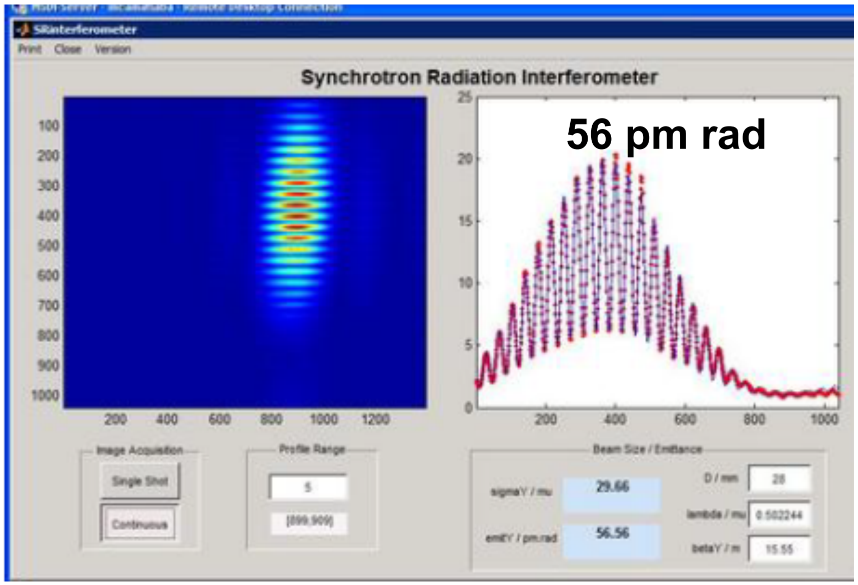
User runs, total current 100 mA

Ions:
A = 2 H_2
A = 16 CH_4
A = 18 H_2O
A = 28 CO, N_2
A = 32 O_2
A = 44 CO_2

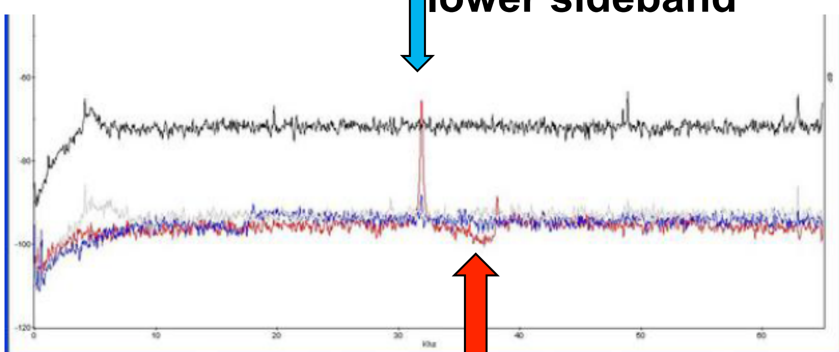
Vertical emittance growth,
Threshold current ~ 60 mA

Vertical Emittance Growth, e- Operation

Jan 15, 2013 240 bunches, 100 mA



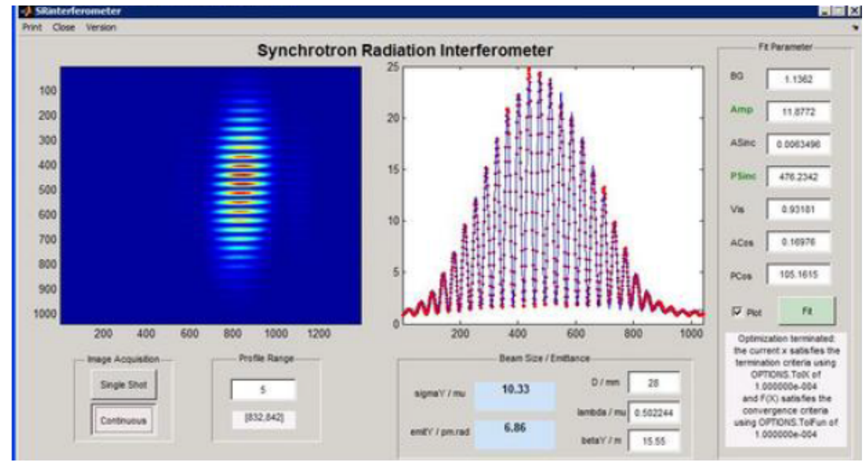
lower sideband



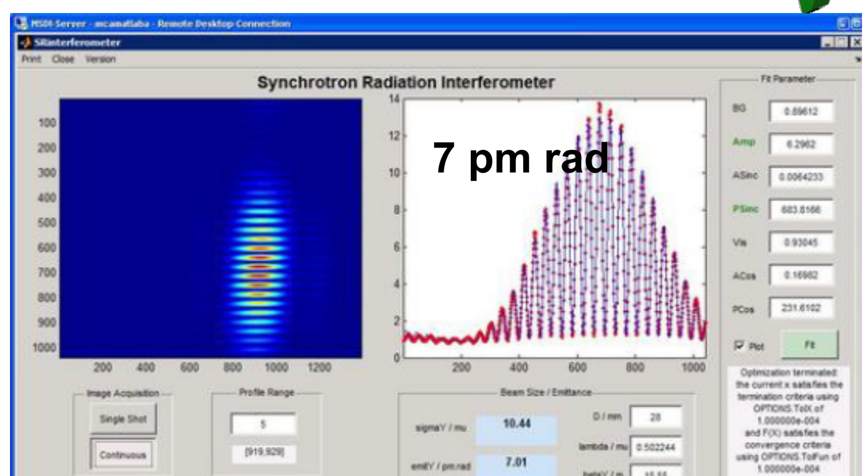
vert. tune

Threshold current ~ 60 mA

Jan 15, 2013 480 bunches, 100 mA

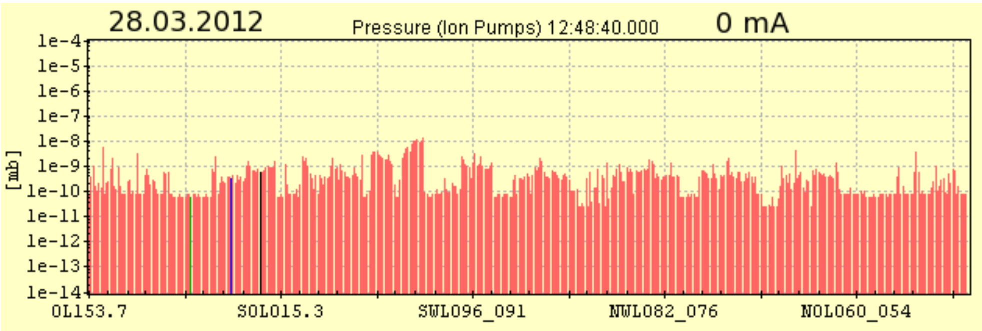


Jan 17, 2013 960 bunches, 100 mA

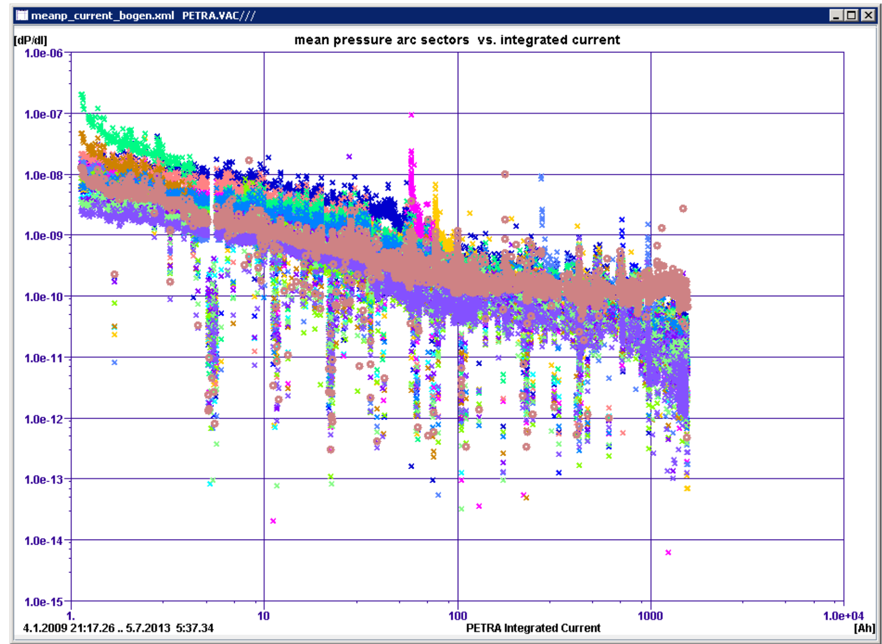


PETRA III: Vacuum

Without beam ~ 6 x 10^{-10} mb



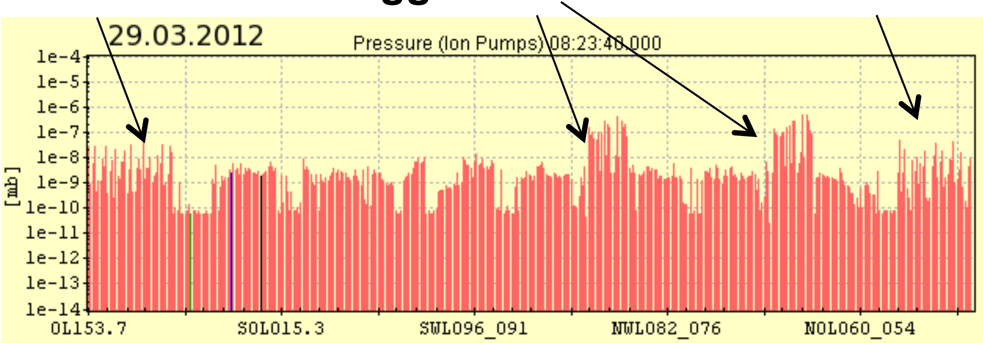
Dynamic pressure rise versus Integrated current



100 Ah **1500 Ah (Dec 2012)**

With beam, 100 mA , 240 bunches
arc ~ 3 x 10^{-9} mb, ring ~ 1.4 x 10^{-8} mb

undulators wiggler sections undulators

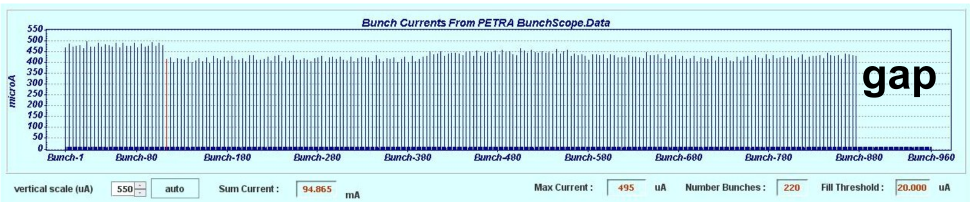


$$\lambda_{ion} = d_{gas}\,\sigma_{ion}\,N_0 = 2\,\mathrm{Mbarn}\,d_{gas}\,N_0$$ **= 230 ions/cm, p = 1 x 10^{-9} mb**
1 turn, 960 Bunches, N = 5 x 10^{9} e- / bunch

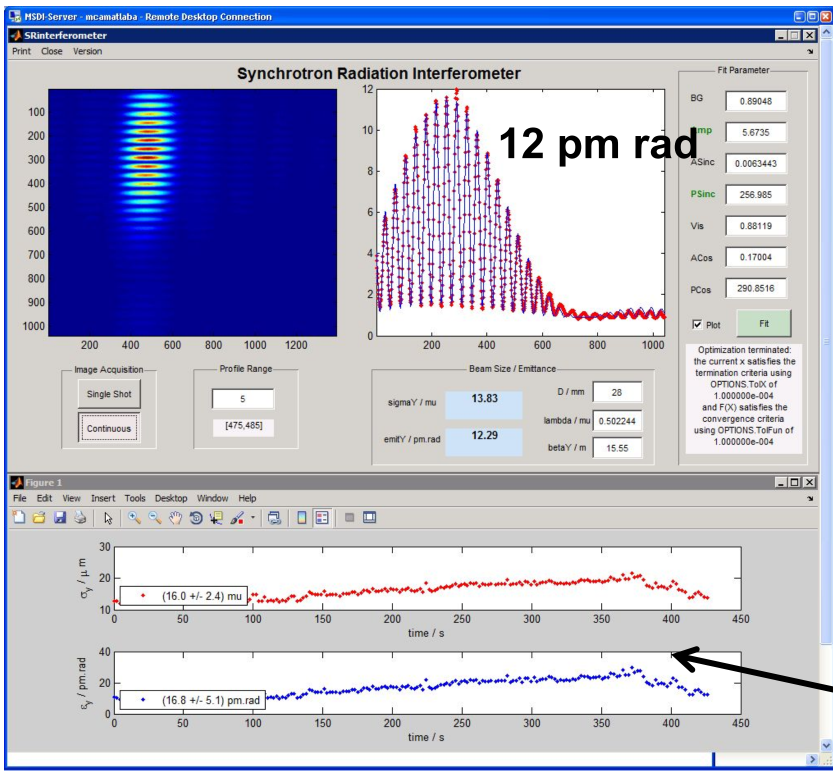
R Böspflug et al., **Vacuum System Design of the Third Generation Synchrotron Radiation Source PETRA III,**
Journal of Physics: Conference Series **100** (2008) 092012

Ion effects: 220 bunches (32 ns spacing) + gap

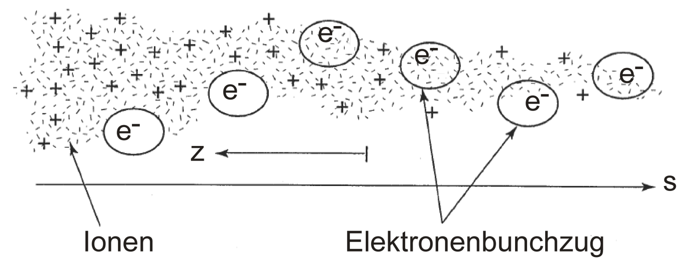
Single bunch intensity versus bunch position



Jan 17, 2013, 220 Bunche, 100 mA, vertical emittance



Fast Ion Instability ?

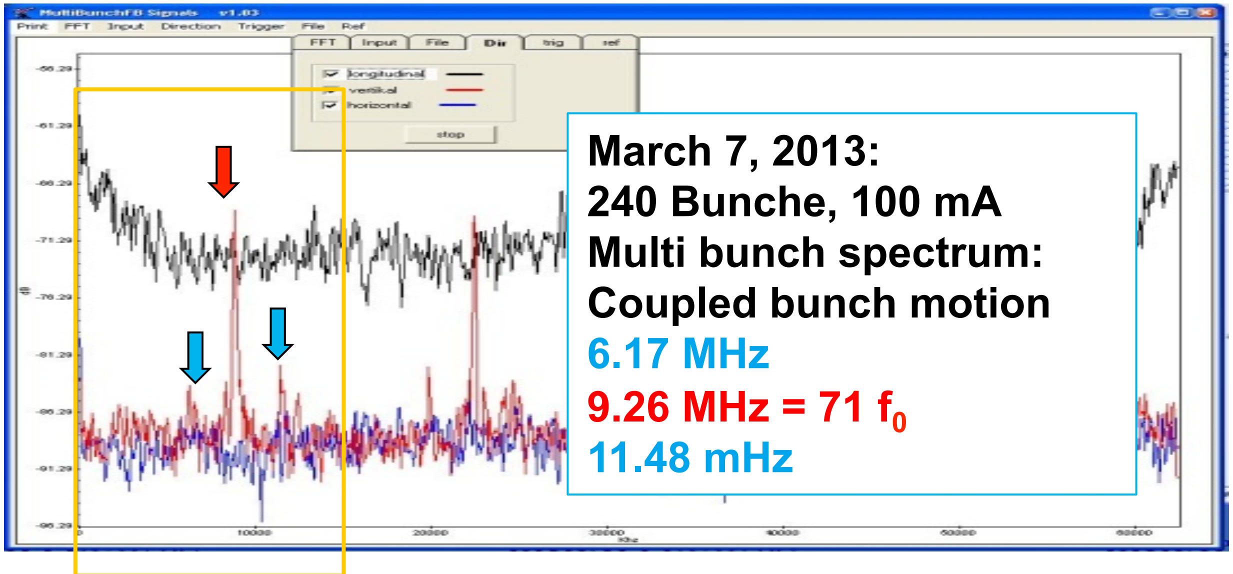


Simulations of the fast ion instability indicate an emittance growth for 960 bunches. (G. Xia et al., Ion Effect Issues in PETRA III, PAC 2009, Vancouver)

The instabilitay should be less prominent for fewer bunches - contary to the observations.

emittance growth (25 pm), but ok at full current

Ionen effects: Couple Bunch Motion



March 7, 2013:
240 Bunche, 100 mA
Multi bunch spectrum:
Coupled bunch motion
6.17 MHz
9.26 MHz = 71 f_0
11.48 mHz

15.6 MHz = 240 f_0 /2 , frequency

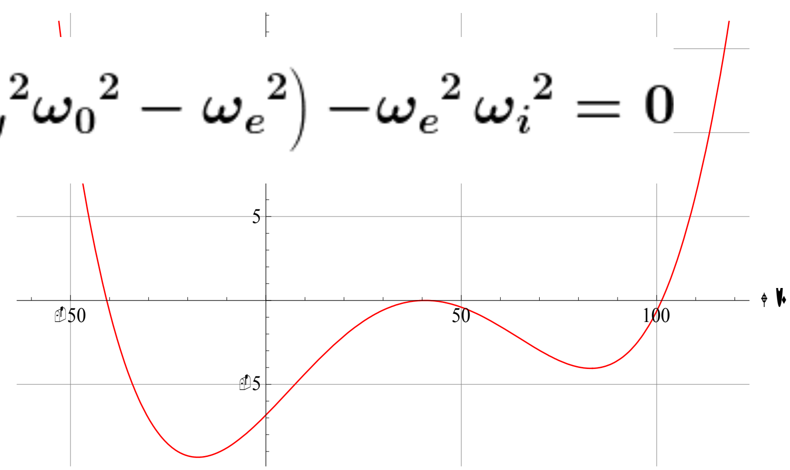
Qualitative Understanding:

Two stream instability, coupled ion and beam motion

k = mode number

$$Ions \sim \exp(i\,\Omega\,t)$$
$$Beam \sim \exp(i\,(k\,\theta - \Omega\,t))$$

$$\left(\Omega^2 - {\omega_i}^2\right)\left((\Omega - k\,\omega_0)^2 - {\nu_y}^2{\omega_0}^2 - {\omega_e}^2\right) - {\omega_e}^2\,{\omega_i}^2 = 0$$

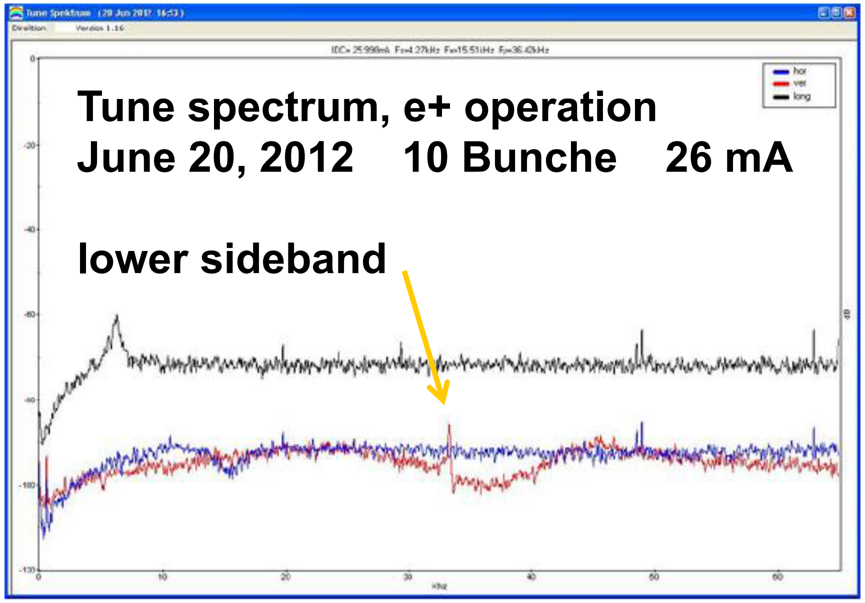


Complex solution of the dispersion relation
Mode k is instable with growth rate:

$$\frac{1}{\tau} = Im[\Omega]$$

S. Matsumoto et al., **Experimental Study of the Ion Trapping Phenomenon in Tristan-AR, PAC 1997 and**
D.G. Koshkarev, P.R. Zenkevich, Part. Acc., 1972, Vol3. pp.1-9

Single Bunch Instabilities (TMCI)



Single bunch
design current 2.5 mA

achieved: 1 bunch with 5 mA
(Feb. 18, 2011)
but with emittance growth
(56 pm rad)

e+ operation

operation with 40 bunches
40 x 2 mA = 80 mA
requires a large vertical chromaticity
(5 … 7 units) to avoid
vertical emittance growths
or beam instabilities

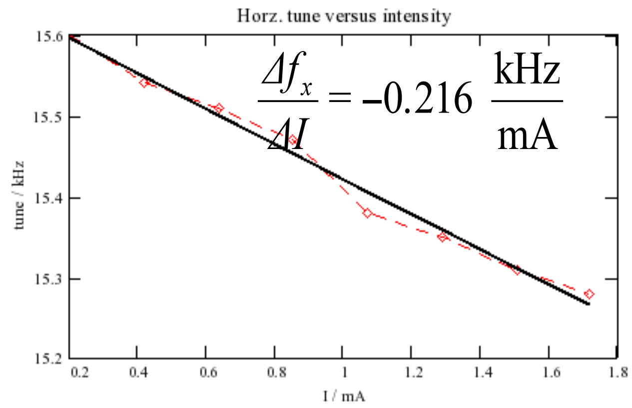
e- operation

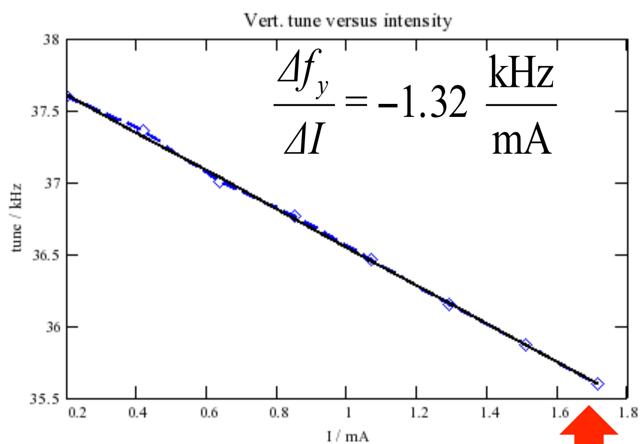
operation with 40 bunches
40 x 2.5 mA = 100 mA
requires a moderate vertical
chromaticity (1… 2 units) to avoids
vertical emittance growth

Additional incoherent tune spread
due to trapped ions ???
or single bunch ecloud effects
for e+ ???

Tuneshift e+ and e-

e+ Oct 17, 2012 — **Chromaticity horz.+1 / vert. +2** — **e- Jan 17, 2013**

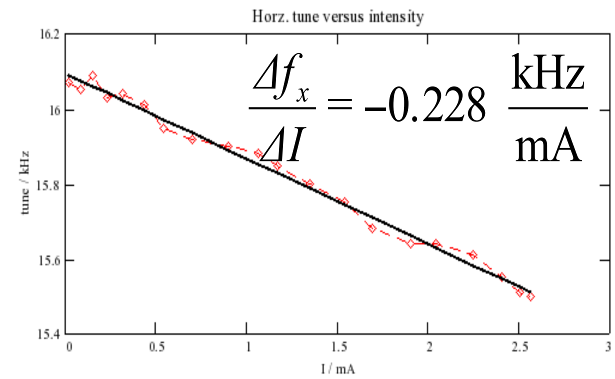


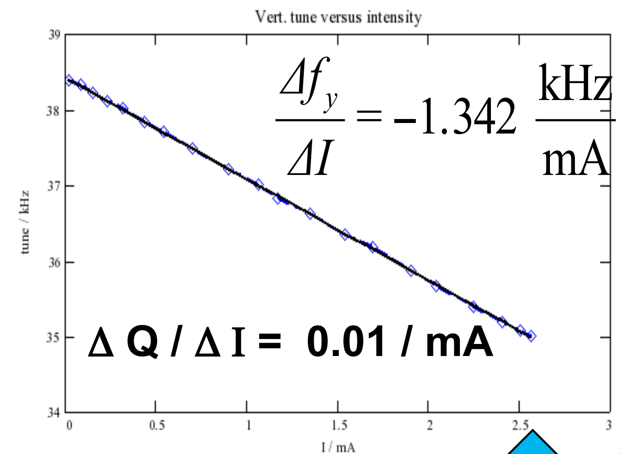


Tuneshift are similar but

e+ instable at 1.7 mA with a chromaticity of +2

f_0 = 130 kHz





1.7 mA

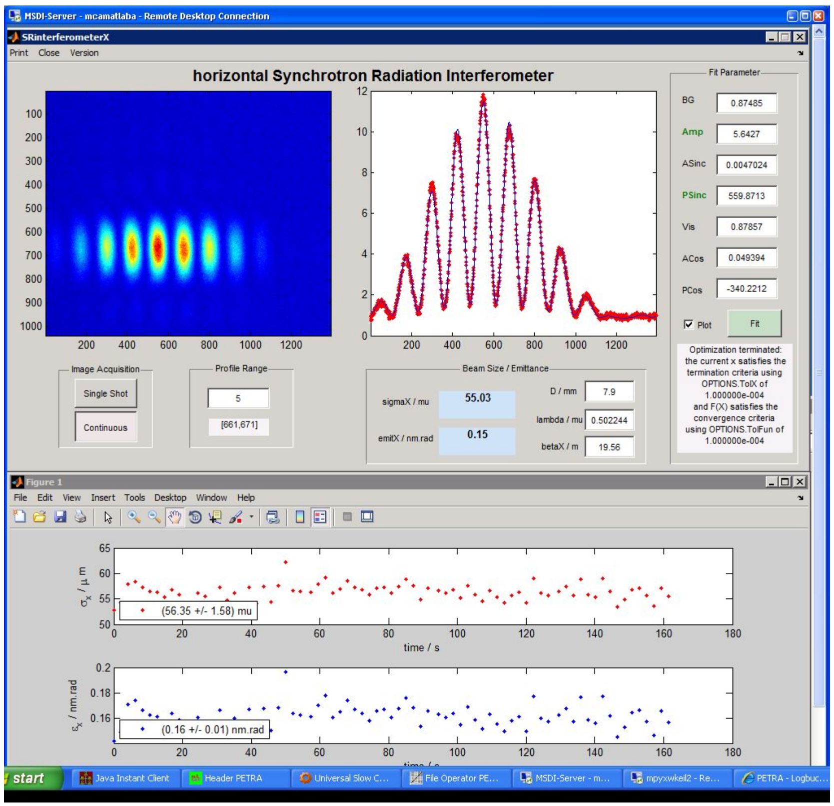
Instability

2.5 mA

(not instable)

Test Runs at Low Energy (3 GeV) and Low Emittance

July 16, 2013
PETRA III, 3 GeV,
horz. Emittance 160 pm rad
I = 5 mA in 480 bunches,
N = 5 x 10^8 / Bunch



July 2013
Several test runs at low energy

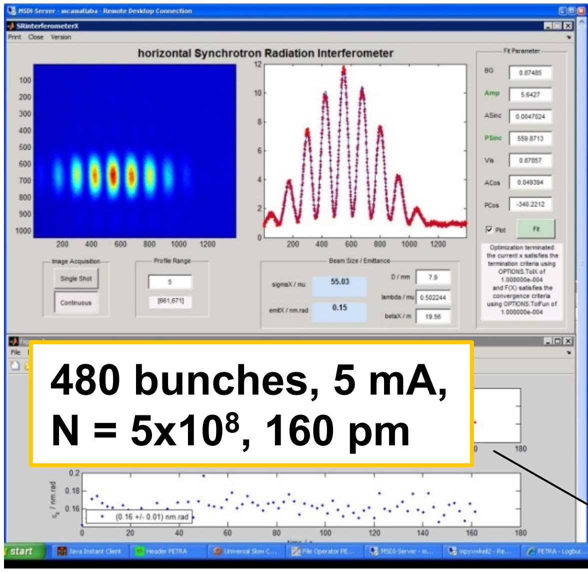
FODO arcs: 72 deg lattice
wiggler section matched,
predicted emittance:
3 GeV: 160 pm rad

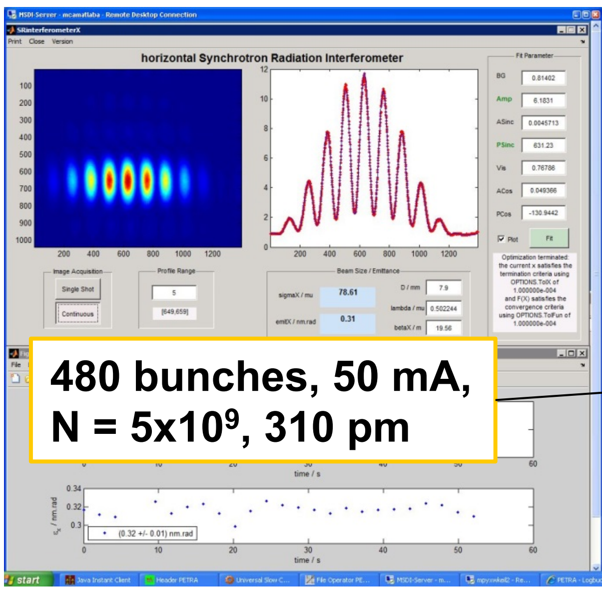
Intrabeam scattering:

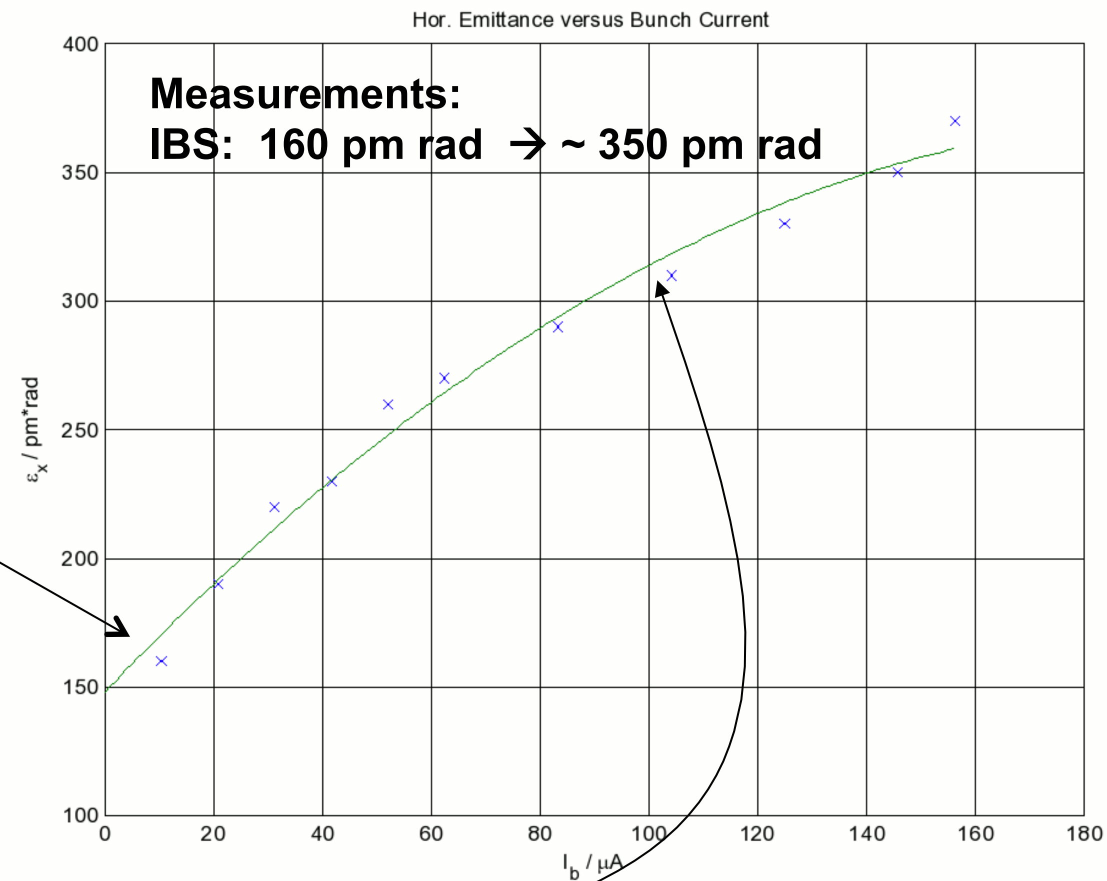
$$A \sim \frac{N_0}{\gamma^4 \, \epsilon_x \, \epsilon_y \, \sigma_s \, \sigma_p}$$

$$\frac{1}{\tau_x} = \left\langle A \left[f(1/a, b/a, q/a) + \frac{{D_x}^2 \, {\sigma_h}^2}{{\sigma_{x\beta}}^2 \, f(a,b,q)} \right] \right\rangle$$

Intra Beam Scattering / Emittance Growth







work in progress:
modelling of the IBS

Conclusion

Collective effects determine the possible operation (filling pattern) of PETRA III :

- Operation with e+
  - User Runs with 40, 60, 240 and 320 bunches (Electron Cloud Effects)
- Operation with e-
  - User Runs with 40, 60, 480 and 960 bunches (Ion Effects)
- Testruns with Low Energy (3 GeV) and Low Emittance
  - εx = 160 pm rad only for low current 10 mA/960 (Intra Beam Scattering)

Challenges for the PETRA III Extension Project:

- New Vacuum System (more prominent ion effects for ~ 1 year)
  - Limitations for the operation mode with 480 or 960 bunches ?
- New Small Gap Chambers (Wakefields and TMCI)
  - Vert. tuneshift : 1.3 kHz → 1.6 – 2.0 kHz ???
  - Limitations for the operation mode with 40 bunches

Thank you for your attention !

Acknowledgment:

Thanks go to my colleagues from DESY:

J. Keil, A. Kling, G. Kube, G.K. Sahoo