Summary of the Luminosity Performance session

Monday PM , Oct.1st, 2007

Vladimir Shiltsev

Fermilab

Presentations

- Guido Sterbini – “Leveling with Angle“
- Valery Lebedev – “Leveling with beta*“
- Tanaji Sen – “Noise Issues“
- Oliver Bruning -“Turnaround time“

High frequency Noises (T.Sen)

Turn-by-turn kicks should be less than (2e-5 x sigma) otherwise emittance growth will be more than 10% over 10 hours (4e8 turns):

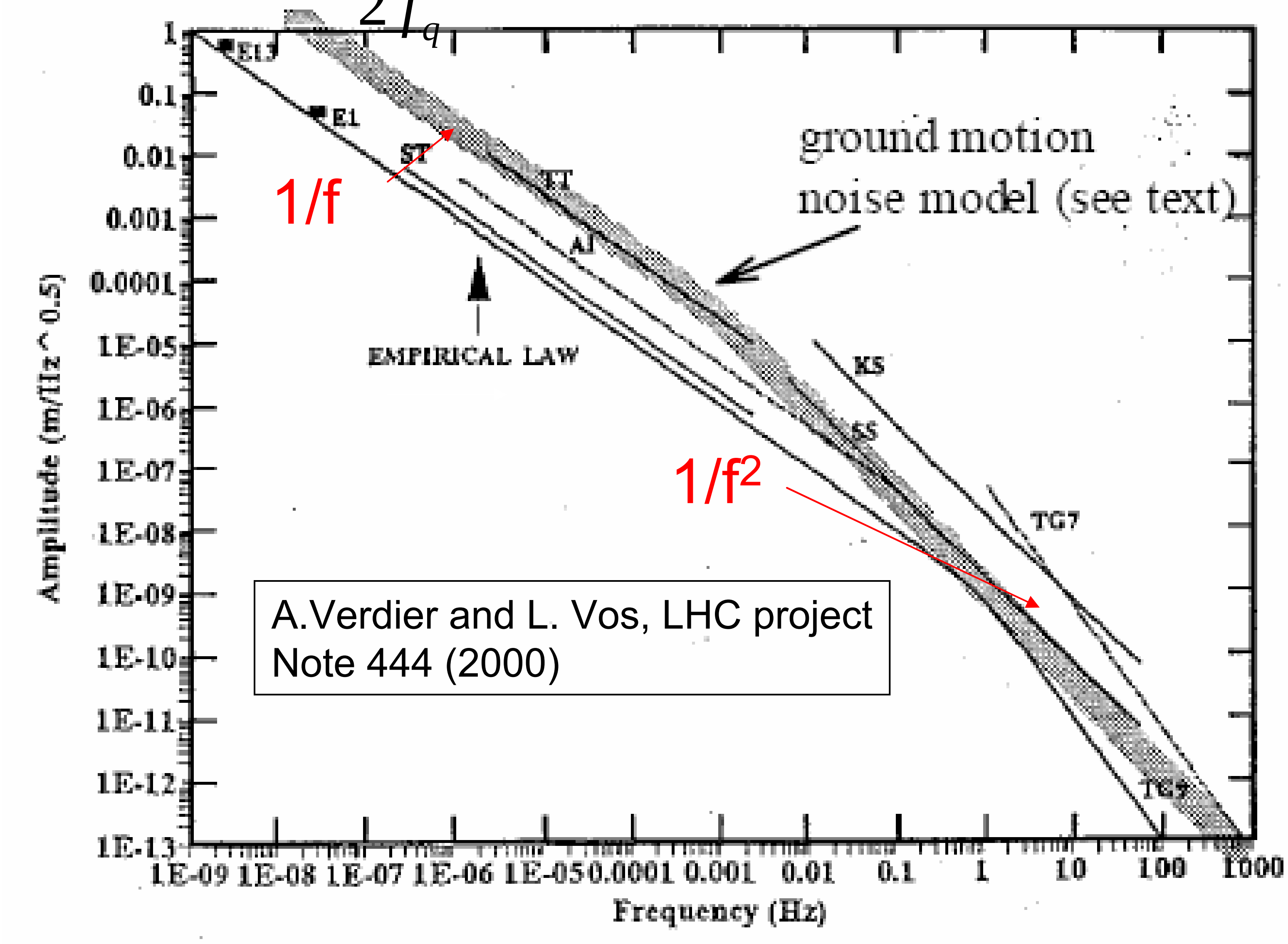
$$\Delta\sigma^2 = N_{turns}(Kick)^2 = N_{turns}(\eta\sigma)^2, \eta = 0.00002$$

- Example: Tevatron IR quad Q2 (f_q = 4 m) → 1A jitter
- Example: LHC IR quad Q3 (f_q=18.5m) → 2A jitter
- Example: LRBBC wire dI/I<2e-5
- Example: 0.3 mrad CrabCav dA/A < 5e-5, dPhi_RF<0.002deg

At What frequencies? At f_0 (Q+-n)

$$\Delta < y^2(t) >= \frac{\pi\beta\beta_q f^2{}_{rev}}{2 f_q^2} t\Sigma_{n=-\infty}^{\infty} S[\Omega(\nu - n)]$$

G. Stupakov, SSCL (1992)



Possible Sources of HF noise

Possible sources include

- Triplet vibrations (incl. beam screen)
- Power supply noise in triplets and beams offset in these magnets
- Noise in feedback kickers, bpm errors
- Crab cavity noise
- Wire compensator current jitter
- Ground motion

Tev dε/dt due to pbar Abort kicker noise

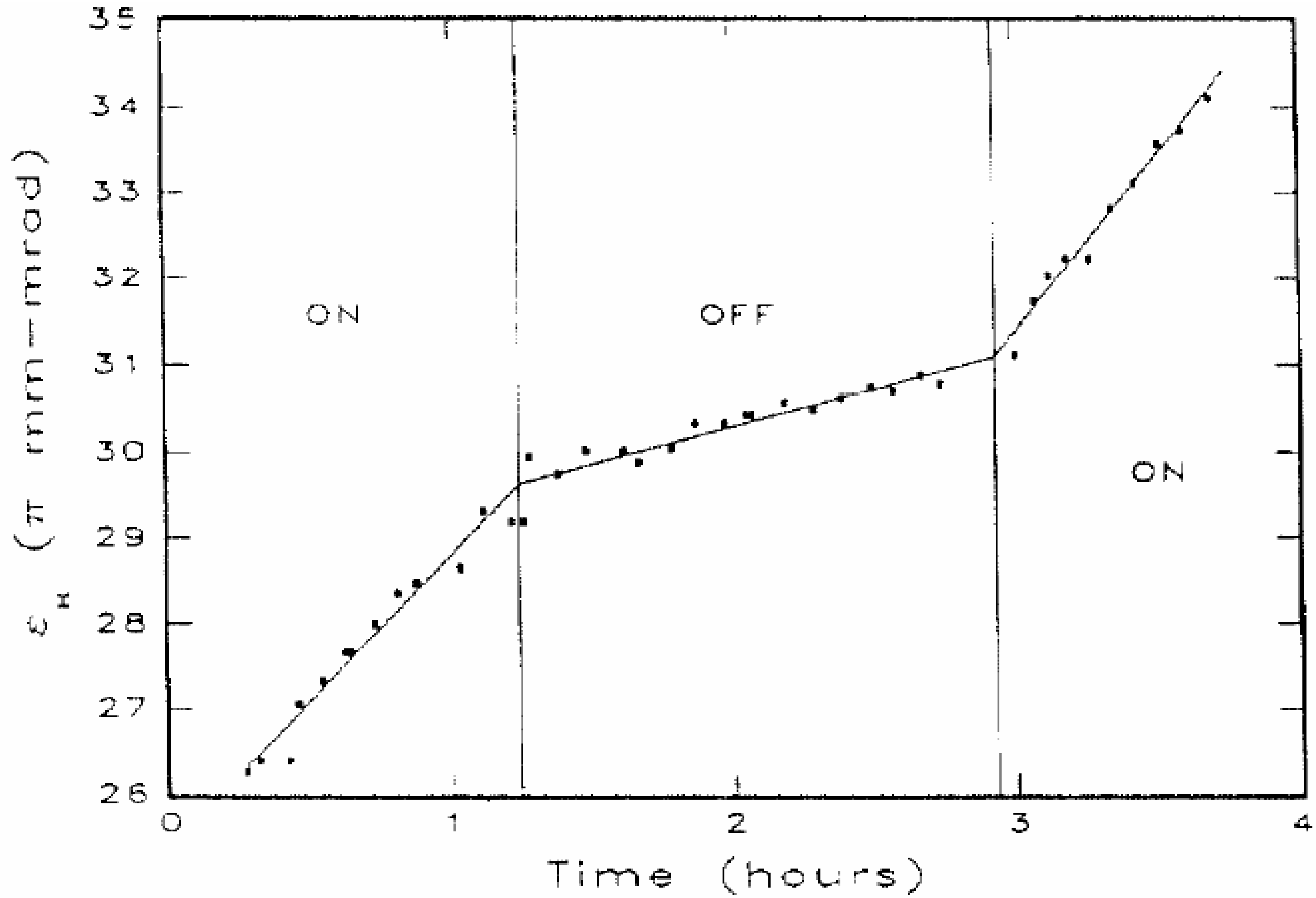
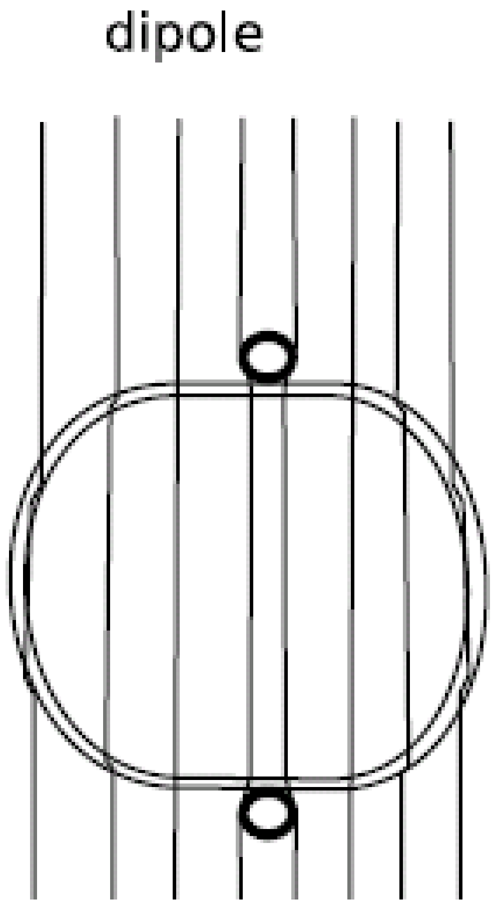


Figure 1: Horizontal emittance as a function of time while the antiproton abort kicker is on and off.

Tev dε/dt due to Beam Screen vibrations



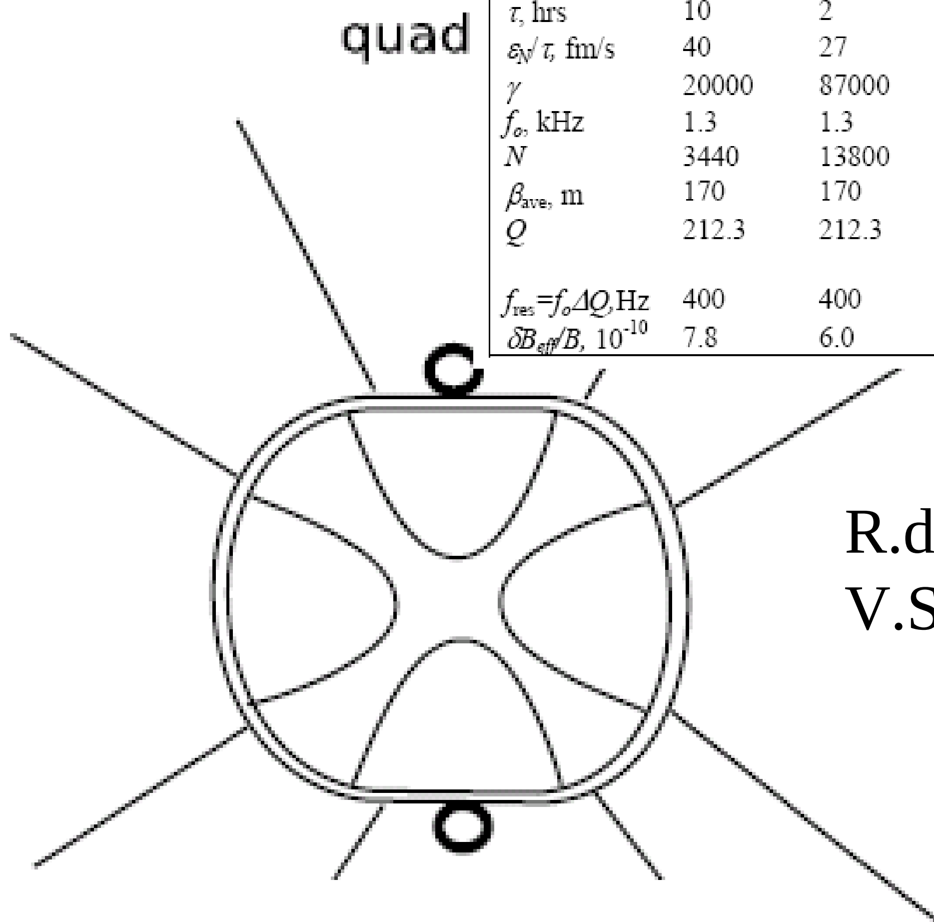


Table 1: Parameters and $\delta B_{eff}/B$ tolerances for large hadron colliders

	VLHC-I	VLHC-II	LHC	Tevatron
ε_N, μm	1.5	0.2	3.75	3.3
τ, hrs	10	2	10	10
ε_N/τ, fm/s	40	27	100	90
γ	20000	87000	7000	1000
f_o, kHz	1.3	1.3	11.3	48
N	3440	13800	1200	774
β_{ave}, m	170	170	67	50
Q	212.3	212.3	63.3	20.55
$f_{res}=f_o\Delta Q$,Hz	400	400	3400	20000
$\delta B_{eff}/B$, 10^{-10}	7.8	6.0	2.8	2.1

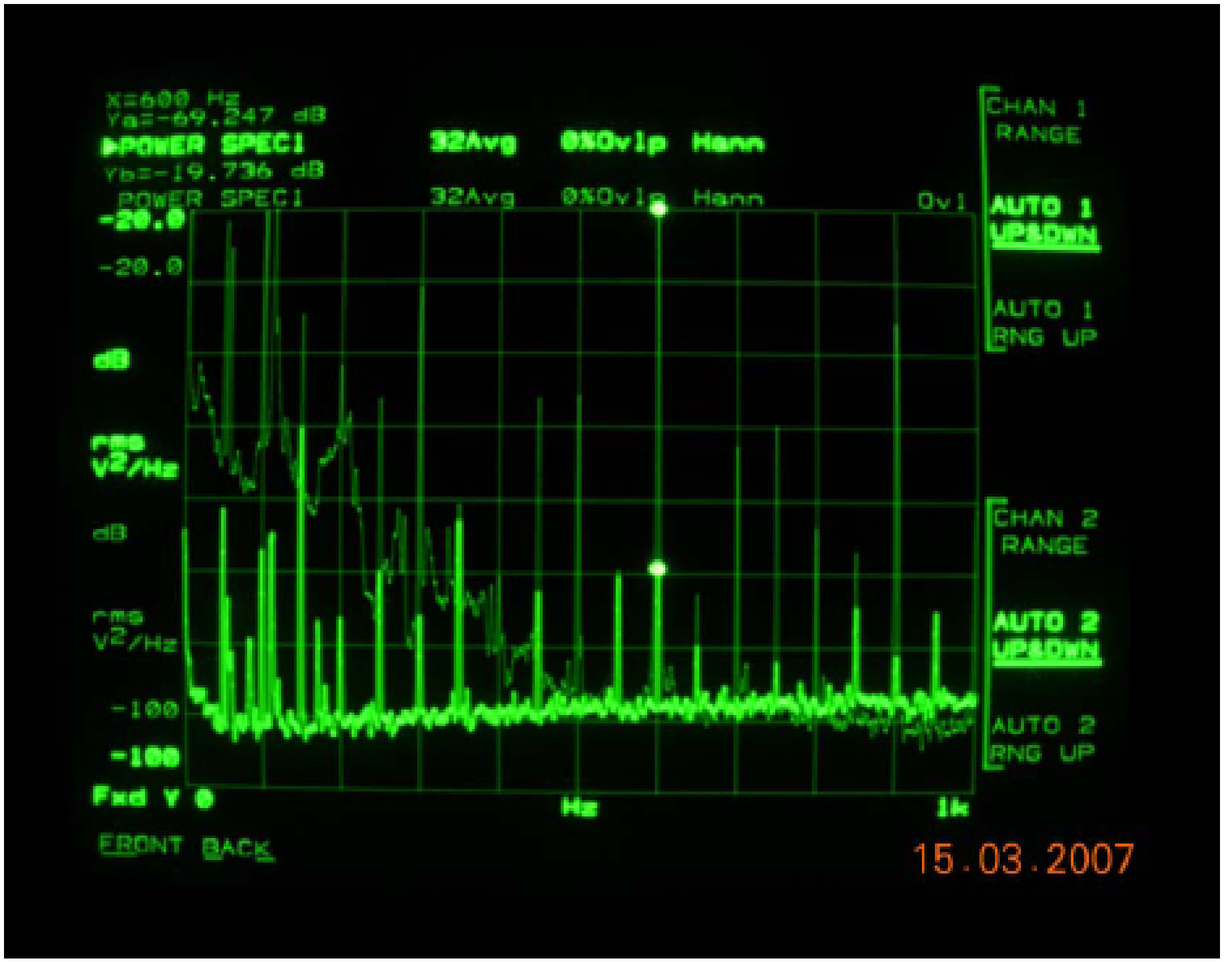
R.deMaria
V.Shiltsev

$$d\varepsilon_N/dt = f_0\,\gamma\beta_{ave}\,(\delta B_{eff}/B)^2/(2N)$$

$$(\delta B_{eff}/B) = [2 f_o \Sigma S(f_o|n-Q|)]^{1/2}$$

LHC rf cavity spectrum

J. Tuchmantel, LHC Project Note 404(2007)



- Phase noise measured in tests is very low, σ_Φ~0.003degrees
- Several strong coherent lines at 50Hz and multiples
- Simulations of only longitudinal dynamics show (1) 50Hz lines cause slight emittance blow-up during ramp

  (2) During a store these lines do not have much impact

Performance Optimization (O.Bruening)

Three main components for luminosity integral:

- Peak luminosity
- Luminosity lifetime
- Turnaround time and run length

Experience from existing superconducting machines: Tevatron
HERA
RHIC

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Luminosity Lifetime

- Luminosity mostly decays due to burn-up plus additional proccesses:

-restgas collisions $\tau_{gas} = 100h$

-IBS $\tau_{IBS} = 80h$

-emittance growth due to beam-beam (difficult to predict → HERA)

-particle losses due to beam-beam (difficult to predict → Tevatron: 16%)

$$\rightarrow \frac{1}{\tau_{L,tot}} \approx \frac{1}{\tau_{\exp}} + \frac{1}{\tau_{IBS}} + \frac{2}{\tau_{gas}} + \frac{1}{\tau_{emit,bb}} + \frac{2}{\tau_{N,bb}}$$

- Nominal LHC parameters: $\Rightarrow \tau_{L,tot-nom} \approx 15h$

- Ultimate LHC parameters: $\Rightarrow \tau_{L,tot-ult} \approx 10h$

- LHC PhaseII upgrade parameters: $\Rightarrow \tau_{L,tot-PhaseII} \approx 2.3h$

(LHC with IBS & rest-gas only)

Expected Turnaround time

- LHC: assuming a minimum turn around time of 1.2h for the LHC it Seems to be reasonable to assume:

  T_{turn} = 10h during first years (8 * theoretical minimum [Tevatron])

  T_{turn} = 5h for during operation with ultimate parameters
  ➔ apply the same ration as HERA – Tevatron improvement
  However: HERA and Tevatron have the same size and similar complexity
  ➔ can this improvement be extrapolated to the LHC?

- LHC Phase II luminosity upgrade is only efficient if $T_{turnaround}$ < 5h:

  ➔ need consolidation efforts for minimizing fault rate!

Experience from HERA

HERA 2006 operation statistics[&]: [&](B. Holzer; DESY)

115 stores in total

230 faults; average store length: 7.4h; (min = 0.16h; max = 14.3h)

# of p-injections = 164; number of e-injections = 185

Top 10 causes: (frequency)

-operation	40 →	17%
-e-RF	35 →	15%
-power supplies	29 →	13%
-beam loss	19 →	8%
-controls	18 →	8%
-injector complex	13 →	6%
-proton RF	9 →	4%
-SC cavities	7 →	3%
-quench protection	7 →	3%
-beam instrumentation	7 →	3%

one can expect most of them also for the LHC operation!

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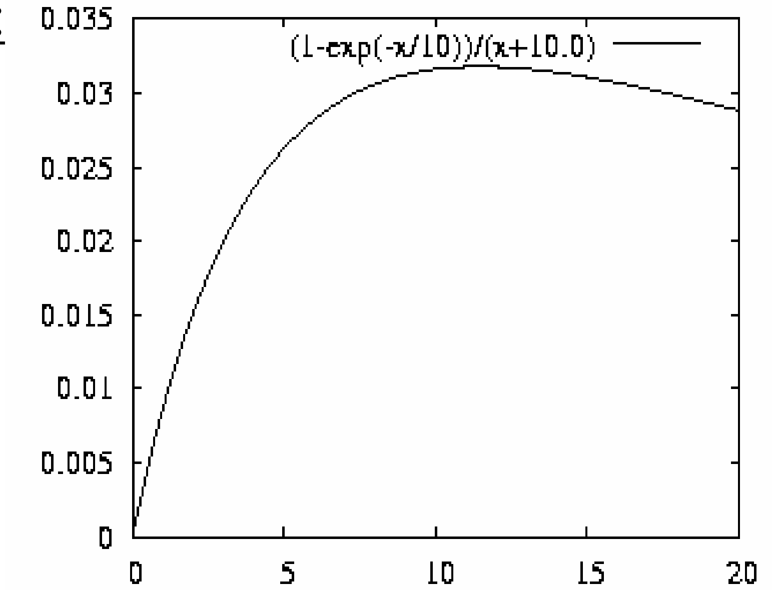
Luminosity Integral not very sensitive to runtime

Integrated luminosity over one run:

example: $\tau_{lumi} = 10h$



- ➔ broad peak
- ➔ not very sensitive to slight variations in the run time

Optimum run time:

$$T_{opt} \equiv \sqrt{T_s \tau}$$

T_{turn} / τ_{lumi}	1	6	10	20
2.5	2	4	5	6
10	4	9	11.5	15
15	5	12	15	20
19	5.5	13	16.5	22

Peak / Average

$$\frac{L_0}{L_{opt}} = \left(1 + \sqrt{\frac{T_s}{\tau}}\right)^2$$

V.Lebedev

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The best way to level luminosity -?

V.Lebedev summarized Tevatron's thinking on the leveling:

Luminosity Leveling in Tevatron

- Any luminosity leveling results in reduced luminosity integral
- (1) Smooth (multi-step) beta-function changes during the store is close to impossible to implement in operations
- (2) Single step beta-function change looks promising
    - Significant time for commissioning
    - More complicated operations – larger probability to lose the store. ~1 min stop for data acquisition beta-function change

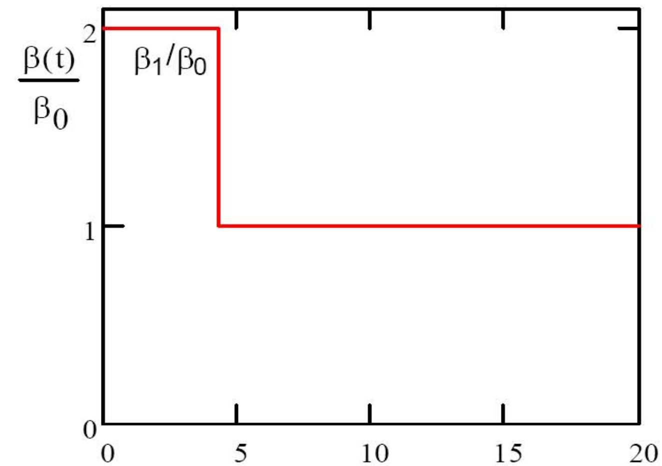
Leveling in Super-LHC: An example

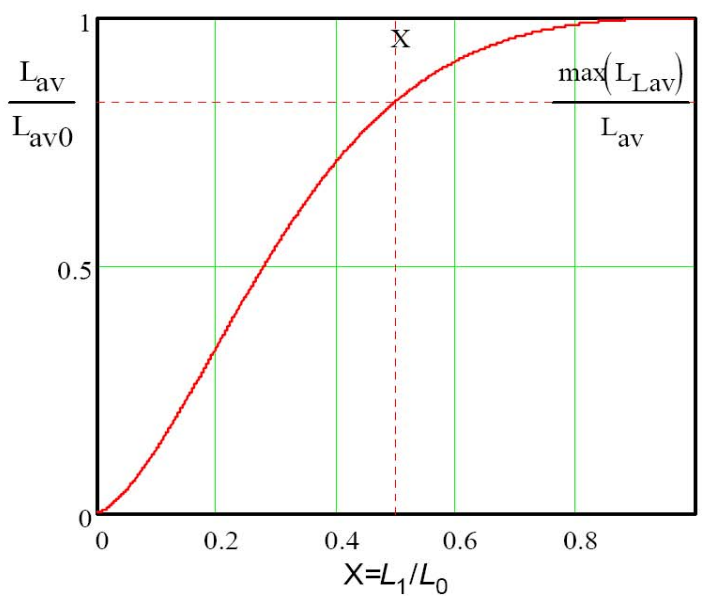
Luminosity evolution with one step β* leveling

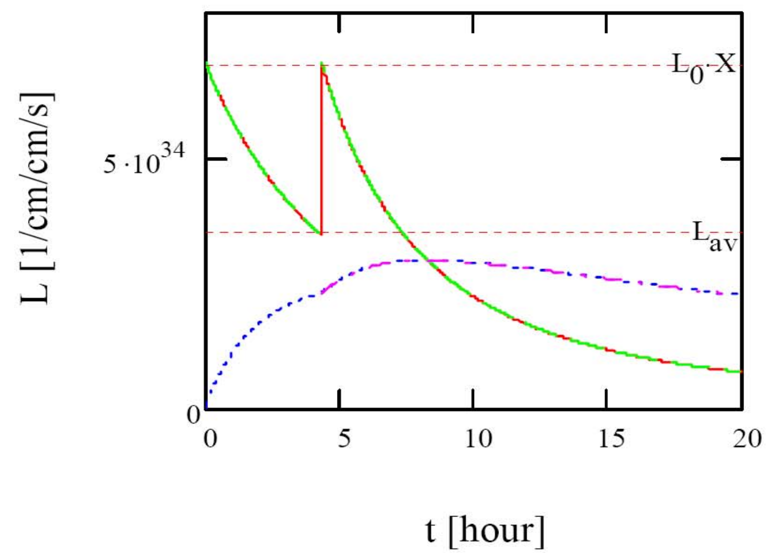
- Luminosity and b-function are directly related

$$X = \frac{L_1}{L_0} = \frac{\beta_0}{\beta_1}$$

- Two times reduction of the peak luminosity results in only 17% average luminosity reduction (relative to the case with no leveling

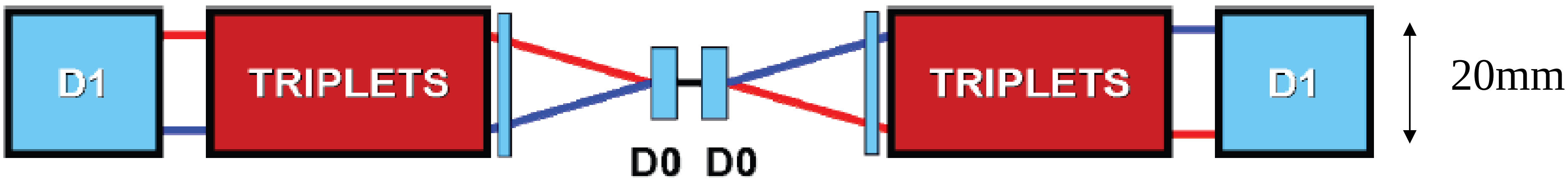






Leveling by variation of crossing angle

G.Serbini and J.P.Koutchouk:



Pros

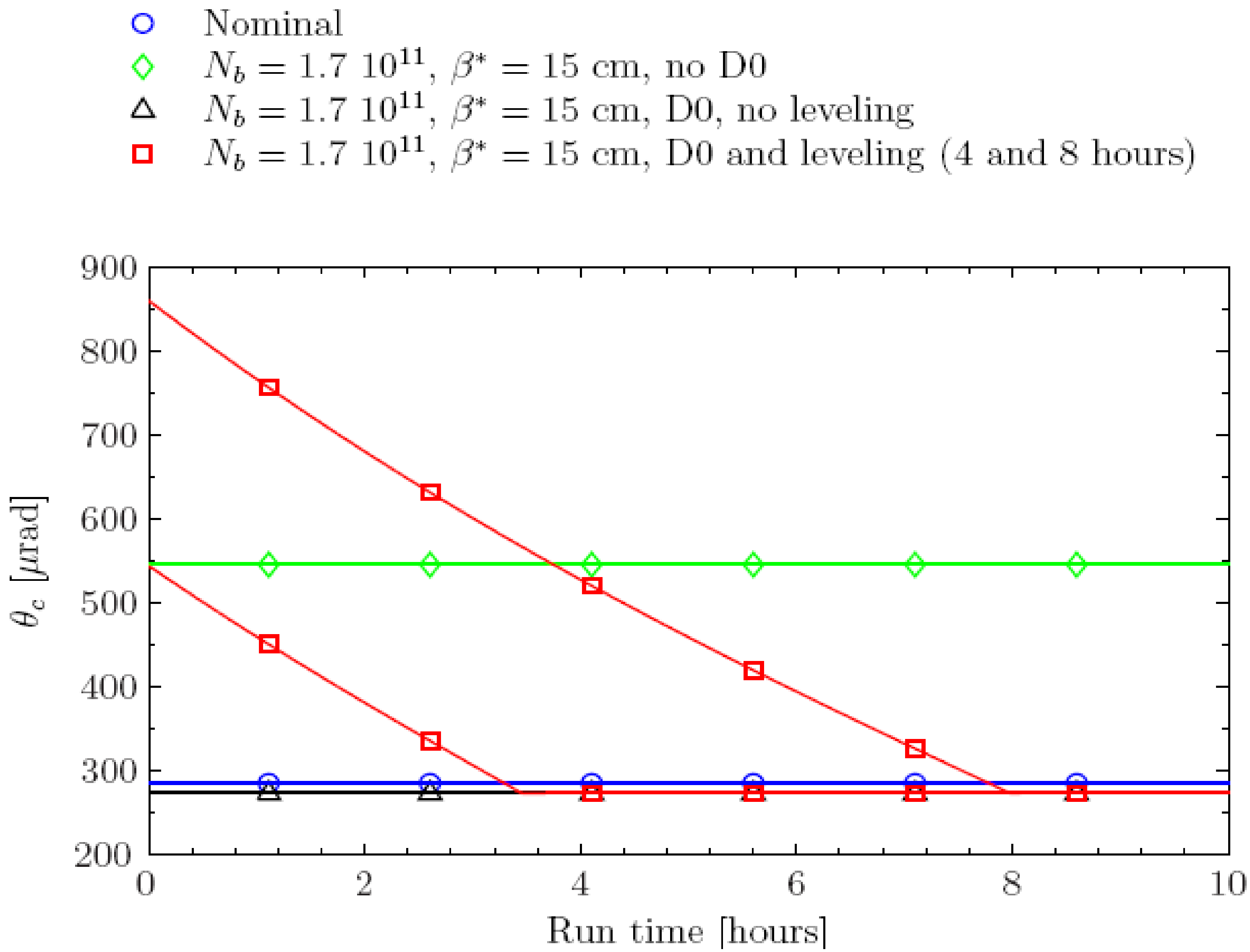
- Increase of integrated luminosity with a reduced peak luminosity increase
- Clean to implement
  - NO chromaticity correction variation
  - NO closed orbit variation around the machine
  - NO sextupoles feed-down
  - NO spurious dispersion at the IP.
- With flexibility: reduced separation when the beam current is decreased.

Cons

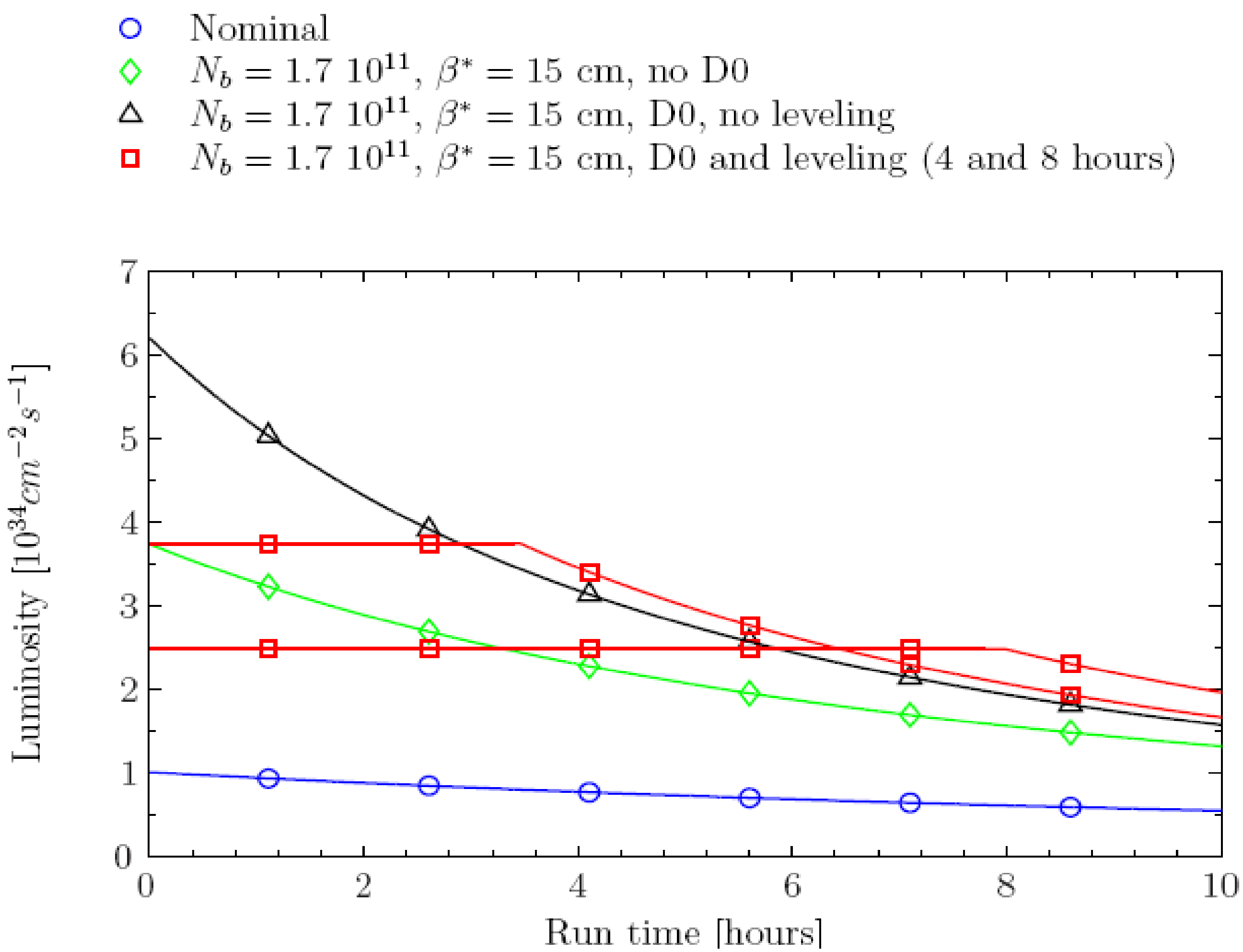
- Dipoles in the detectors
- Variation in the luminous region longitudinal size
  - synchro-betatron coupling
- BB effect to understand better.

* head-on/LR beam-beam dQ reduced

Angle - Leveling in Super-LHC: An example



Angle - Leveling in Super-LHC: An example



		Peak L $[10^{34}$ cm^{-2} s$^{-1}]$	Integrated L [fb^{-1}]
Nominal scenario		1.01	86.37
$\beta^* = 0.15$ m	no D0	3.74	257.37
$\beta^* = 0.15$ m	D0, no leveling	6.20	369.65
$\beta^* = 0.15$ m	D0 and leveling	3.75	340.70