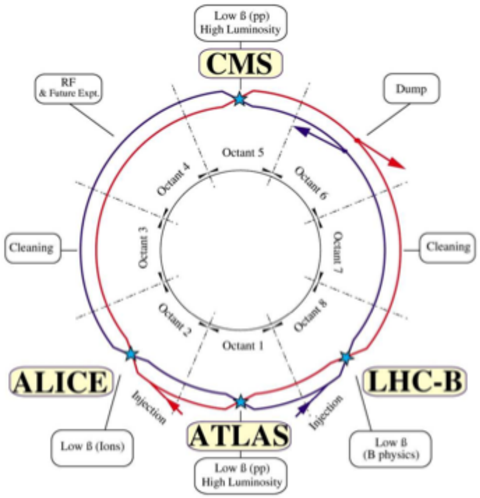
LHC Beam-beam observations 2011

Outline:

- First collisions Fill 1603 with Schottkys
- Leveling in IP8
- Beam-beam head-on MD

Fill 1603



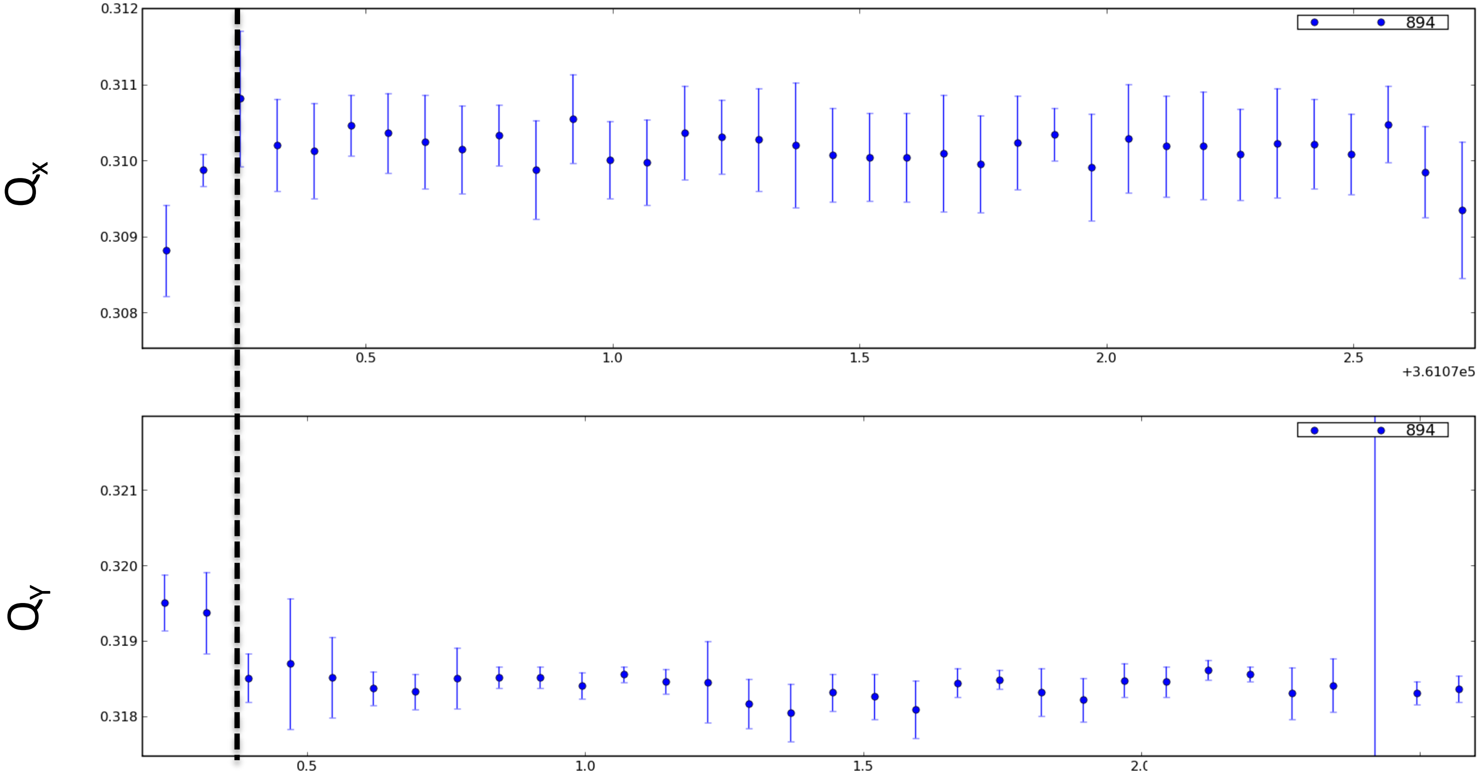
	IP1	IP2	IP5	IP8
1	**1**	**892**	**1**	**-**
895	**-**	**1786**	**-**	**1**
1786	**1786**	**-**	**1786**	**892**

IP1	Alice-IP2	IP5	LHCb-IP8
H crossing angle	H sep 4σ V crossing angle	V crossing angle	V sep 3-4σ H crossing angle

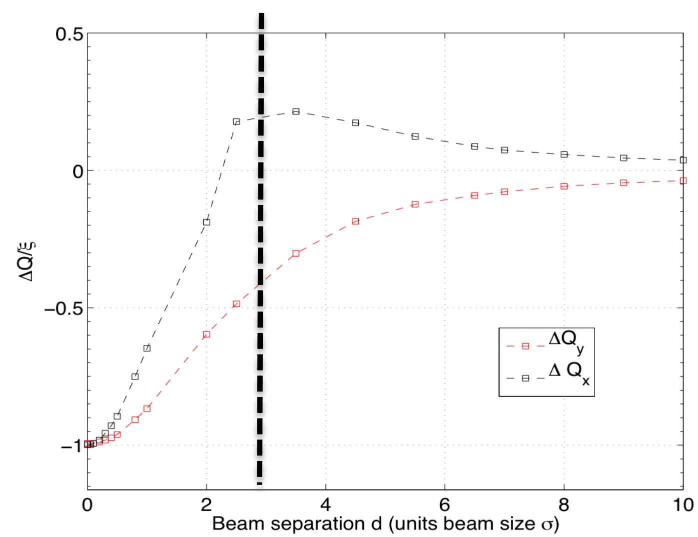
- ADT always on so BBQ difficult measurements
- BBQ cannot select bunches to measure (pacman- super-pacman)
- Beam-beam optimization based on pacman super-pacman knowledge
- **That's why Schottky important for tune optimization during collisions**

Fill 1603

Schottky incoherent tune shift



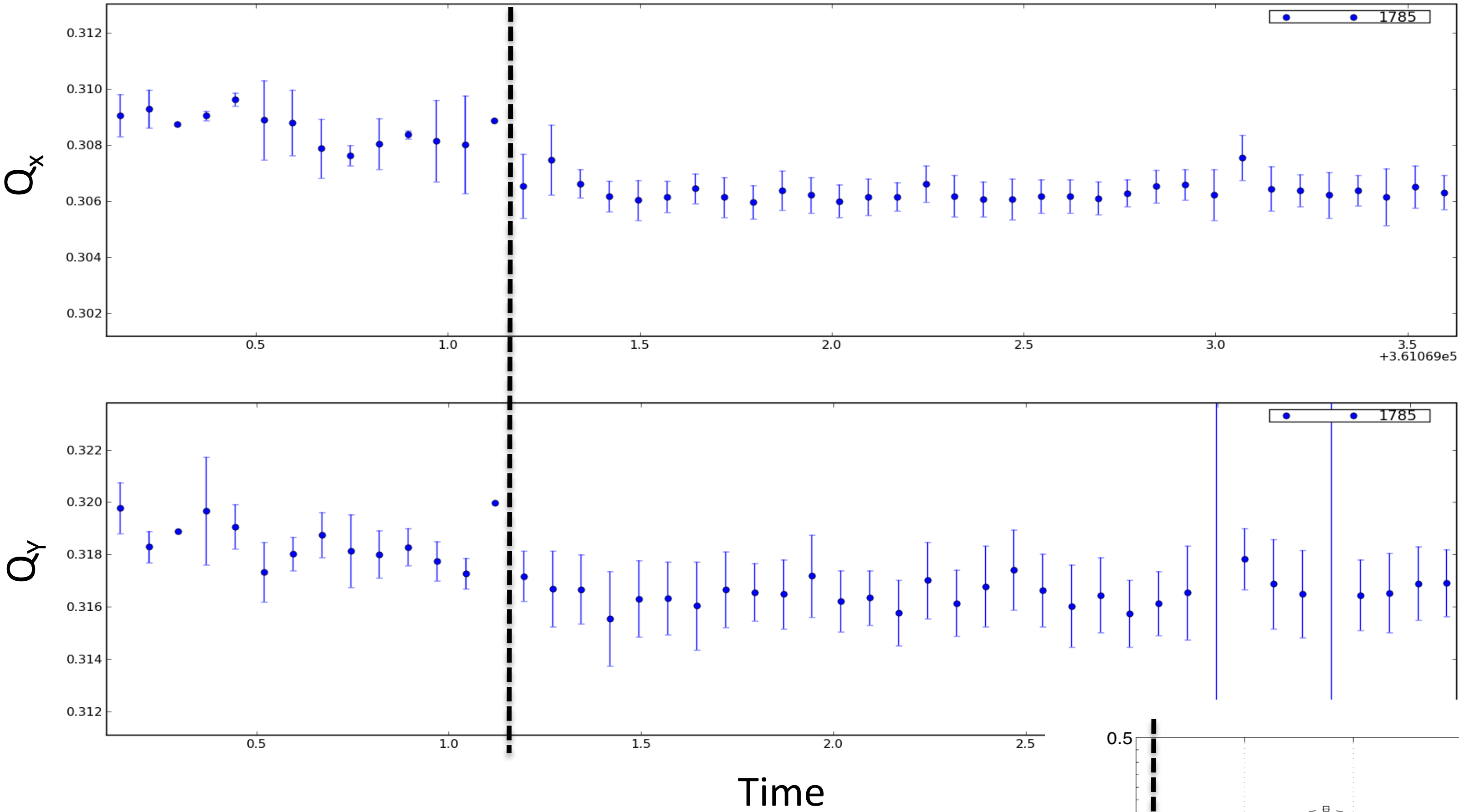
Time

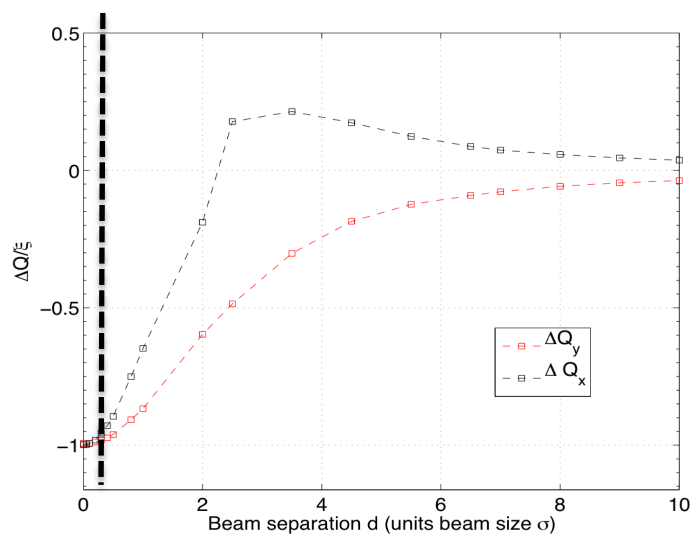


Bunch 895 collides in Alice IP2:
Horizontal separation 4 σ
Vertical crossing angle

- Horizontal tune shift at 0.3108
- Vertical tune shift at 0.318

Fill 1603





Bunch 1785 collides IP1:
No separation
Horizontal crossing angle

- Horizontal tune shift at 0.306
- Vertical tune shift at 0.316

Leveling in IP8 LHCb

LHCb wants to operate at reduced luminosity and a separation of 0.5-2σ can give this reduction factor 3 in lumi.

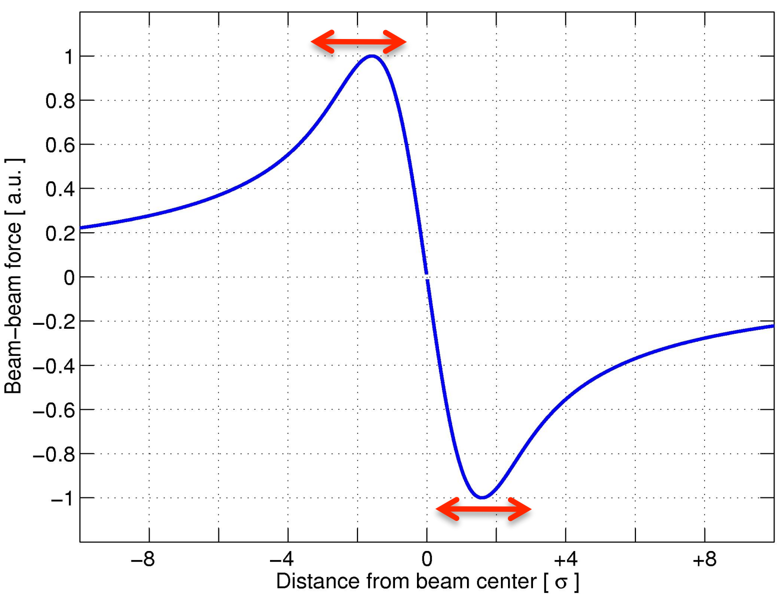
Can we operate the collider with a separation at IP8:

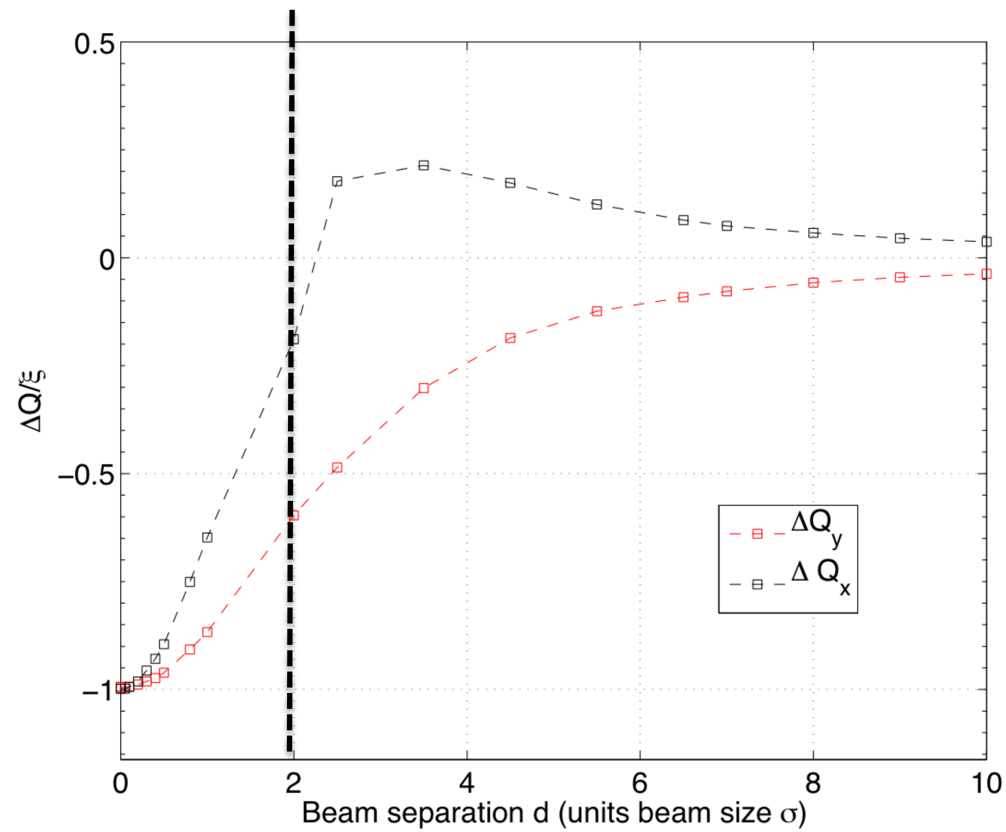
Possible beam-beam effects:

- Beam losses and bad lifetime
- Emittance growths
- Coherent motion or orbit effects
- Effects on other IPs

Beam:

- 75 ns spacing 24 bunches/train
- 40 LR per bunch at 12 σ
- Nominal Intensities and emittances 2.5 μm

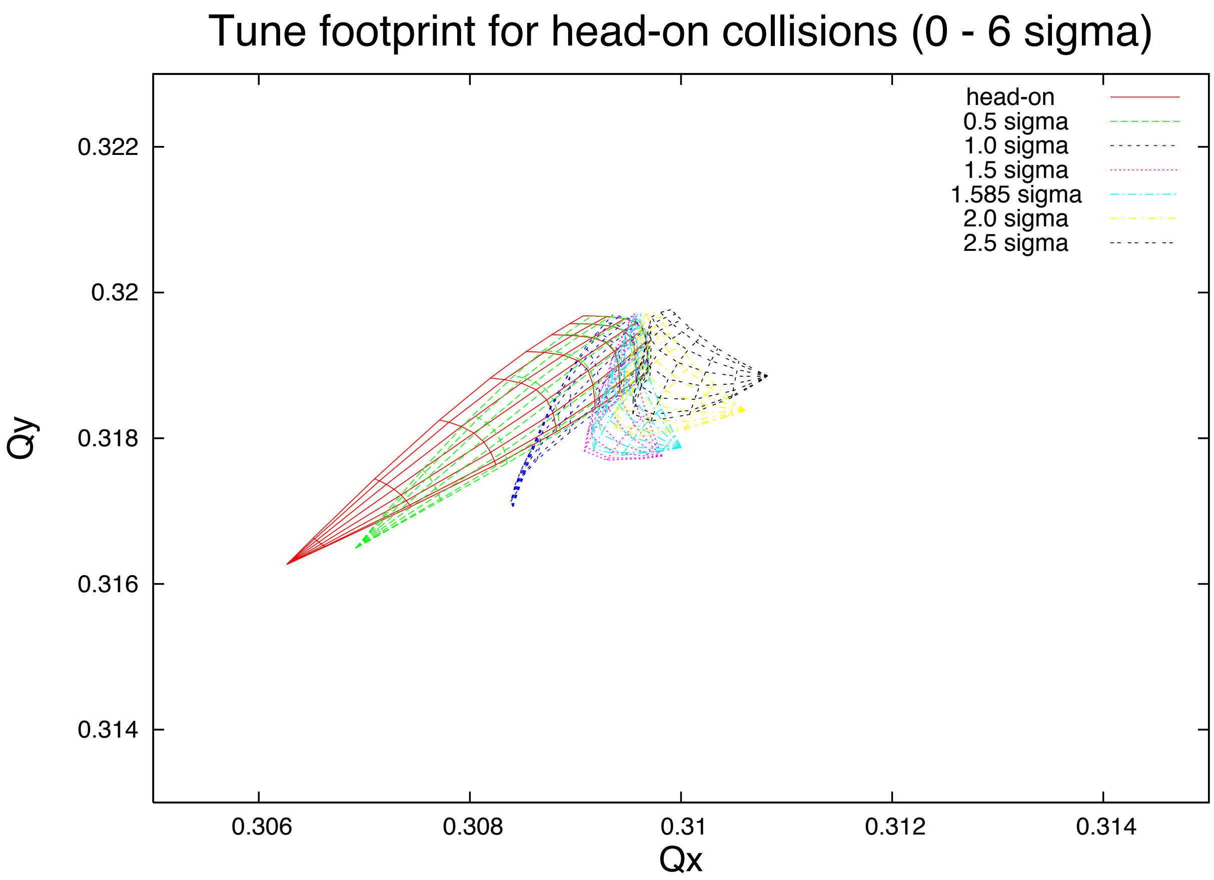




Past Experiences:

- SppS no problem with collisions with separation
- Tevatron also
- Other machines lepton show effects due to mismatch H/V

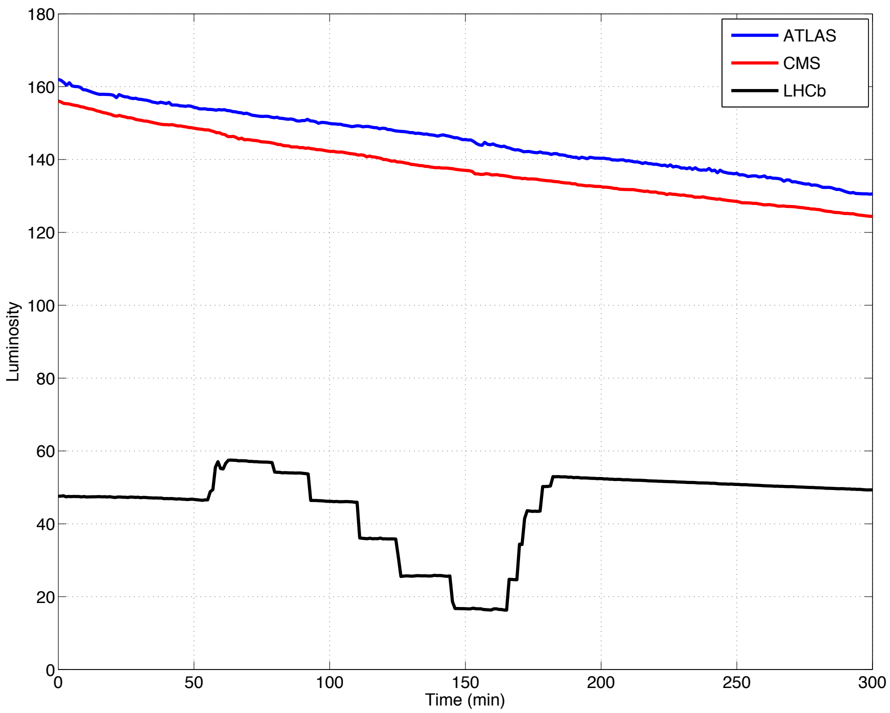
Leveling in IP8 LHCb



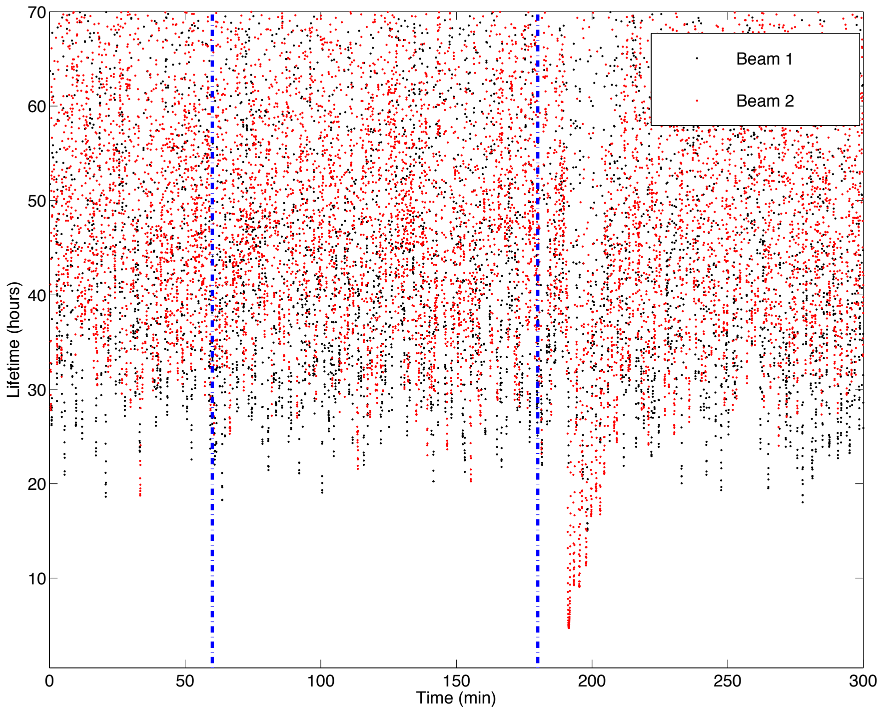
The tune diagram space occupied by the detuning with amplitude of particles is reduced that's why it should not be a worry

Leveling in IP8 LHCb

Luminosity at IP1-5-8



Beam lifetimes



- No effects on Luminosity of other experiments (no evidence of orbit effects)
- Life times always higher than 20 hours

Leveling in IP8 LHCb

ISSUES during MD:

- Leveling steps too fast for Schottky to follow tune change due to separation applied
- BBQ system mixing among different bunches families, EoF MD
- ADT on so BBQ measurements not optimum

FUTURE:

- Repeat the MD with non negligible long-range contribution 120 LR and reduced separation
- Add leveling in other IPs to check the leveling feasibility, for these cases we will see effects

IMPORTANT:

- **Since it is ok in this configuration doesn't mean it will be always ok.**
- **Long range will change dynamics**

Motivation:

Experimentally probe the head-on beam-beam effects by exploring the achievable beam parameter space to highlight future goals for the LHC and possibly HL-LHC (High intensity and low transverse emittance)

Experiment Set-up:

- Injection energy (450 GeV) & optics ($\beta^* = 11$ m)
- Collision tunes $Q_H = 0.31$ and $Q_V = 0.32$
- Nominal crossing angles and parallel separation
- IP 2 and IP8 spectrometers magnets off
- Transverse Damper off during BB measurements

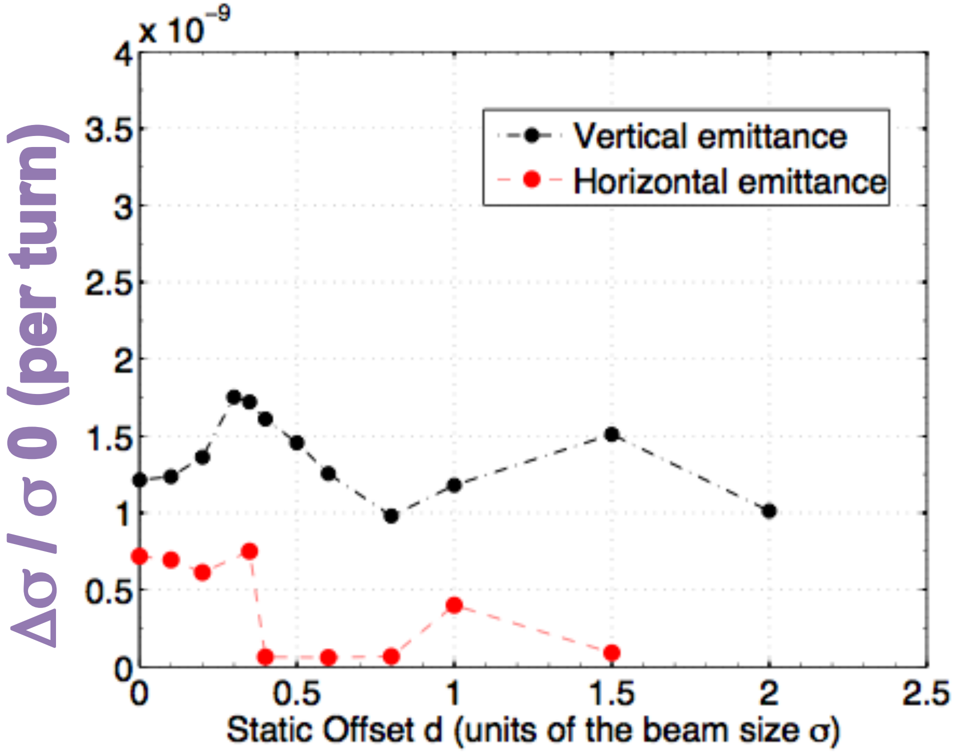
From LHC Beam Commissiong Working Group 26th Oct 2010

Head-on effects (protons only)

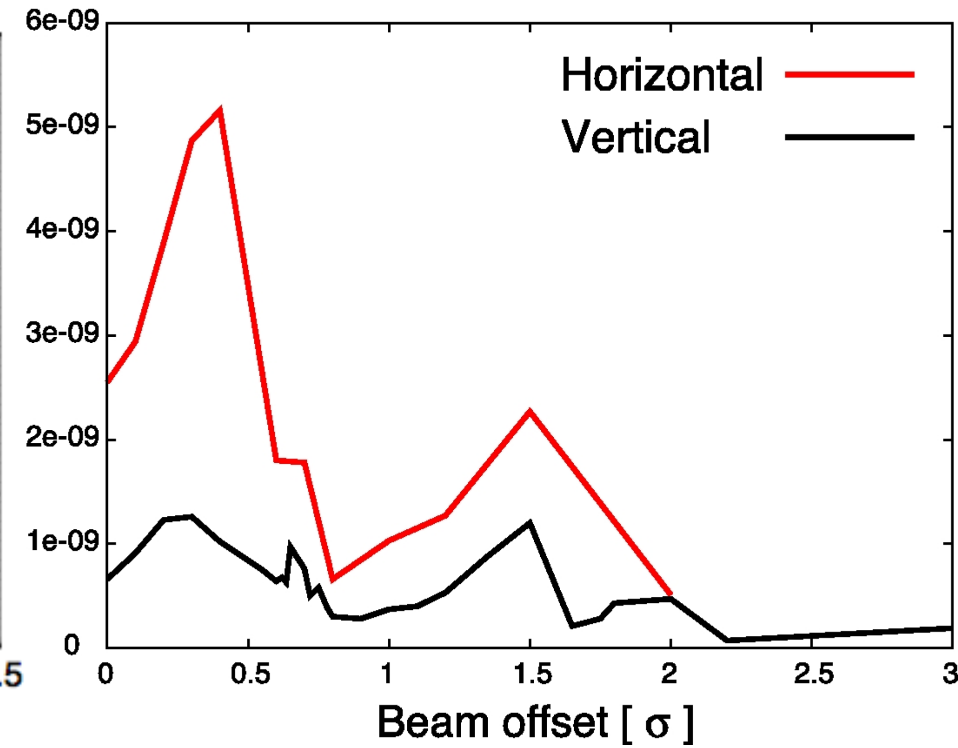
- **But: we can lose particles only at large amplitudes !**
- **What happens for very strong (exact) head-on effects ?**
  - **For single particle models: nothing (see e.g.: L. Evans ..)**
  - **With self-consistent models: small and (very) slow emittance growth (see e.g.: W.Herr, T.Pieloni, J.Qiang)**
- **When can we expect more dramatic effects?**
  - **Unequal beams (emittance, β-beating, offsets, ...)**
  - **External perturbations (noise, modulation, relative movement of the two beams, ...)**
- **Makes it difficult to analyse ...**
  - **Still looking, first look at the tunes ...**

Emittance growth on offset amplitudes

Gaussian Approximation



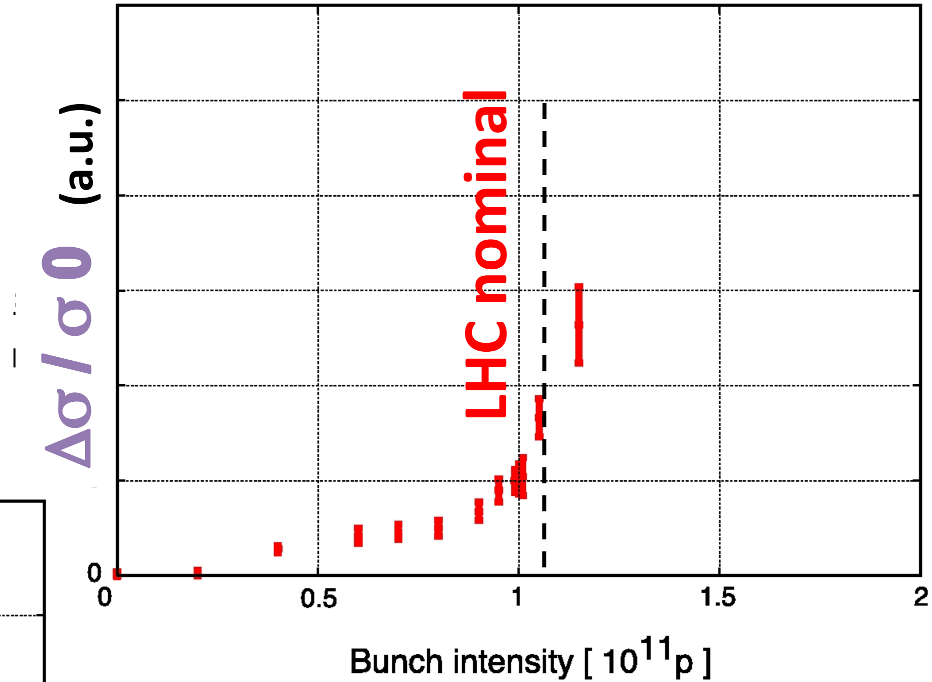
HFMM arbitrary beam profiles

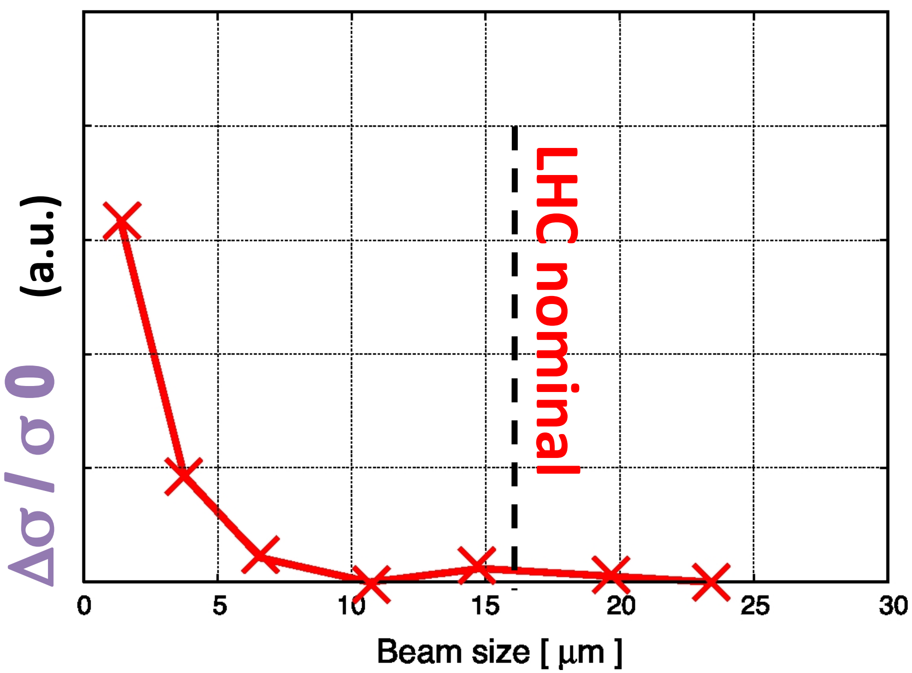


Dependency on beam parameters

Beam growth vs transverse beam size

Smaller beams have stronger effect

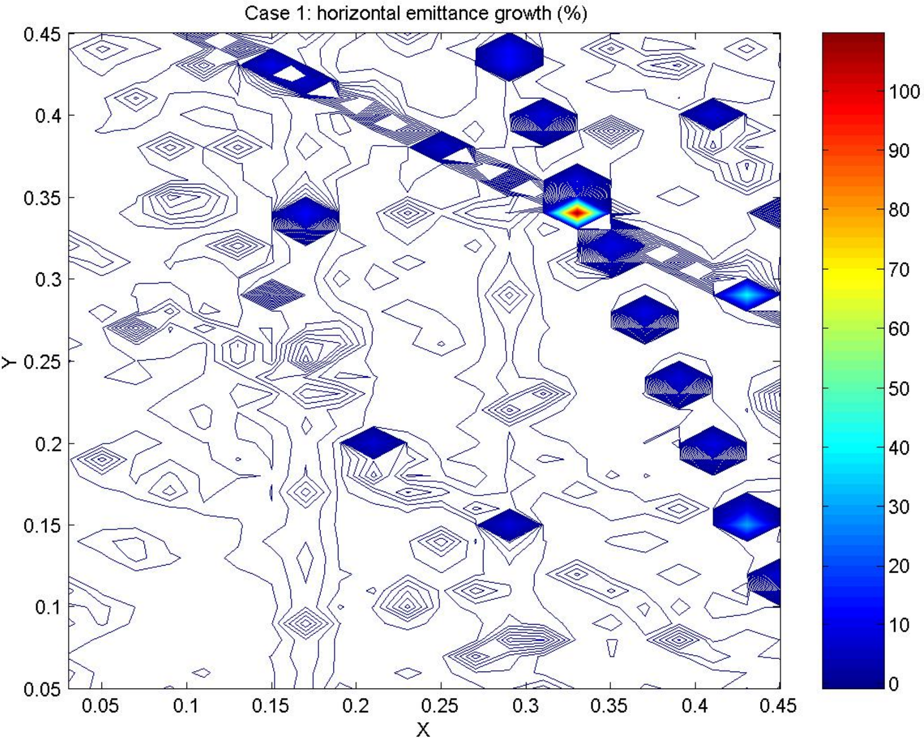




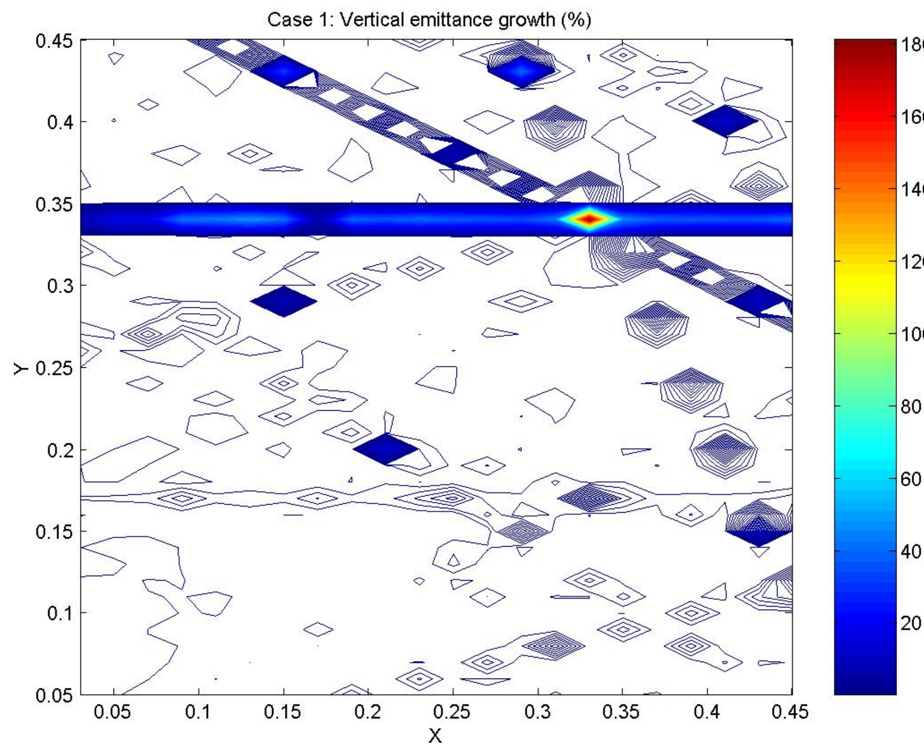
Beam growth vs beam intensity

Intense beams have stronger effect

Dependency on tunes: J. Qiang



$N_p = 1.15\ 10^{11}$
$\varepsilon\ \ = 1.5\ \mu m$



Cases with closer MD parameters still running

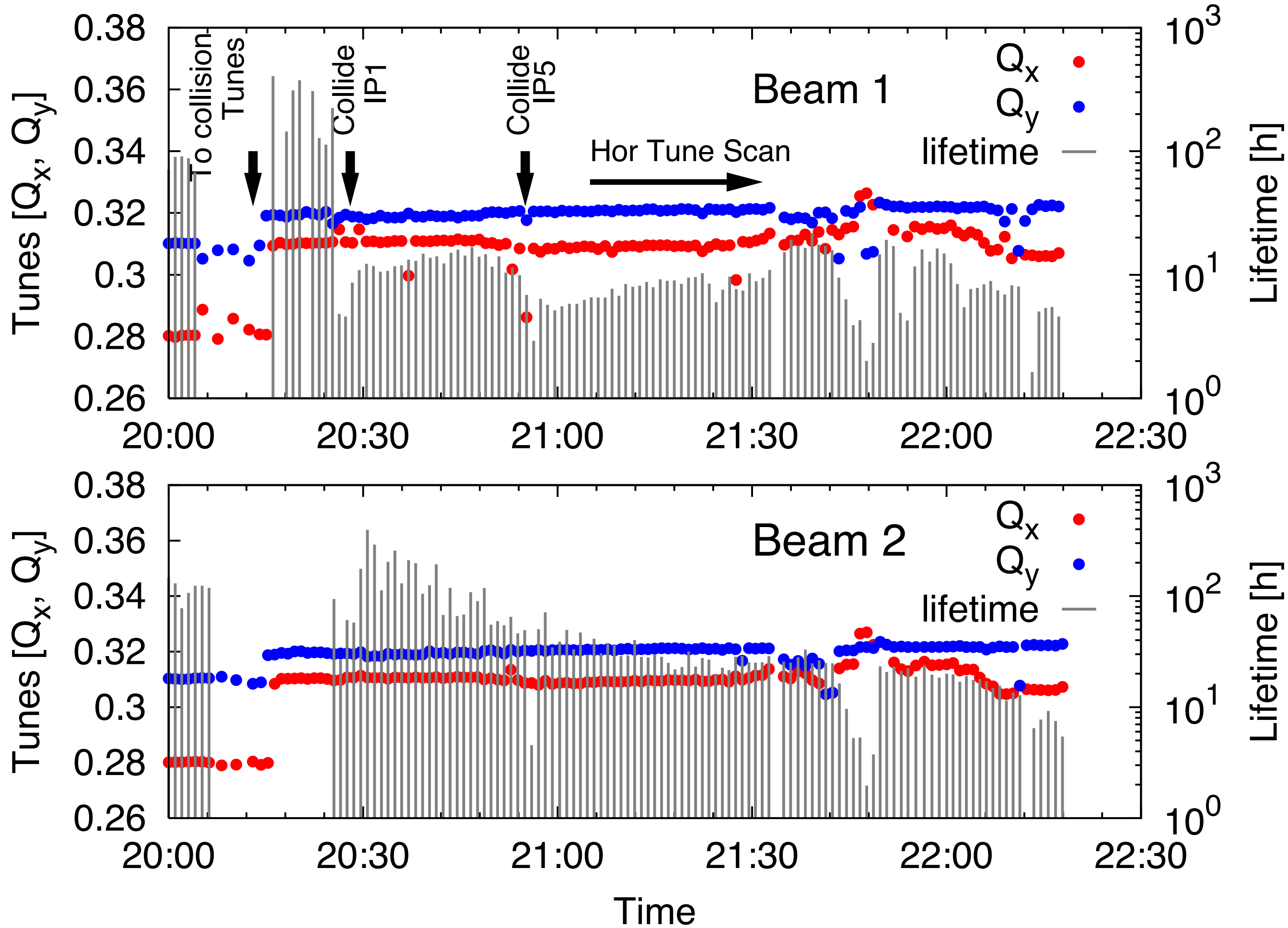
Total of Five Fills

N_p = 1.6-1.95 10^{11}, ε = 1.2-1.6 μm

Fill	# of bunches /beam	# of collisions /bunch	Comment
1	1	2	IP1 & IP5 collisions + lumi-scans Hor tune scan
2	2	1,2,3	IP1, IP5 & IP2 collisions + lumi scans Ver tune scan
3	3	4	Unsafe intensity, beams dumped
4	1	2	IP1 & IP5 collisions, lumi-scans qh/qv = 0.31/0.32
5	1	2	IP1 & IP5 collisions, preset conditions qh/qv = 0.31/0.31

Fill 1: bch_{100} collides in IP1-5

N_p = 1.6 10^{11}
ε = 1.3 μm



Before tune scan:

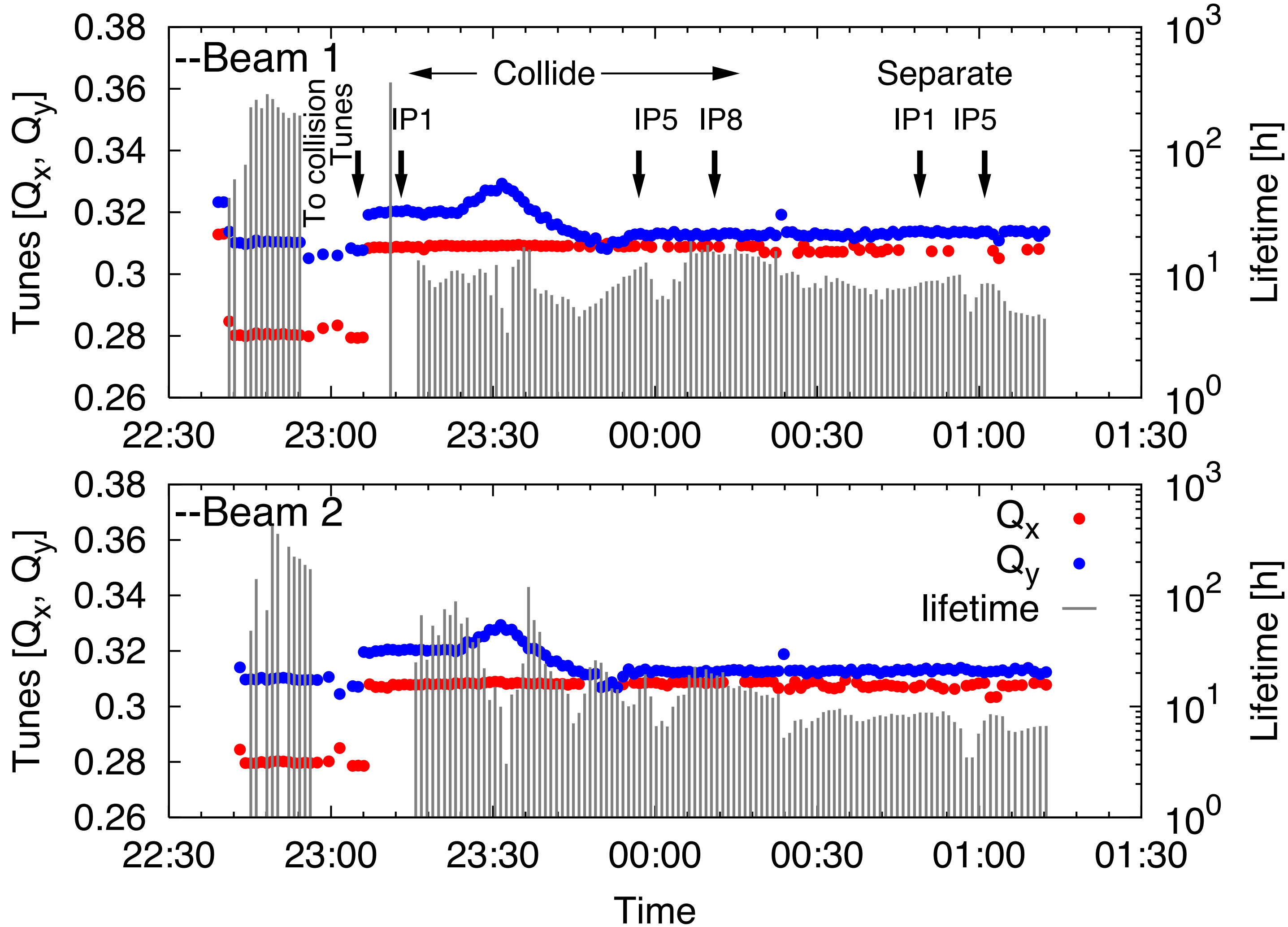
- Lifetime > 20h
- Vertical emittance blow up
- Tune shifts as expected

During tune scan:

- Lifetime drops close to 3rd and probably 10th order
- Emittance blow up

Case 2: bch_{100} collides IP1-5-2, bch_{1885} IP2

N_p = 1.7-1.8 10^{11}
ε = 1.3 – 1.6 μm



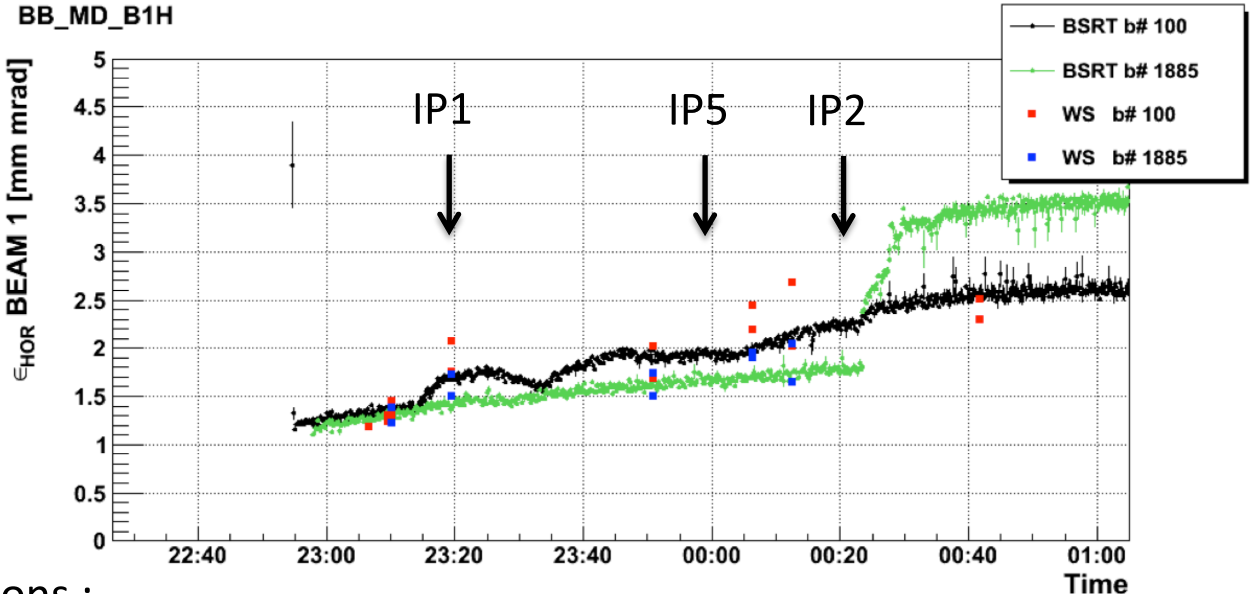
Observations during ver tune scan:

- Lifetime drop approaching 3rd order resonance and 10th order
- Emittance blow up beam 2

Observations after Ver tune scan:

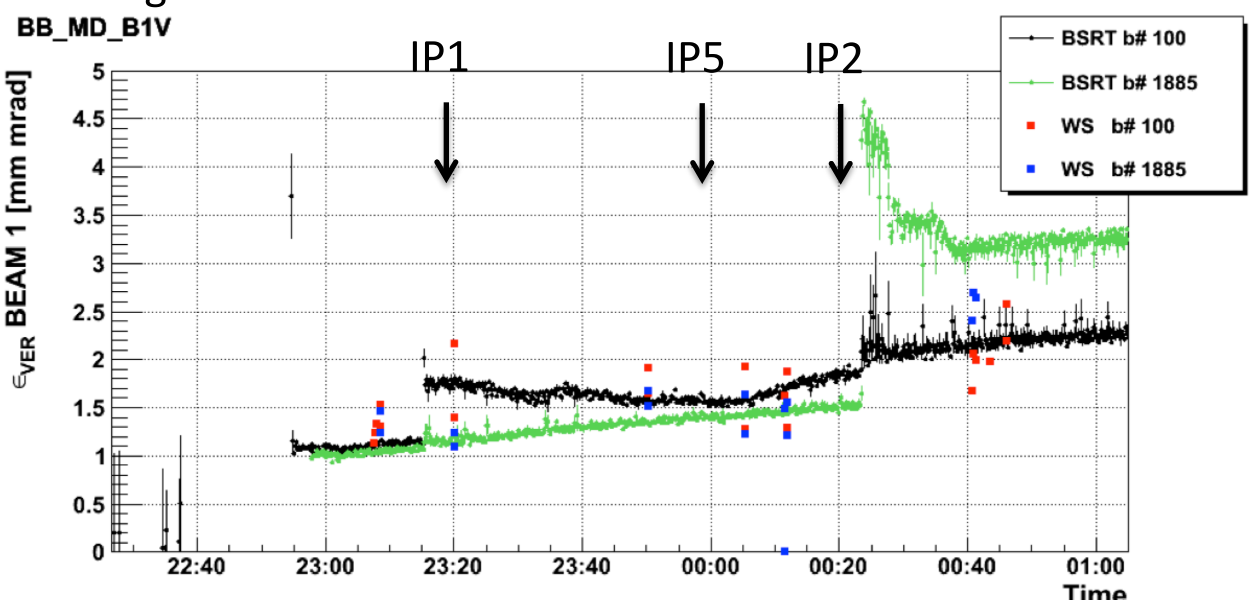
- Lifetime always above 20h
- Vertical emittance blow up
- Tune shifts as expected

Case 2: emittances

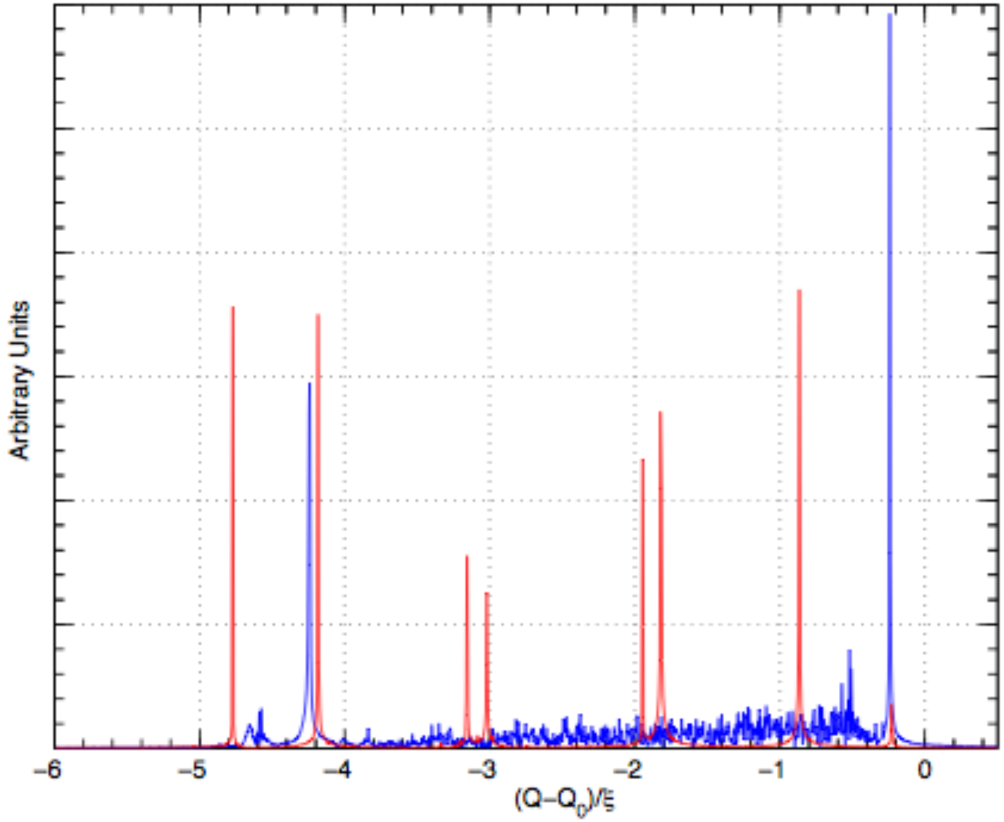


Observations :

- Emittance blow-up for bunch 1885 colliding in IP8 during luminosity optimization
- Bunch colliding in IP1&IP5&IP8 ok



Case 3: what we wanted to see



Expectations :

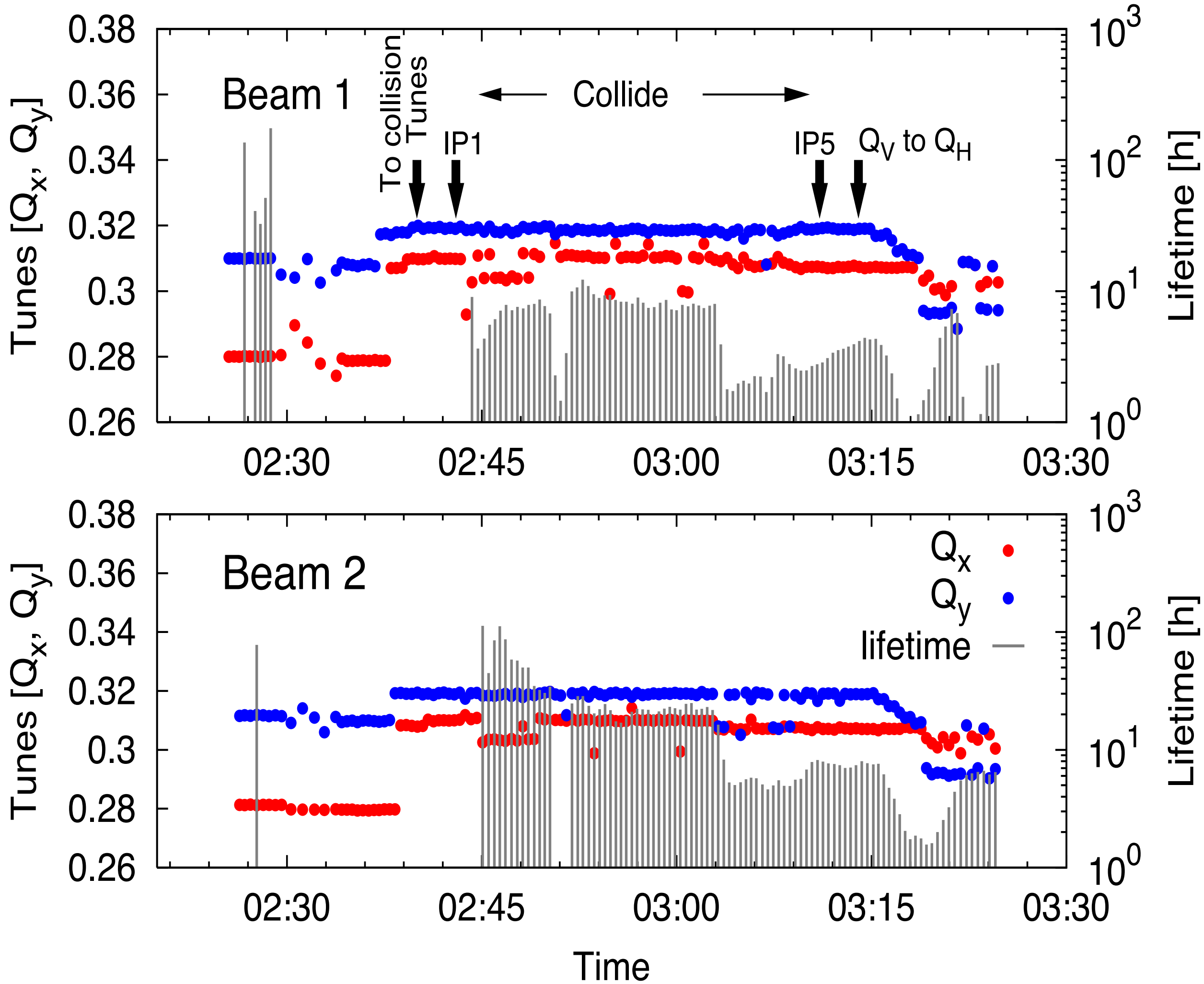
- For the nominal LHC phase advance between IPS and geometry we expect 2 modes outside the Landau damping region at approximately 4 * Y * ξ_{bb}
- With a bit of luck single bunch diagnostic could have revealed these modes if present

ISSUES :

- Emittance blow up spoiled the modes location merging in the Landau damping region
- No single bunch tune measurement

Fill 4: bch_{100} collides IP1-5

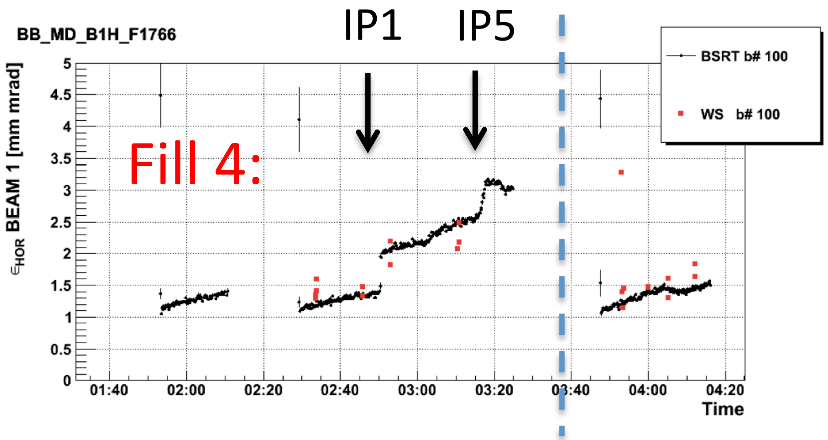
N_p = 1.86-1.95 10^{11}
ε = 1.3 μm
ξ> 0.017 / IP
Qh/Qv = 0.31/0.32

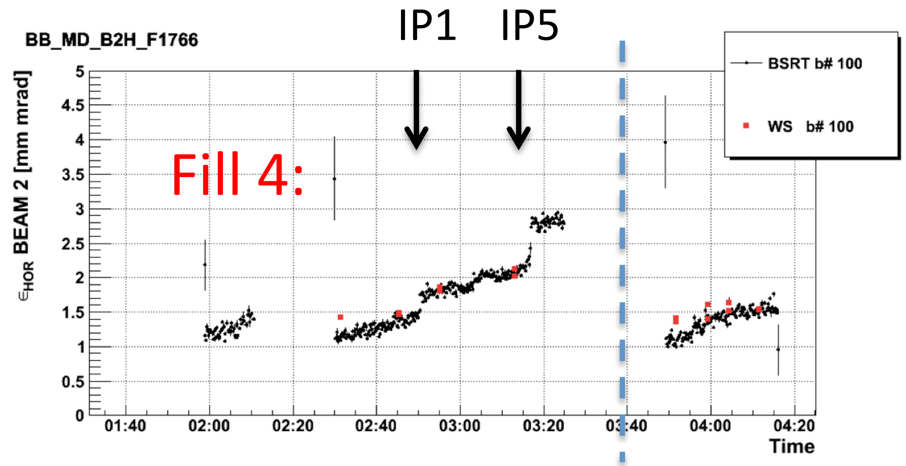


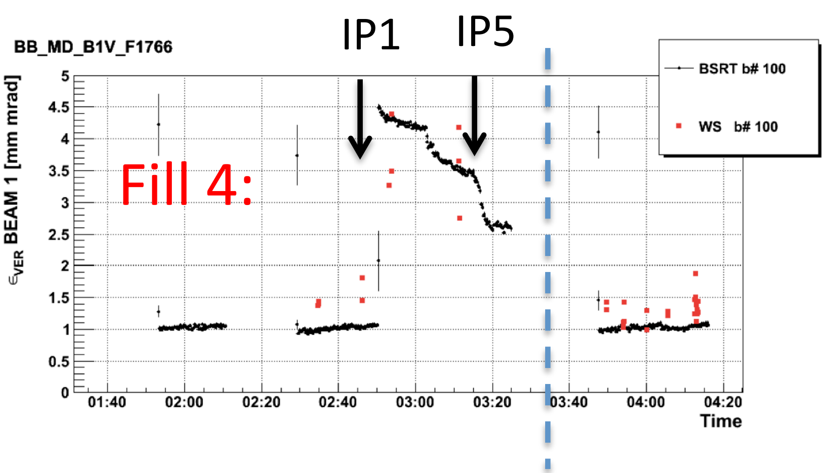
Observations :

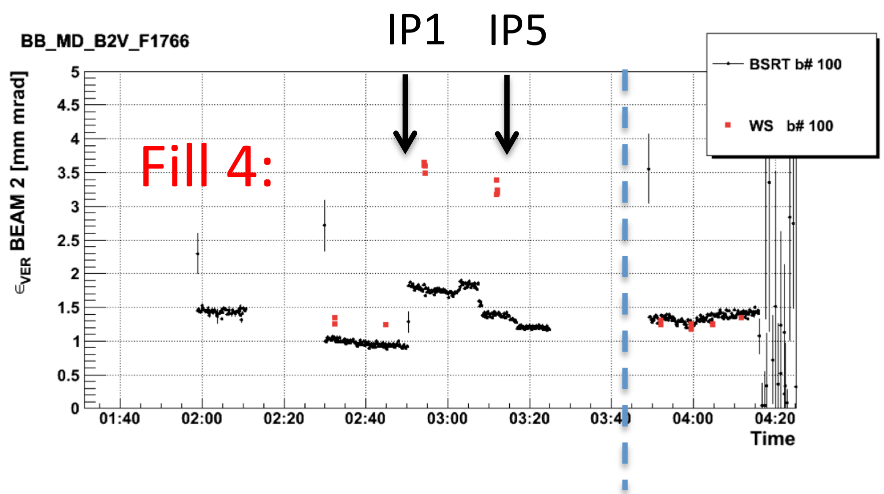
- Collision of IP1 important vertical emittance blow-up during lumi scan
- Vertical tune of beam core on 10th order (tune shifts as expected)
- After some time in collision, instability develops then stabilizes

Fill 4: emittances





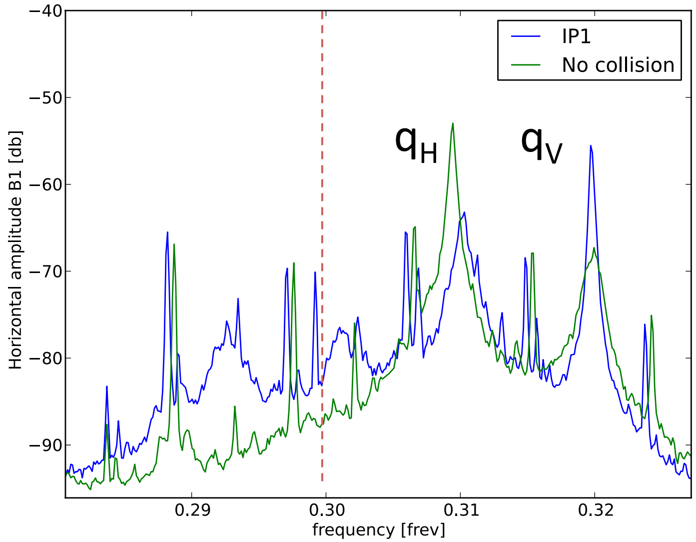




Observations :

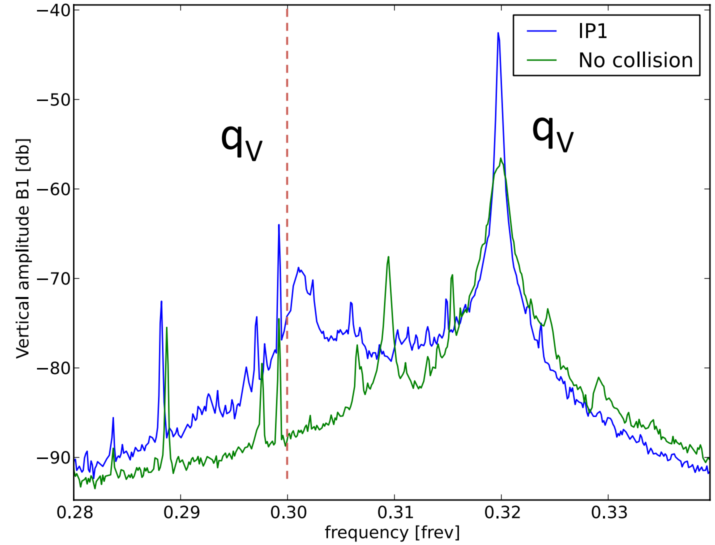
- Vertical plane critical
- Emittance blow-up occurs during lumi scan optimization

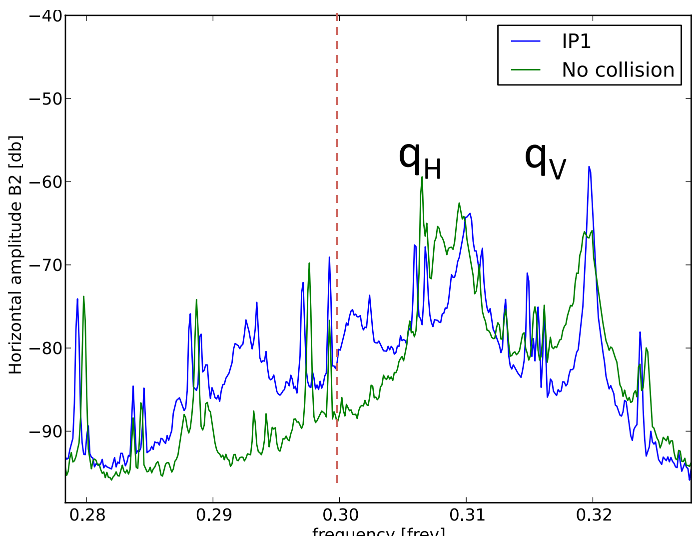
Fill 4: tune spectra before emittance blow-up

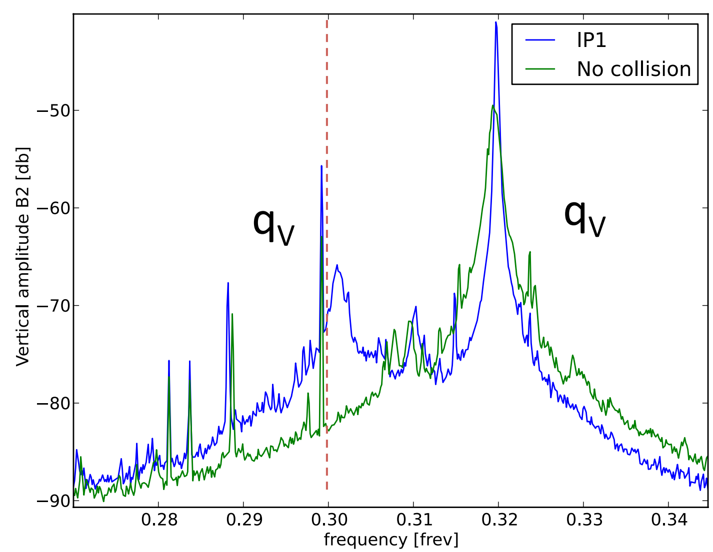


$$\Delta Q_{HO} = Y * \xi_{bb}$$
$$N\, r_o\, \beta^*/4\, \pi\, \sigma^2$$

$$\xi_{bb} = 0.015$$



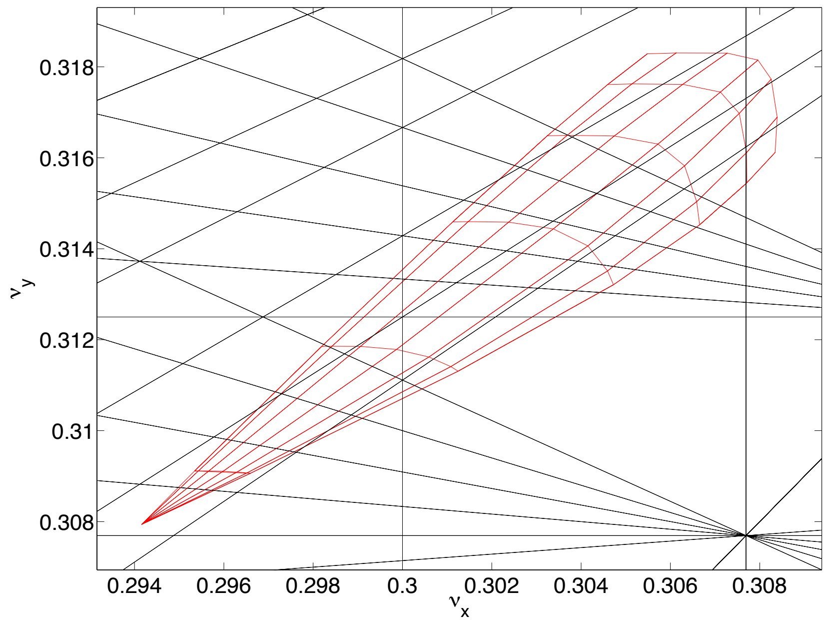


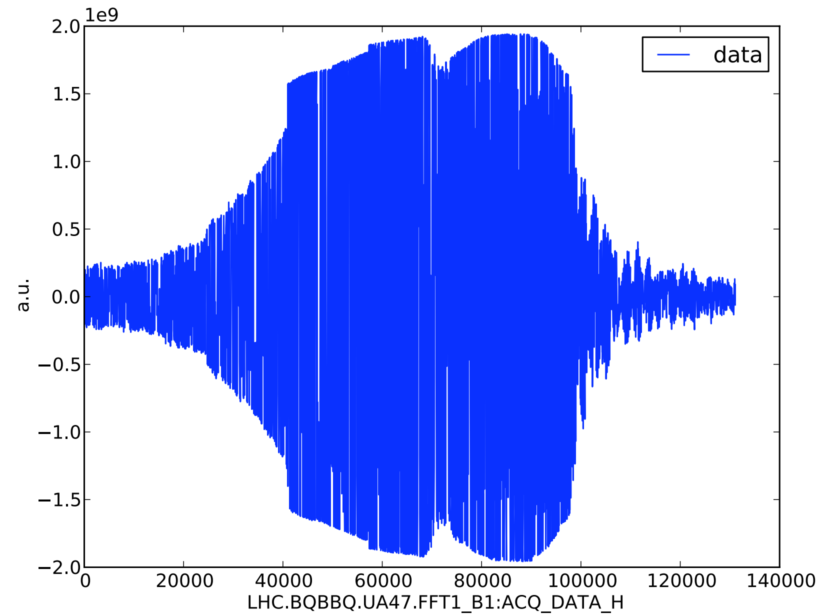


Observations :

- Vertical bb tune shift brings beam core on top of 10th order, vertical plane affected
- Horizontal tune shift well below the 10th order
- BBQ raw data show instability developing in vertical

Fill 4: tune spread and instability





Observations:

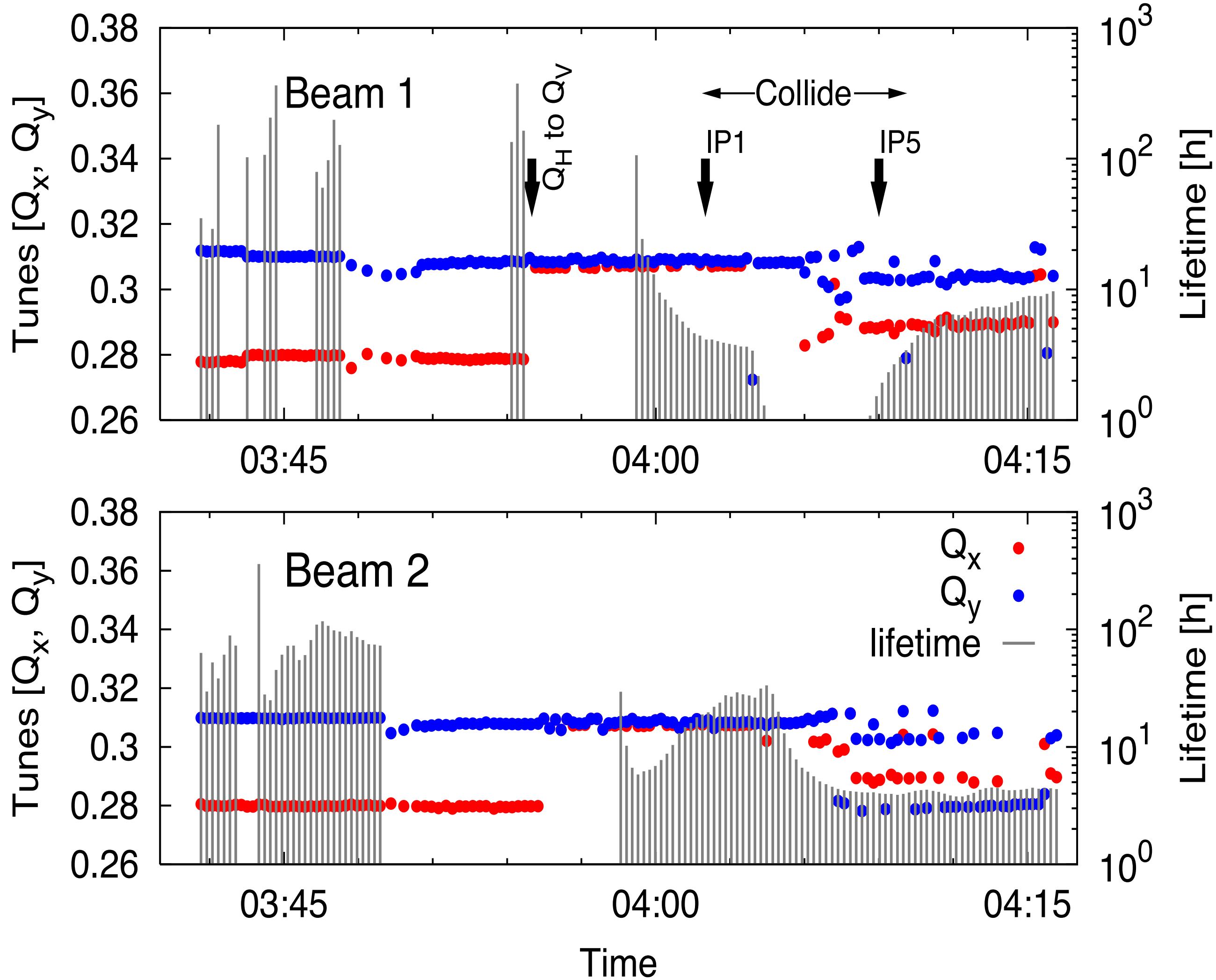
- For this case tune shift measured with BBQ give 0.019
- Expectations around 0.016 leads to Y = 1.2
- Beams differences in intensities, emittances and tunes could explain variation of Y

ON-GOING :

- The instability starts developing during the lumi scan not when the separation is collapsed this indicates a dependency on dynamic offsets of the scan(analysis on-going X. Buffat)
- The instability occurs in vertical plane, check simulation of emittance growth for these beam parameters

Fill 5: bch_{100} collides IP1-5

Np = 1.8 10^{11}
ε = 1.3 mm
ξ> 0.015 / IP
q_H/q_V = 0.31

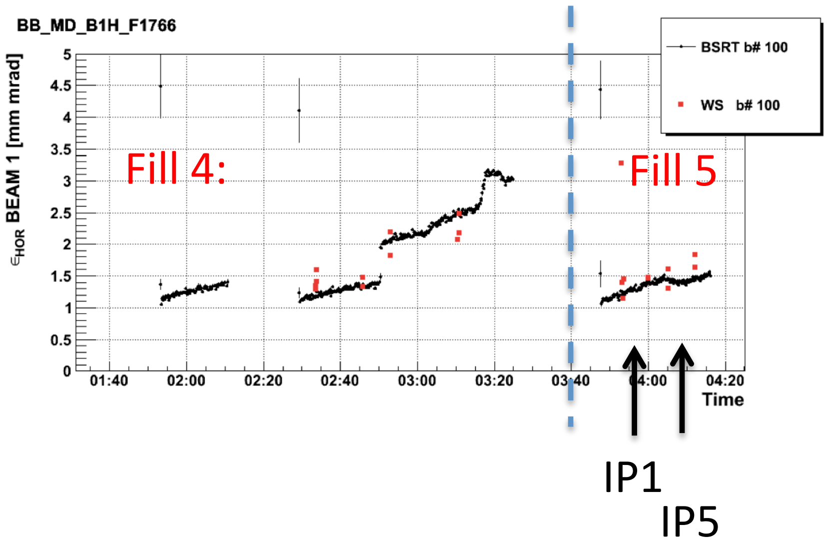


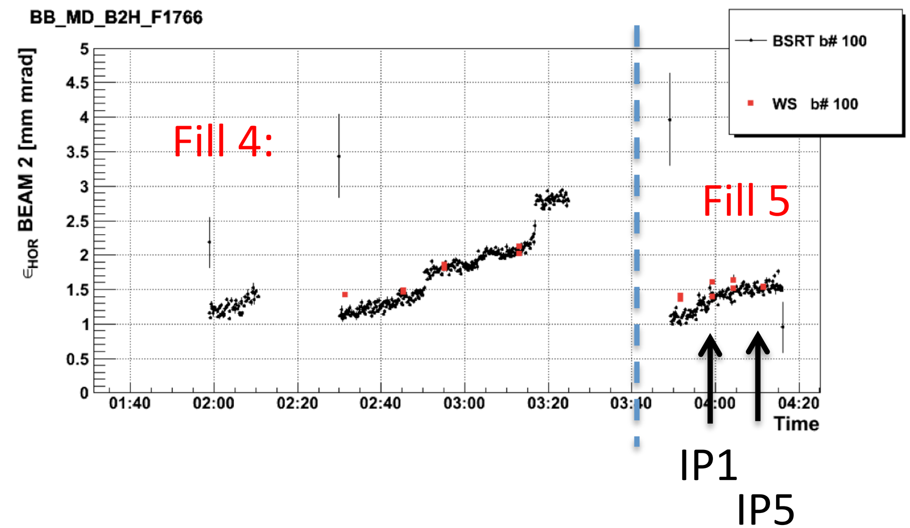
Observations :

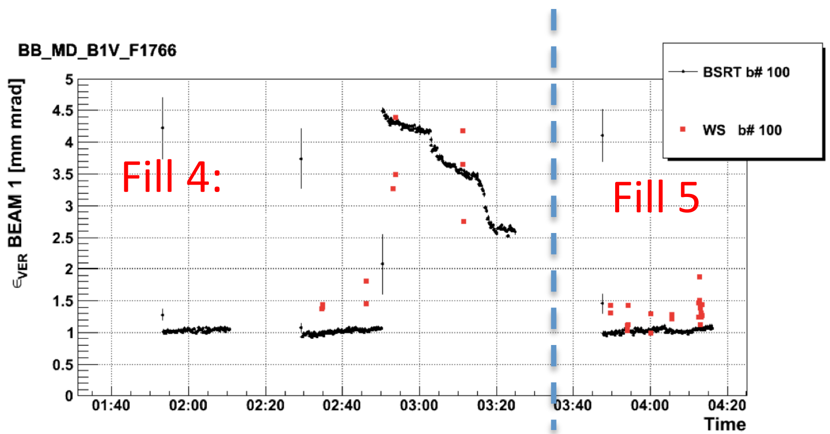
- Adjust vertical tune equal to horizontal $q_V = q_H = 0.31$
- Collision IP1 no effect then collision IP5

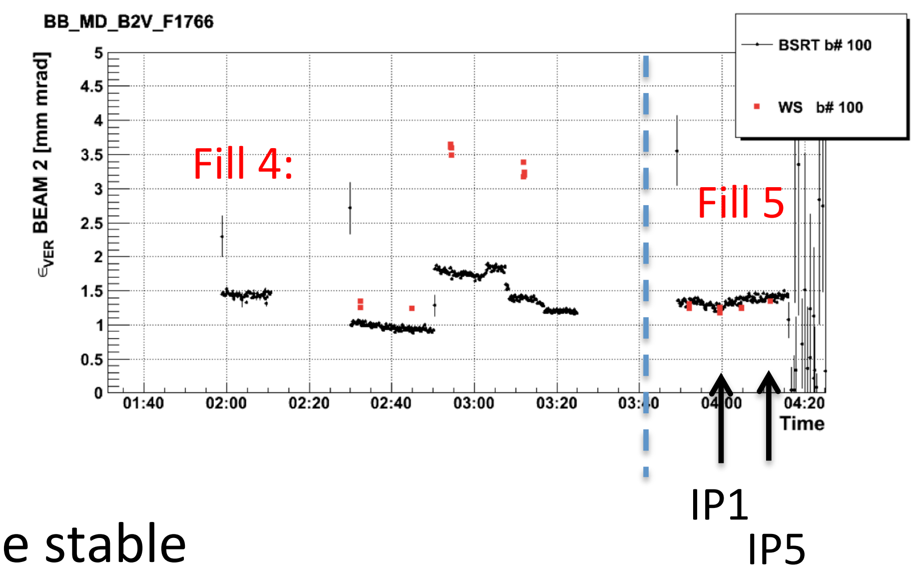
Fill 4 Vs. 5: emittances

No blow up from adding IP1/IP5 collisions



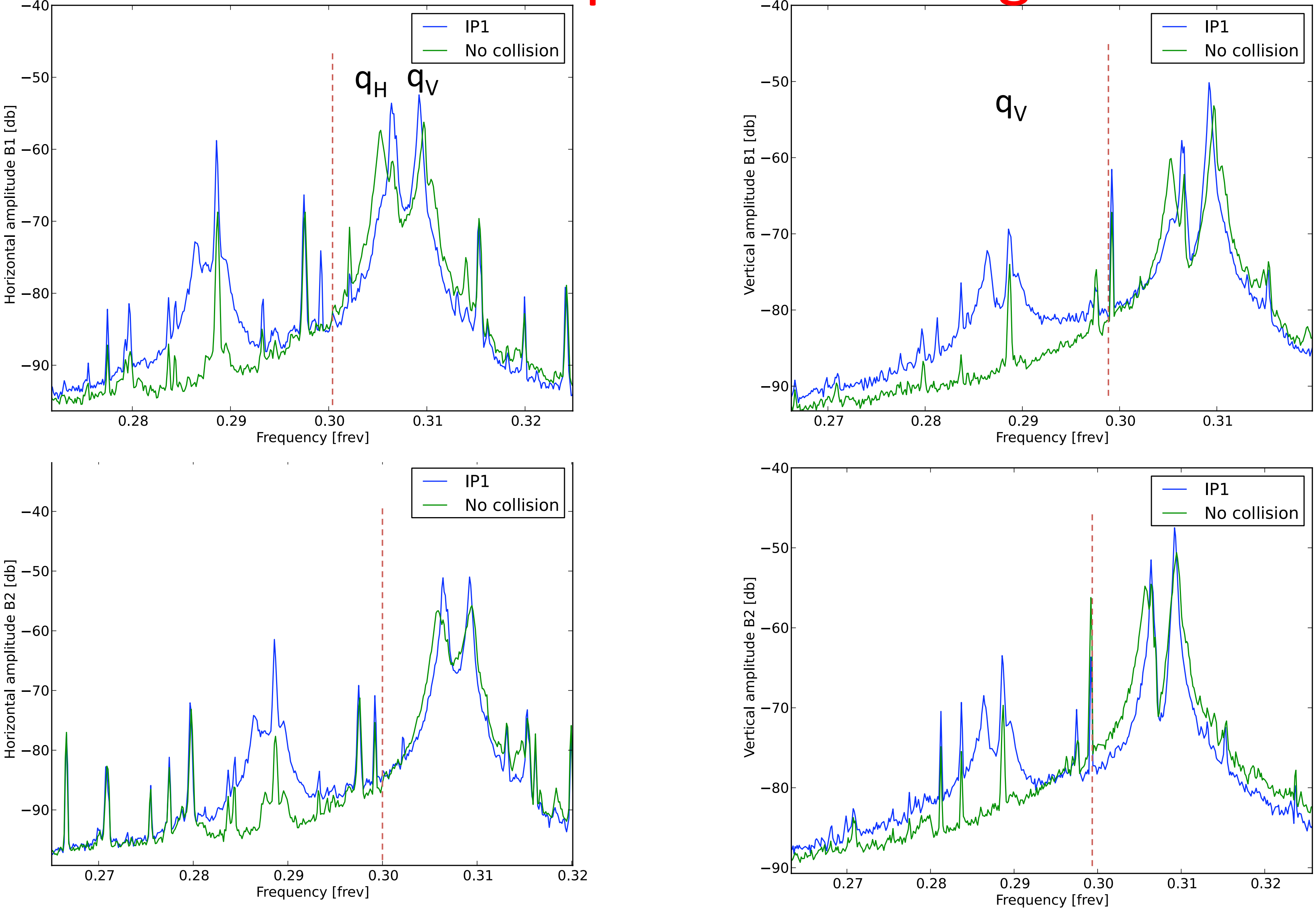






Lifetime stable

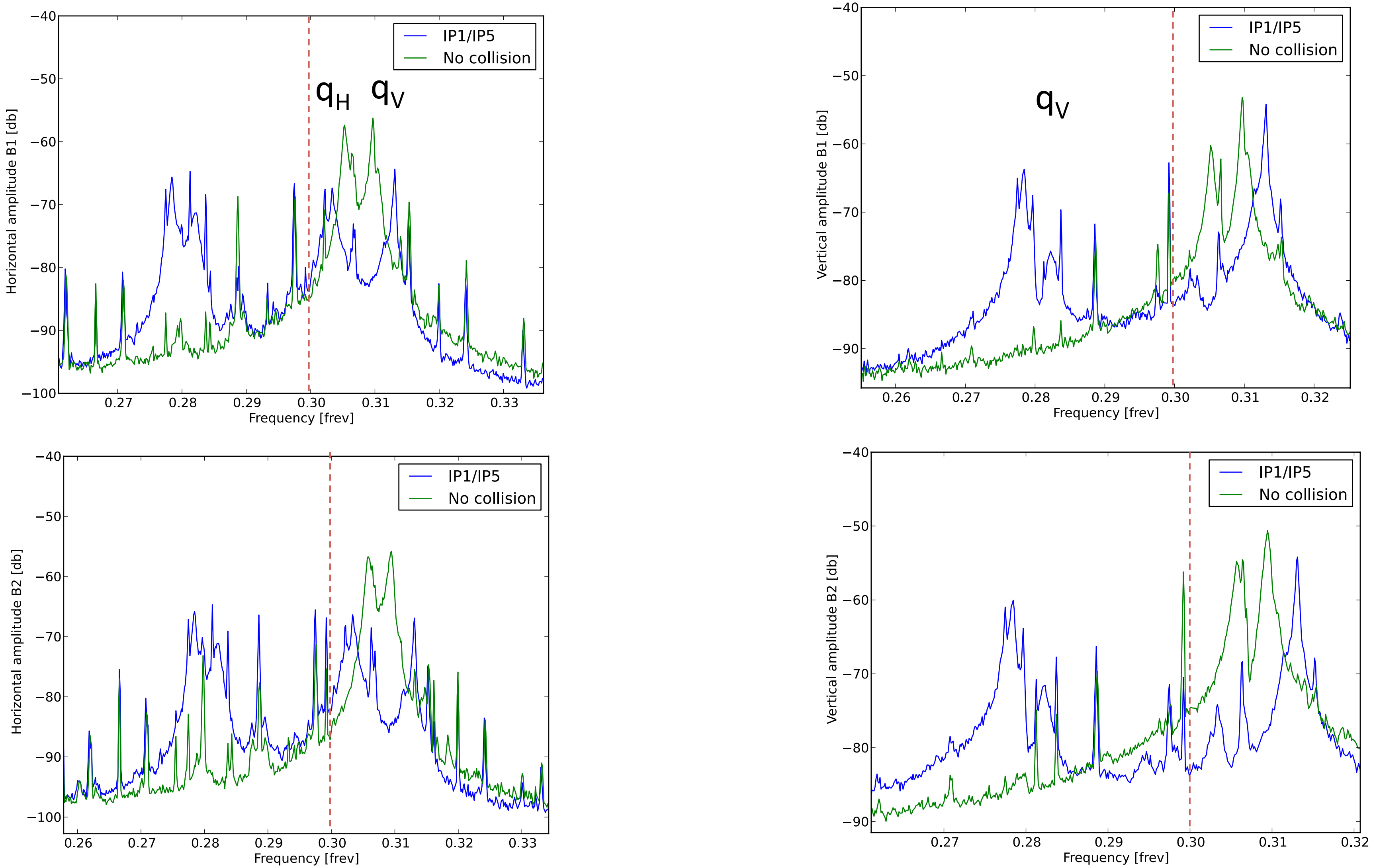
Fill 5: tune spectra colliding IP1



Observations :

- Collision IP1 bring both beams tunes at $q_H = q_V = 0.29$ (beam core jumps 10[th] order)

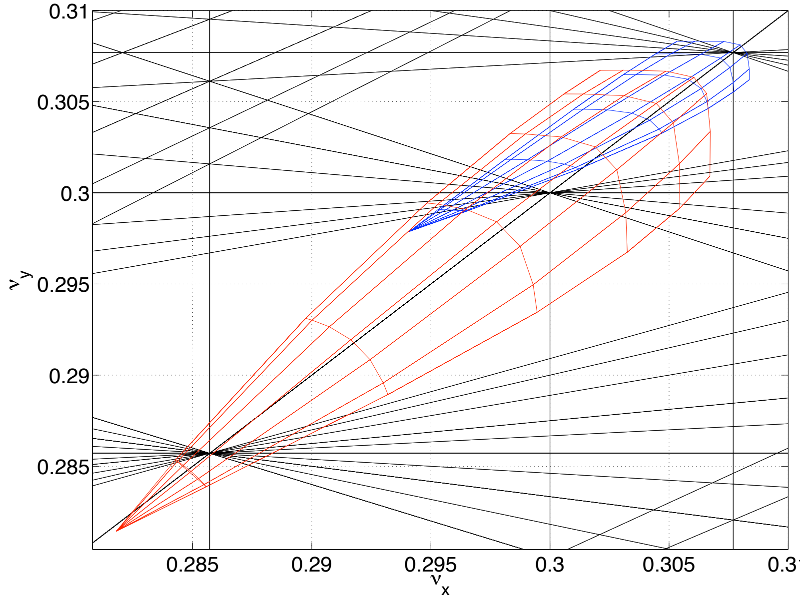
Fill 5: tune spectra colliding IP1 & IP5



Observations :

- Beam-beam tune shift for 2 IPs = 0.034
- No lifetime drops
- No losses

Fill 5: tune spread colliding IP1 and IP1-5



Observations:

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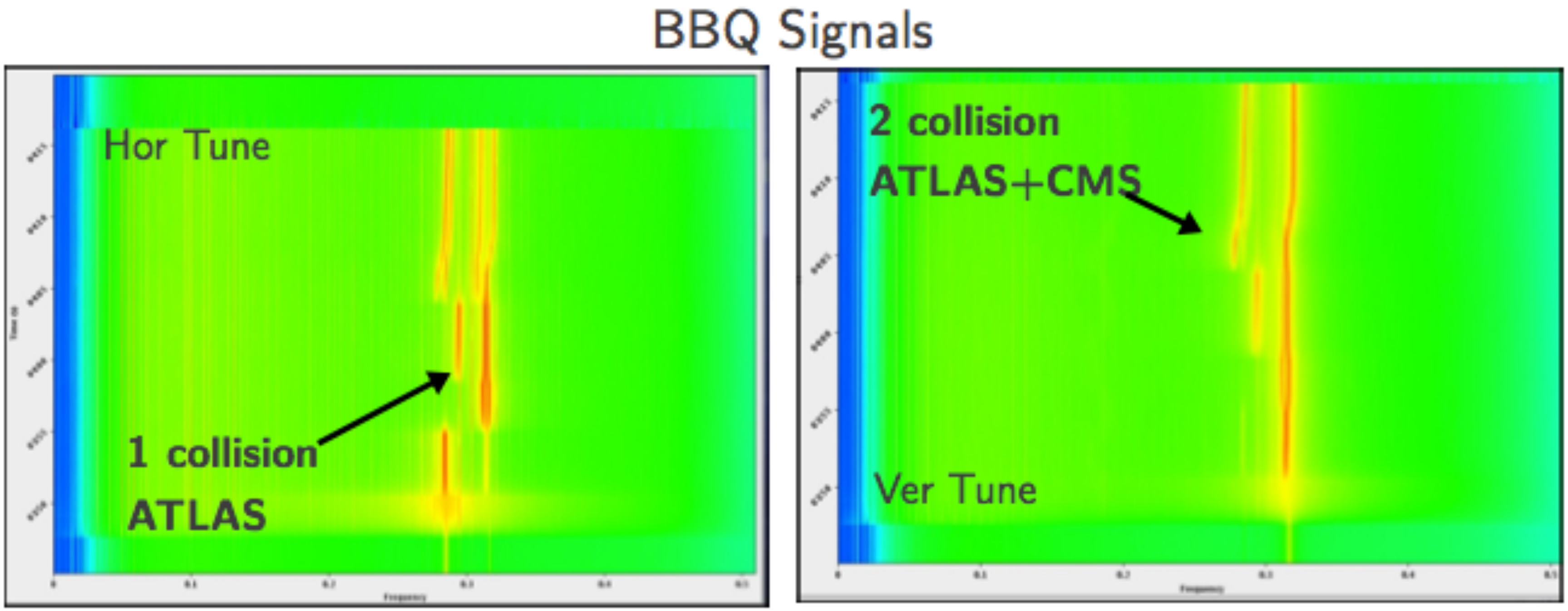
ON-GOING :

- The instability starts developing during the lumi scan not when the separation is collapsed this indicates a dependency on dynamic offsets of the scan(analysis on-going X. Buffat)
- The instability occurs in vertical plane, check simulation of emittance growth for these beam parameters

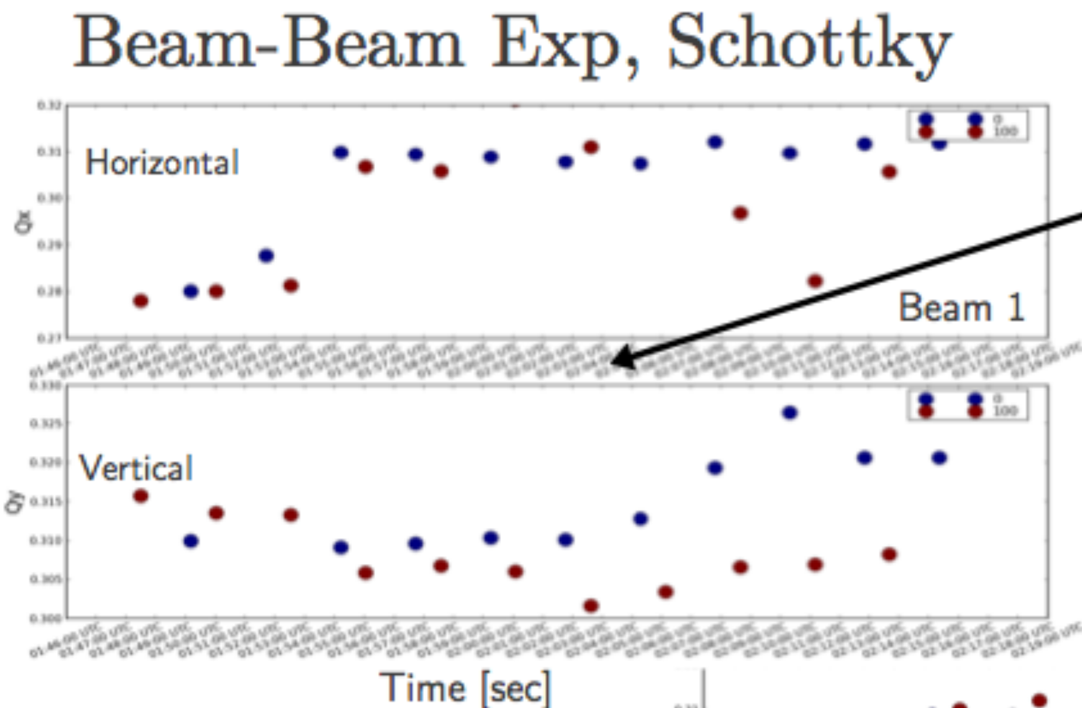
Fill 5: tunes vs time



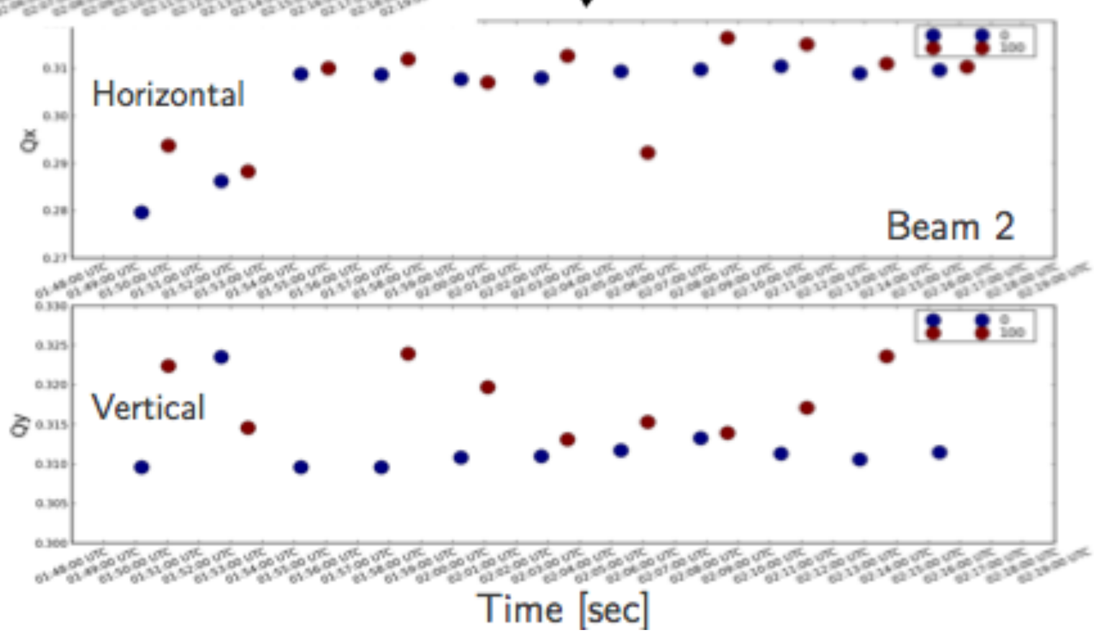
Puzzling feature:

- Tunes moves when colliding IP5
- Seen also in other fills for physics (X. Buffat)

Fill 5: tunes vs time



2 collisions
ATLAS+CMS

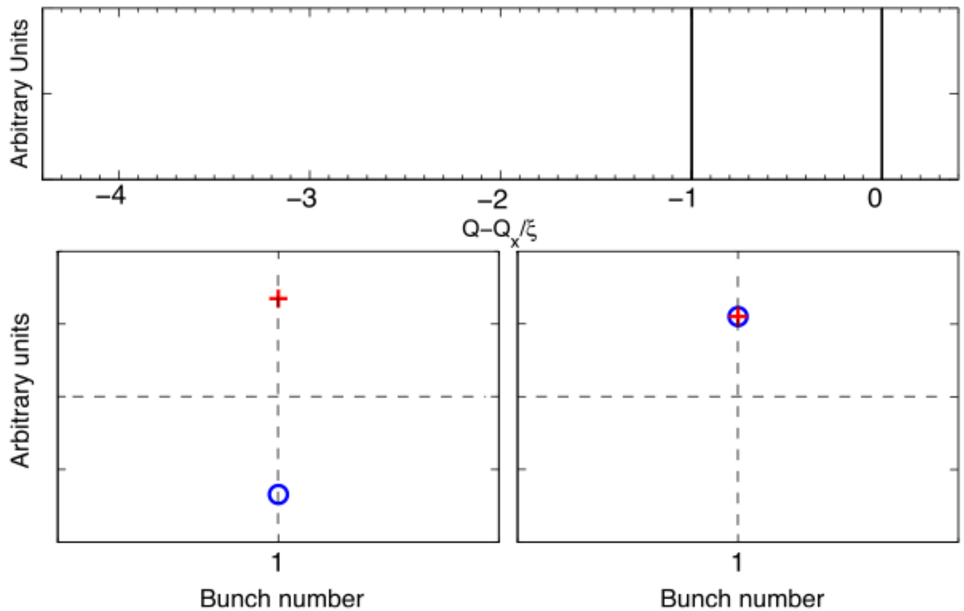


1 collision
ATLAS

Issues:

- Schottky application bug

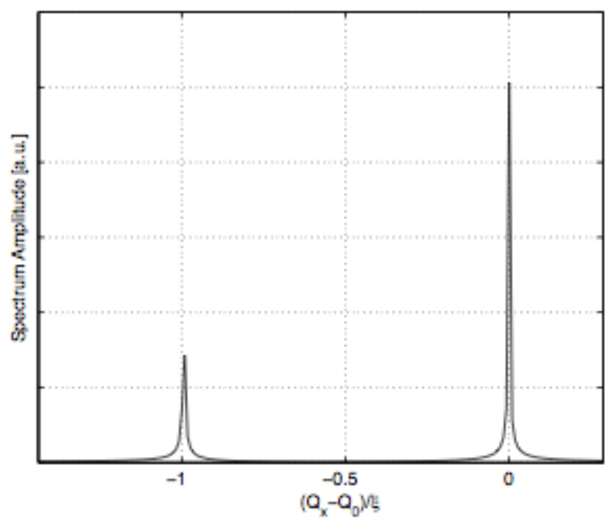
Coherent beam-beam modes and Yokoya factor

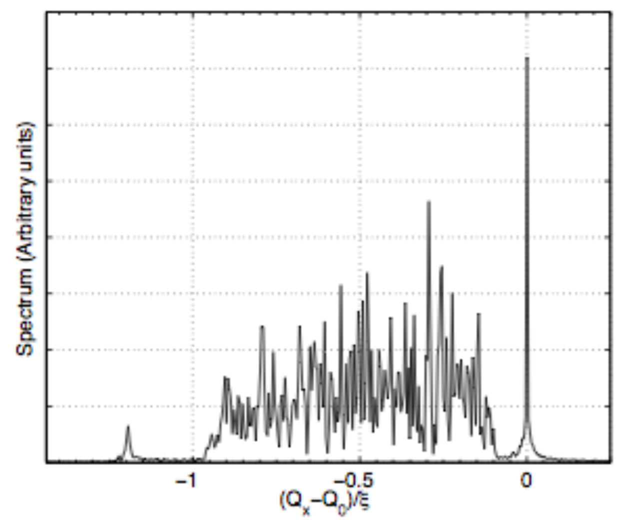


$$\Delta Q_{HO} = Y * \xi_{bb}$$

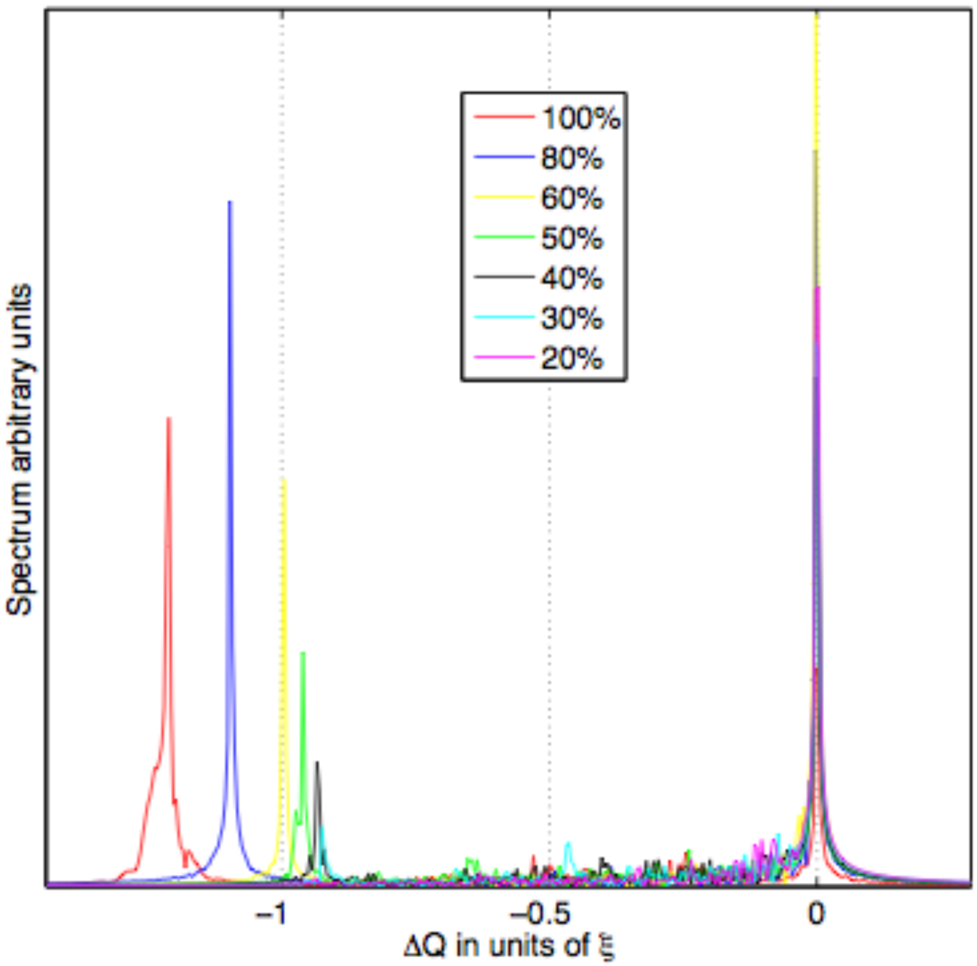
$$\Delta Q_{HO} = Y\ N\ r_o\ \beta^*/4\ \pi\ \sigma^2$$

Y = [1.21-1.23] for LHC case





Coherent beam-beam mode and intensity dependency



$\Delta Q_{HO} = Y * \xi_{bb}$

$\Delta Q_{HO} = Y\, N\, r_o\, \beta^*/4\, \pi\, \sigma^2$

Y = [1.21-1.23] for LHC case

Tune shifts

- Head-on tune shift depend on N and $\varepsilon_n[\alpha, \sigma_s]$

$\Delta Q_{HO} = \xi = N\, r_o\, \beta^*/4\, \pi\, \sigma^2$

$$\sigma(s) = \sqrt{\epsilon \cdot \beta(s)}$$

$$\Delta\ \mathbf{Q}_{ho}\ \neq\ \xi\ !$$

- depends on phase advance for LHC tunes $\Delta Q_{HO} = \xi$
- Reduced by crossing angle in plane of crossing

$$S = \frac{1}{\sqrt{1 + (\frac{\sigma_s}{\sigma} \tan \frac{\alpha_{net}}{2})^2}} \approx \frac{1}{\sqrt{1 + (\frac{\sigma_s}{\sigma} \frac{\alpha_{net}}{2})^2}}$$