The abort gap: longitudinal time scales and possible diagnostics

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- Time scales for the particle motion with
  - RF off
  - RF on
- Diagnostic from 400 MHz component
- Plans for MDs in the SPS

RF off

- The azimuthal position θ of a particle with a momentum deviation $\delta p/p$ changes with time as

$$\theta(t) = \theta_0 + \omega_0 \eta \frac{\delta p}{p} t,$$

$f_0 = \omega_0/(2\pi)$ is the revolution frequency,
$\eta = 1/\gamma_t^2 - 1/\gamma^2$ is the slip factor.

- The bunch length increases as

$$\tau(t) = \tau_0 \sqrt{1 + t^2/t_d^2},$$

with the debunching time ($\tau(t_d) = \tau_0\sqrt{2}$)

$$t_d = \tau_0/(2\eta \frac{\delta p}{p}).$$

- For $t \gg t_d$

$$\tau(t) = 2\eta \frac{\delta p}{p} t.$$

Time scales with RF off

E_s [TeV]	η	ε [eVs]	τ_0 [ns]	$\delta p/p$	t_d [ms]	t_{bb} [ms]	t_{gap} [s]
0.45	3.42×10^{-4}	1.0	1.76	8.62×10^{-4}	3.0	42.4	5.09
		1.0	2.48	5.88×10^{-4}	6.17	62.2	7.46
7.0	3.47×10^{-4}	2.5	1.08	2.16×10^{-4}	7.21	166.8	20.0

t_{bb} - time needed to fill $\Delta t_{bb} = 25$ ns,

t_{gap} - time needed to fill $\Delta t_{gap} = 3$ μs.

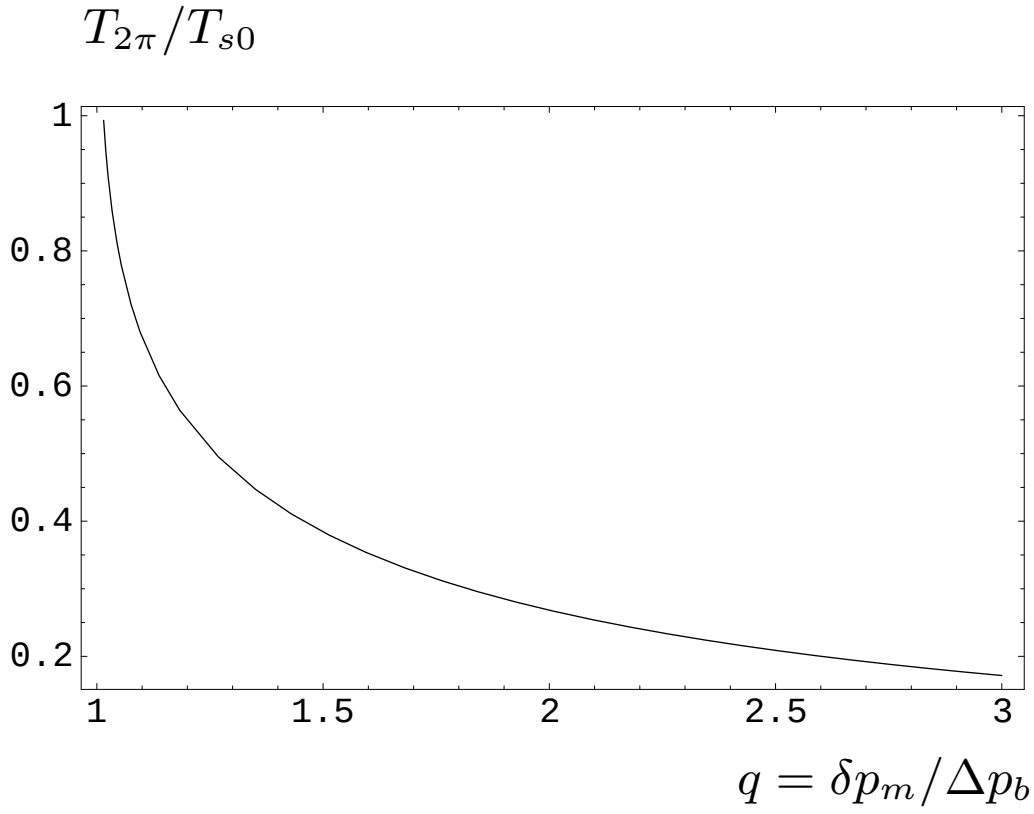
Intensity effects (inductive wall impedance) are not important.

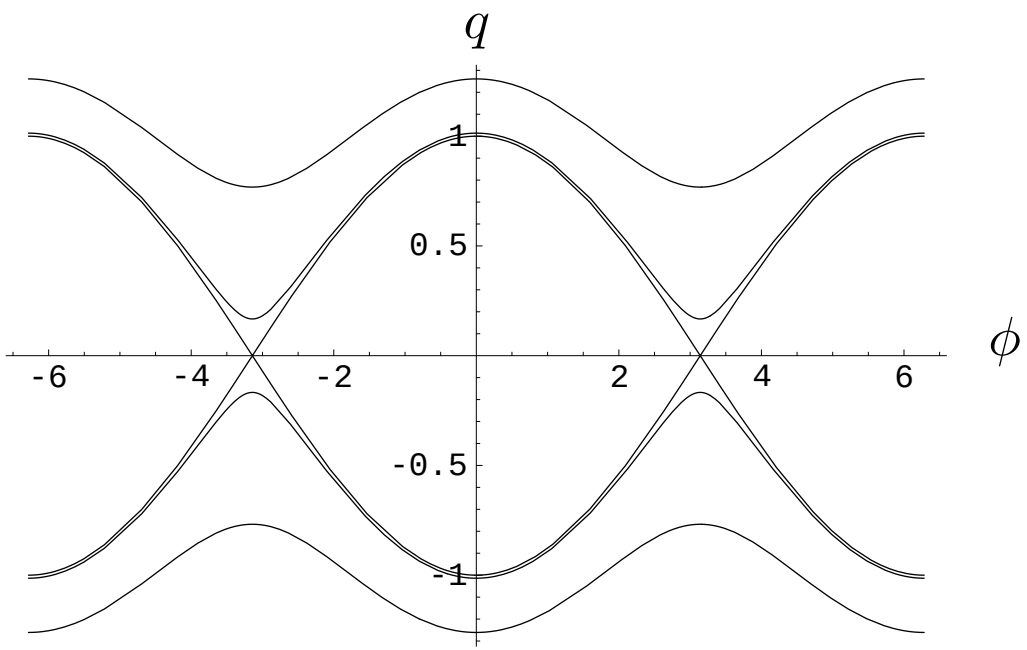
RF on

The time $T_{2\pi}$ it takes for a particle outside the separatrix to travel one RF period (T_{rf}) is

$$\frac{T_{2\pi}(q)}{T_{s0}} = \frac{K(1/q)}{\pi q},$$

T_{s0} is the period of small synchrotron oscillations, $K(x)$ is a complete elliptic integral of the first kind, $q = \delta p_m/\Delta p_b$, $q > 1$.





Phase space trajectories of particles with different q (maximum momentum deviation, normalised to the bucket height):

$q = 1$ (separatrix),

$q_1 = 1.014$ ($T_{2\pi} = T_{s0}$),

$q_2 = 1.261$ ($T_{2\pi} = T_{s0}/2$).

Time scales with RF on

E_s [TeV]	f_{rf} MHz	V [MV]	T_{s0} [ms]	$t_{bb}(q_1)$ [ms]	$t_{gap}(q_1)$ [s]	$t_{gap}(q_m)$ [s]	$\Delta p_b/p$ $\times 10^{-4}$	q_p
0.45	400	8.0	15.1	75.35	9.04	1.55	9.68	0.89
0.45	200	3.0	34.9	87.2	10.46	1.81	8.38	0.70
7.0	400	16.0	41.9	209.5	25.14	4.33	3.53	0.61

- $q_1 = 1.014$ ($T_{2\pi} = T_{s0}$),
- the cut of momentum deviation by the collimation system (B. Jeanneret):

  - at injection at $\delta p/p = 3 \times 10^{-3}$,

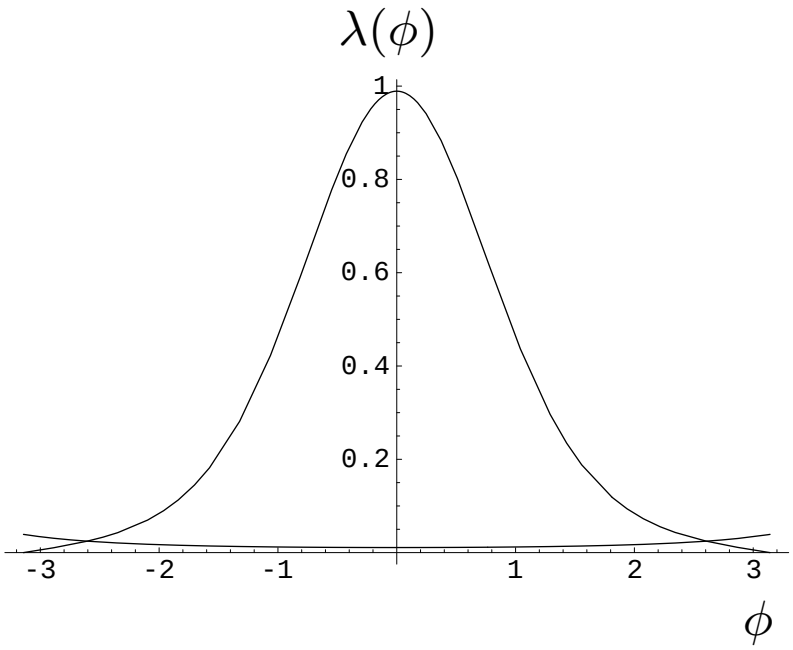
  - at top energy $\delta p/p = 1 \times 10^{-3} \longrightarrow$ in both cases $q \sim q_m = 3$,

- q_p is the bucket filling factor for the bunch with nominal parameters.

Diagnostic from 400 MHz component

Example:
The distribution function $F(H) = F_0 \exp(-H/H_0)$,
where $H = \dot{\phi}^2/(2\omega_s^2) + (1 - \cos\phi)$.
For short bunches $\sqrt{H_0} \simeq \sigma_\phi$.

Line density of captured and uncaptured particles
$(\sqrt{H_0} = \pi/4)$

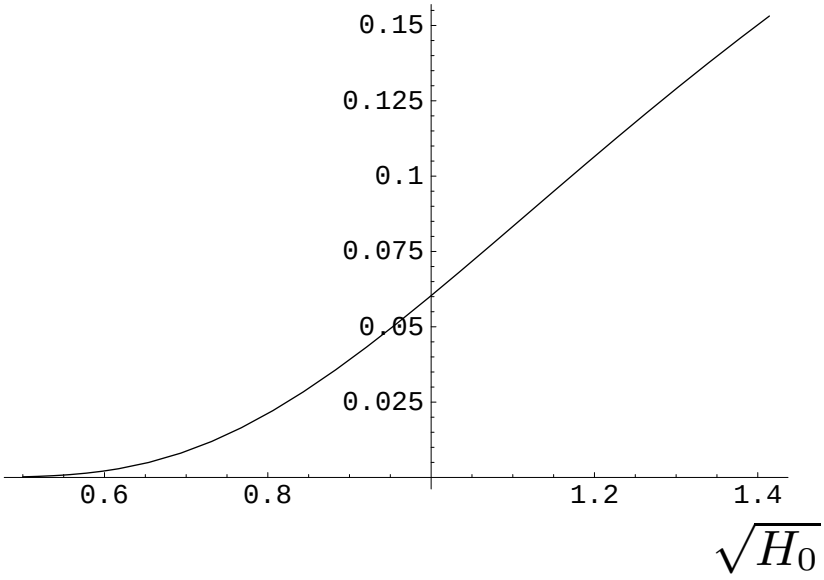


Beam spectrum

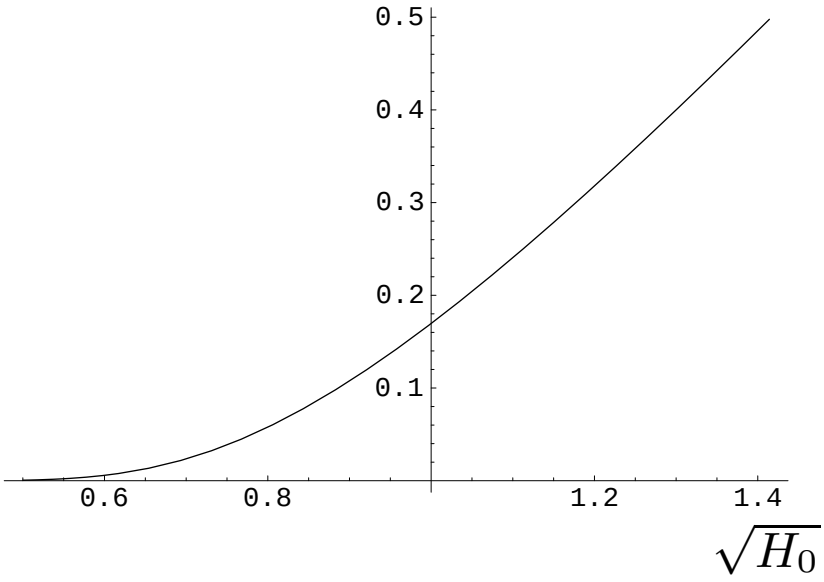
- captured particles: $n \times 40$ MHz
- uncaptured particles: $n \times 400$ MHz
  (after some time)

Beam component at 400 MHz

I_{uncap}/I_{cap}



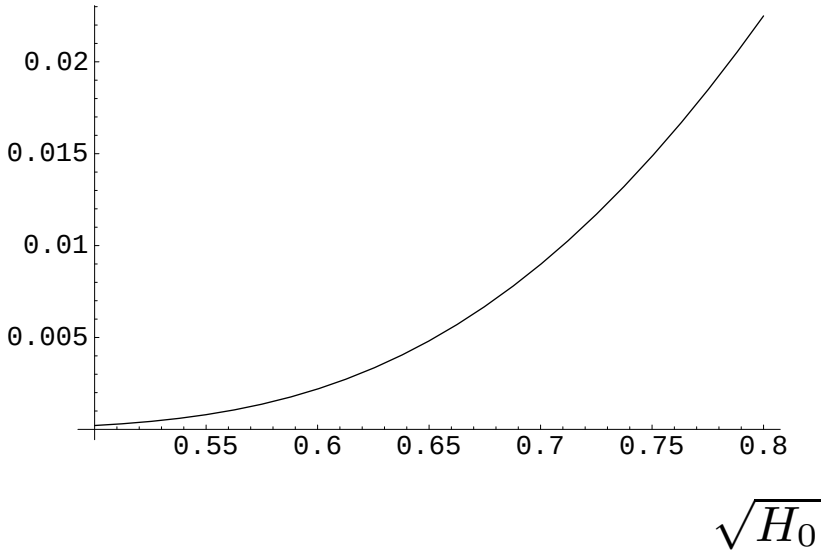
N_{uncap}/N_{cap}



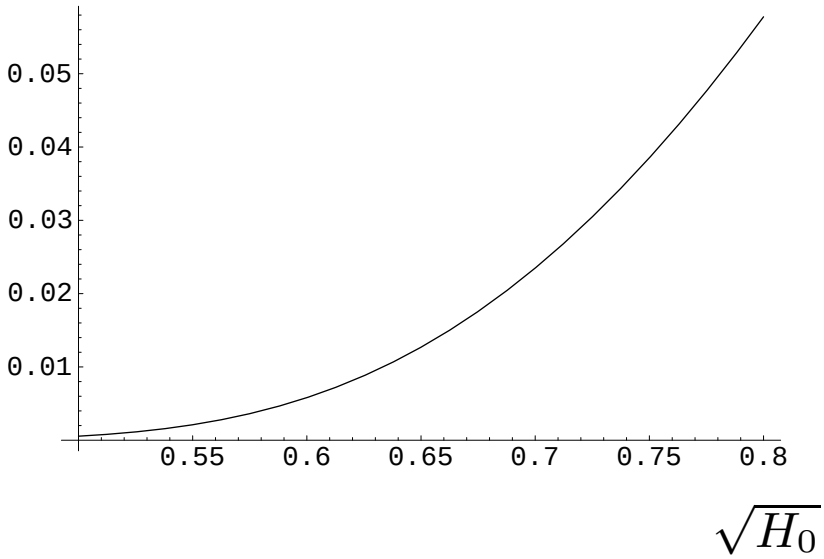
$H_{max} = 3\ (H_{sep} = 2) \rightarrow q_{max} = \sqrt{1.5} \simeq 1.22$

Beam component at 400 MHz

I_{uncap}/I_{cap}



N_{uncap}/N_{cap}



$H_{max} = 18\ (H_{sep} = 2) \rightarrow q_{max} = 3$

Possible MDs in the SPS

Two or more LHC batches in the coast

- RHIC approach (40 MHz component)
- measurements of 400 MHz component only in the gap (gating)
- excitation in the gap at different frequency (scanning in momentum)
- beam echo?

All methods need careful calibration