Summary of Working Group on Weak-Strong Beam-Beam Effects

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`wwwslap.cern.ch/keil/LHC-Workshops/Beam-Beam/15apr99.ps`

Contributed Talks on Weak-Strong Effects

We listened to the following talks and discussed them to various degrees:

CWS4 Influence of Vertical Dispersion and Crossing Angle on the Performance of the LHC, L. Leunissen

CWS1 Incoherent beam-beam tune shifts in the LHC, H. Grote

CWS5 Effect of the beam-beam interactions on the dynamic aperture and amplitude growth in the LHC, T. Sen

CWS6 Weak-strong beam-beam simulations for the LHC, F. Zimmermann

CWS2 Filling Schemes, Collision Schedules and Beam-beam Equivalence Classes, J. Jowett

CWS3 Application of Beam-beam Interaction to a Particle Density Function, T. Koyama

CWS7 Effect of Very Low Frequency Ground Motion on the LHC, L. Vos

The results will be discussed later during my talk.

Measurable Quantities and Instrumentation

Lifetime: DCCT for total beam current, fast bunch integrator and sampled bunch display for bunch-by-bunch currents

$\sigma^*, \Delta x^*, \mathcal{L}$**:** Beam-beam scans, transfer function, luminosity and vertex detectors

$Q(J)$**, footprints, modulation:** stepped kicker magnet in LHC, AC dipoles in RHIC, resonant Schottky cavity in Tevatron, bunch-by-bunch tunes by gated beam excitation and response

Tails, diffusion: Movable collimators, *any better idea?*

Emittance growth: Flying wires, ion profile monitor, synchrotron light monitor

- Willeke emphasizes usefulness of loss monitors for checking health of HERA
- Not known whether LHC will have a bunch-by-bunch feedback system that can also be used to excite bunches, and systems for measuring tails

Experiments

- Watching commissioning of RHIC and Tevatron Run II might be best method for accumulating information relevant to LHC
- RHIC can be filled quickly and offers possibilities for formal experiments on crossing angle, head-on and/or parasitic collisions, some immediately, some others later on after upgrades
- Organized experiments require
  - a model, applied to a configuration in a specific machine, making predictions for a measurable quantity
  - confronting model and experiment
  - all sorts of verifications that machine behaves according to model
  - E778 always presented as glaring example

Simulation I

- Codes in use are MAD8, SIXTRACK, TEVLAT and Sen's unnamed code for Tevatron and LHC work at FNAL; MAD, SIXTRACK and Zimmermann's code at CERN; Shatilov's code LIFETRAC similar to codes by Irwin and Siemann et al.,
- Codes should be validated by comparing results on observable quantities with:
  - other codes
  - experiments

    Comparisons at different machines by teams of experimenters other than code developers
  - analytical results

    We are not too optimistic about getting analytical results for complicated cases. Hence validity is demonstrated at best in a restricted range of parameters.
- Need complicated code(s) with (most of) the physics to get close to reality; fear that it/they are slow, and therefore cannot be used for extensive parameter searches.
- Need less complicated, faster codes, including only the most important physics, to eliminate parameter ranges that don't work.
- We have such codes!

Simulation II

- Ensure that different codes get identical machine descriptions, cf. SXF for LHC descriptions understood by MAD, SIXTRACK, TEAPOT, TEVLAT
- Facilitate further code development by a library of well-documented library of modules, e.g. for 4D or 6D beam-beam kicks, maps through non-linear elements and/or entire arcs, etc.

  Note that all simulation codes consist of a small number of modules, selected by judgement/prejudices of the developer(s) of what physical effects are important
- Facilitate comparison of results by adopting common styles of inspection and presentation

  WWW is one way of providing access to modules

Reformulated General Questions I

- Do you know a reason why the present choice of the LHC working point (64.31, 59.32) might be bad?

  Working points (64.232, 53.242) and (64.385, 53.395) are crossed by fewer non-linear resonances.

- How are the beams brought into collision in existing and planned colliders?
  - *In Tevatron beams were brought into collision by longitudinal cogging; beams will be brought into collision transversely within a few seconds, given by discharge time of separators*
  - *In HERA beams are brought into collision transversely at slow speed*
  - *In RHIC beams are injected and accelerated with two rings unlocked, then brought into collision longitudinally and transversely. What about overlap knockout resonances for unlocked beams?*

  Do you know a reason why the same procedures do not work for LHC?

  No

Reformulated General Questions II

- Do we expect luminosity or beam lifetime degradation from ground motion, dynamic effects (e.g. tune ripple) and chromaticity?
  - *According to model of L. Vos, the two beams will get separated as in a random walk, unless they are kept centered every so many minutes. Although the model was questioned, the conclusion is most likely correct. It should be checked with standard ATL models.*
  - *Tune modulation with* $\Delta Q \approx 10^{-4}$ *at* Q_s *had no effect in Zimmermann's simulation;* $Q' \leq 5 \ldots 6$ *with* $\sigma_e \approx 10^{-4}$ *works in Tevatron? To avoid drop in luminosity lifetime in SPS* $\Delta Q \leq 210^{-4}$
- What procedures shall be followed to validate beam-beam design choices?

  Answers in section on simulation and experiments.
- What are the implications of beam-beam effects for linear optics, machine instrumentation and operation?

  Keeping track of more than 4000 bunches with only about half of them in the most populated equivalence class, as proposed by J. Jowett, and producing meaningful displays for the operators is a tough job for the controls people, and should be tackled soon.

Questions for the Working Group on Weak-Strong Effects I

- Given the triplet errors, can we recommend an optimum crossing angle?

  Simulations by H. Grote, T. Sen and F. Zimmermann agree that there is a lower limit on the crossing angle at about ± 150 μ*r from parasitic collisions, but no upper limit in the range scanned up to* $\pm ?$ μ*r from triplet errors. Avoid drop in luminosity by working close to lower limit.*

- Can we give a recommendation for the minimum beam separation?

  Answer for crossing angle in collision implied in answer to first question.

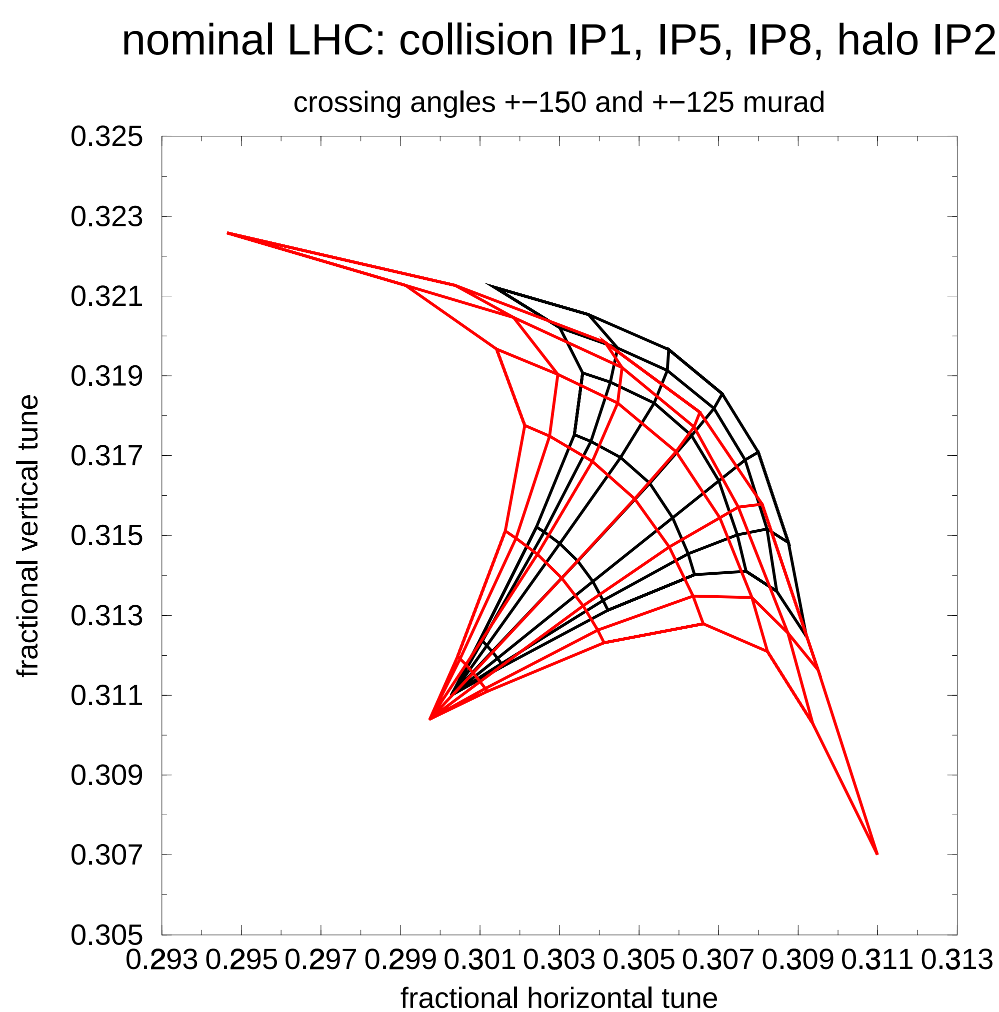
- How can we measure and control the head-on collision of the bunches?

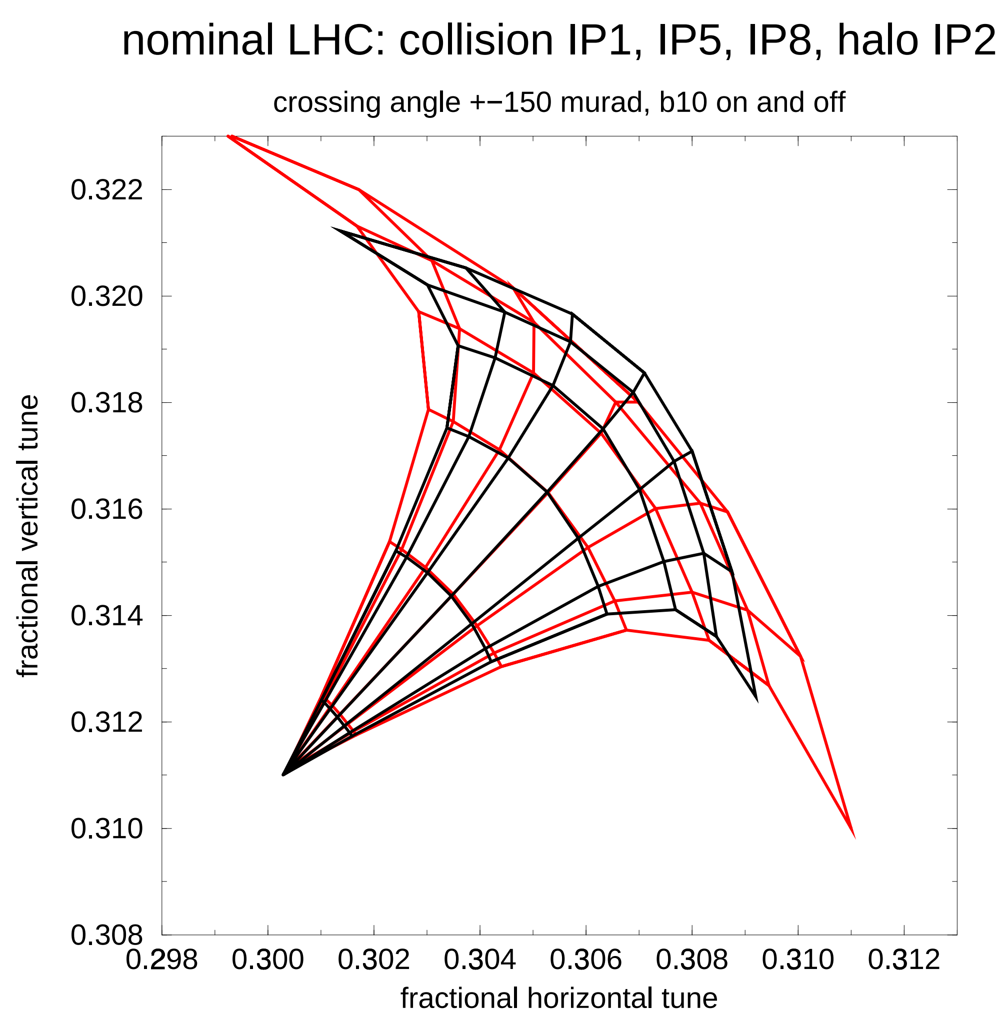
  By measuring luminosity bunch by bunch, beam-beam luminosity scans, beam-beam defelction scans.

  – *Collision point moves along beam while scanning in the plane of crossing, luminosity monitors must cover range*

  – *Beam-beam luminosity scans only at end of fills in Tevatron, rarely done in HERA at* $\xi \leq 0.002$

  – *Workshop on continuous beam-beam scans at* $\sigma/10$ *for LHC this week*


nominal LHC: collision IP1, IP5, IP8, halo IP2
crossing angles +−150 and +−125 murad
fractional vertical tune
0.325
0.323
0.321
0.319
0.317
0.315
0.313
0.311
0.309
0.307
0.305
0.293 0.295 0.297 0.299 0.301 0.303 0.305 0.307 0.309 0.311 0.313
fractional horizontal tune

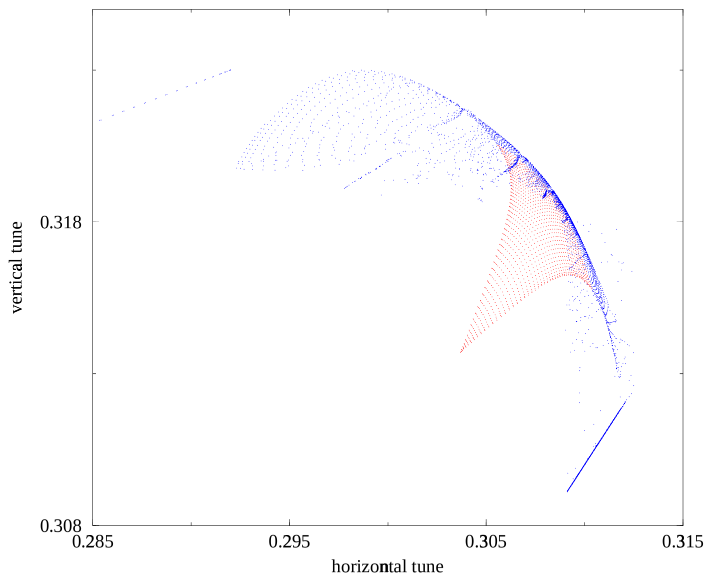

nominal LHC: collision IP1, IP5, IP8, halo IP2
crossing angle +−150 murad, b10 on and off
fractional vertical tune
0.308
0.310
0.312
0.314
0.316
0.318
0.320
0.322
0.298
0.300
0.302
0.304
0.306
0.308
0.310
0.312
fractional horizontal tune

Ingredients of Zimmermann’s Program

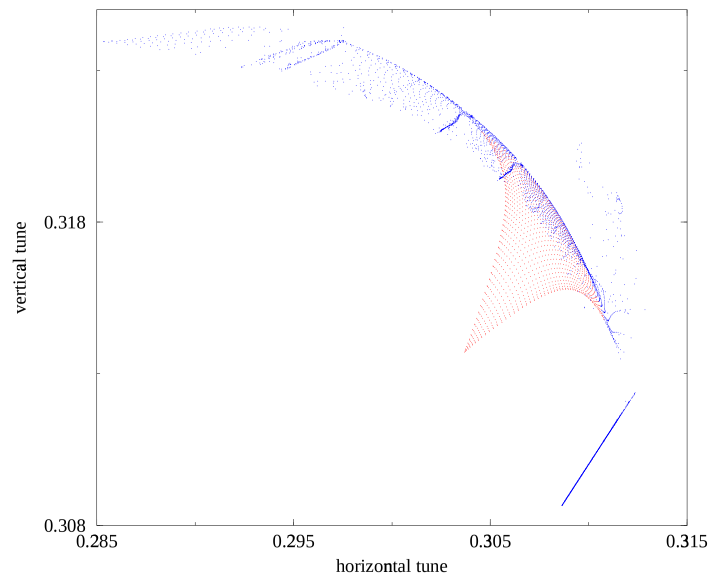
- Simulate in 4D
- Apply 5 kicks near each IP
  - Systematic and random triplet nonlinearities
  - Lumped parasitic collisions of round beams
  - Head-on collisions of round beams
  - Lumped parasitic collisions of round beams
  - Systematic and random triplet nonlinearities
- Tune modulation in linear arcs

Footprints and b_{10} Triplet Errors – Zimmermann

head−on plus long−range collisions

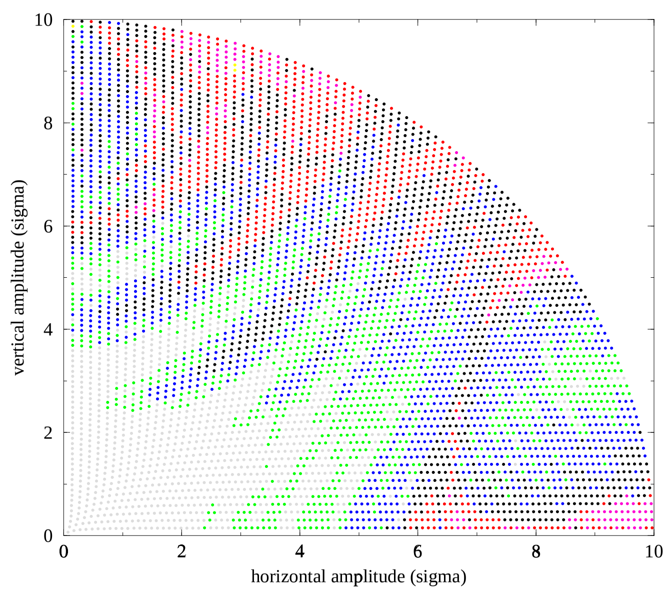


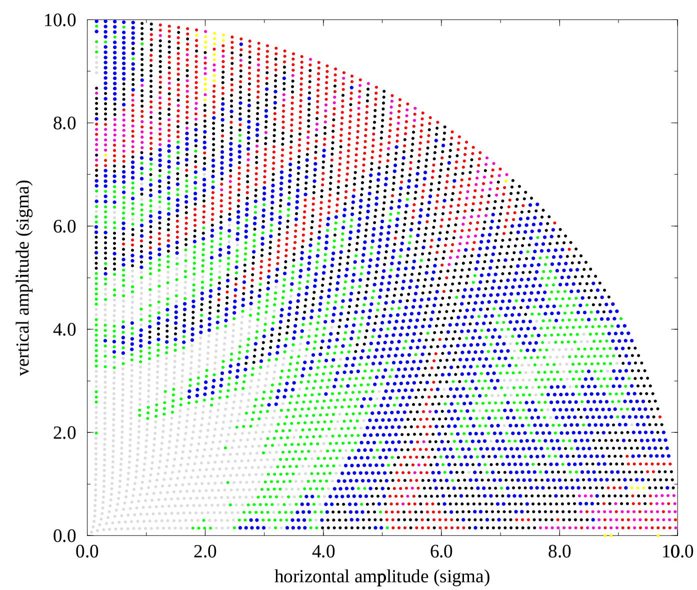
head−on + long−range + FNAL triplet errors



Red $0 \ldots 5\ \sigma$, blue $6 \ldots 10\ \sigma$

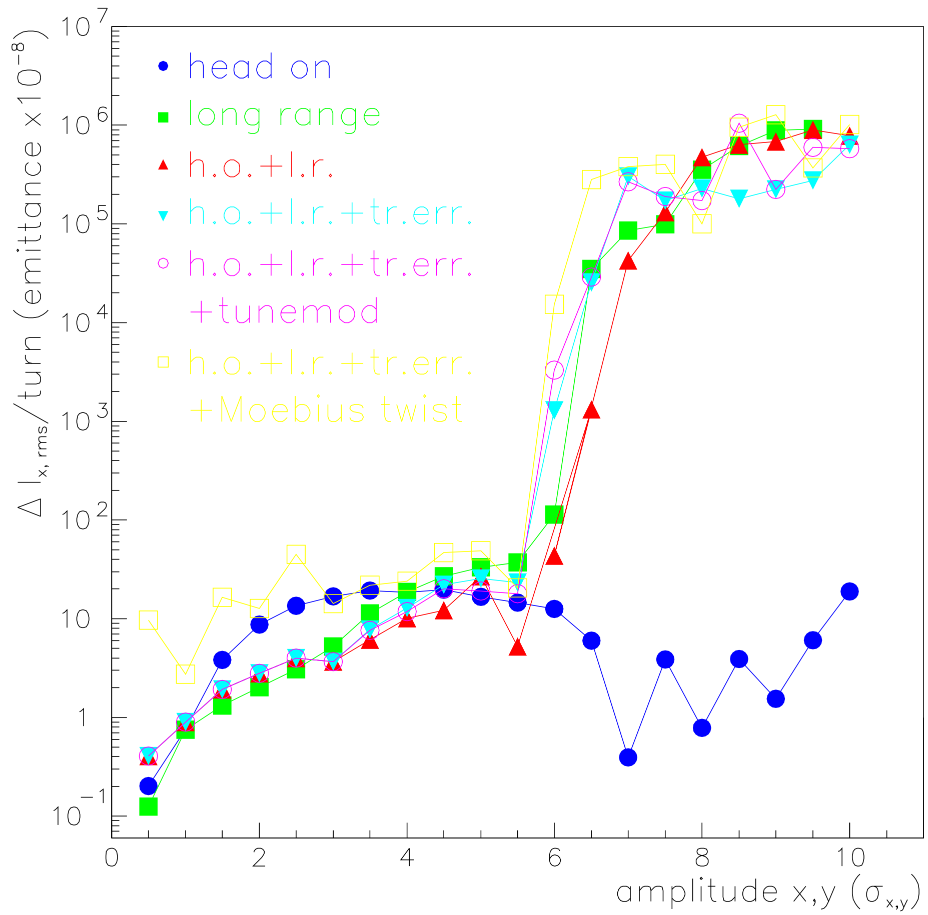
Tune Diffusion and b_{10} Triplet Errors – Zimmermann



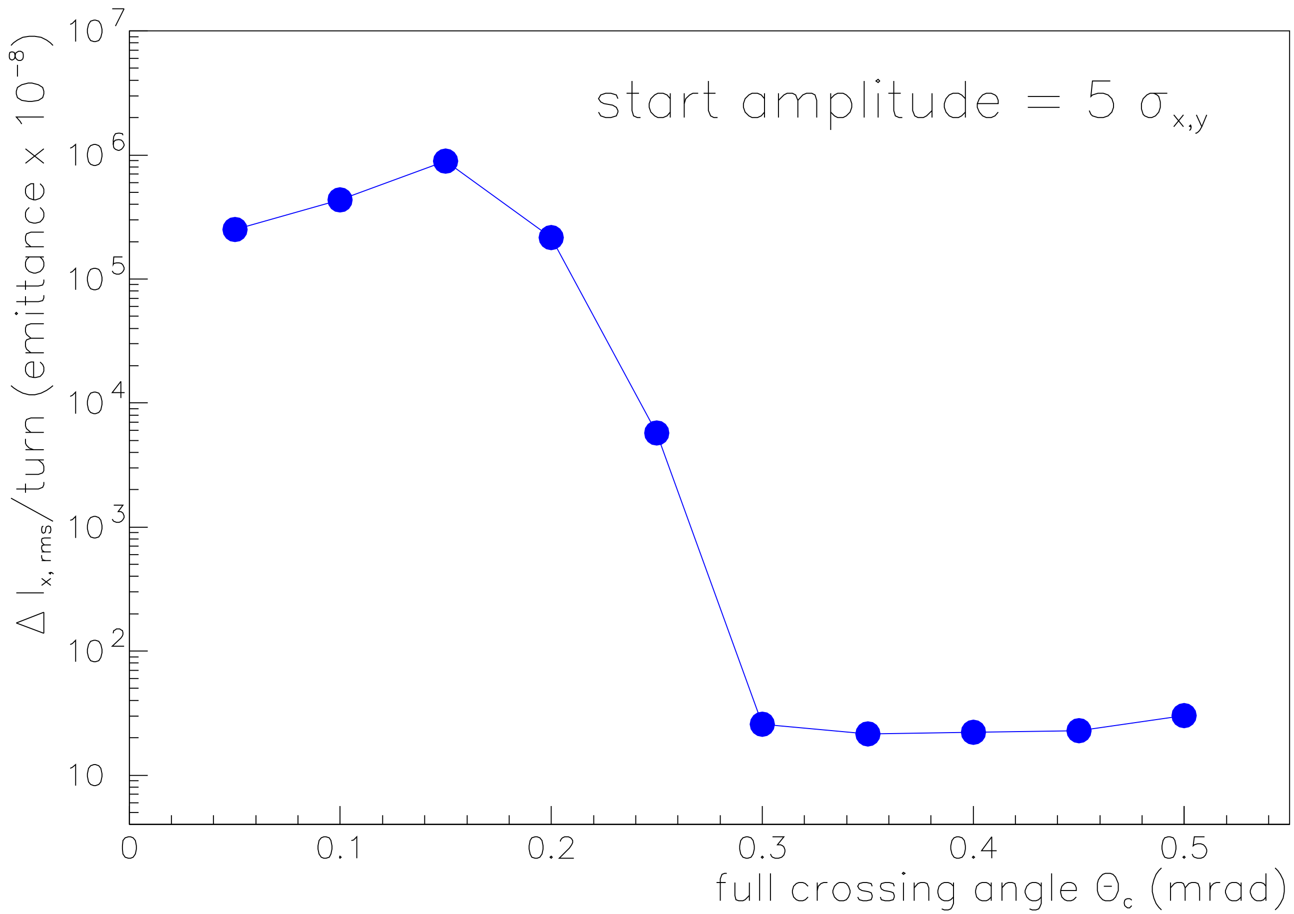


Grey $\log \Delta Q \leq -7$; green $\log \Delta Q \leq -6$; blue $\log \Delta Q \leq -5$; black $\log \Delta Q \leq -4$; red $\log \Delta Q \leq -3$; magenta $\log \Delta Q \leq -2$; yellow $\log \Delta Q \leq -1$

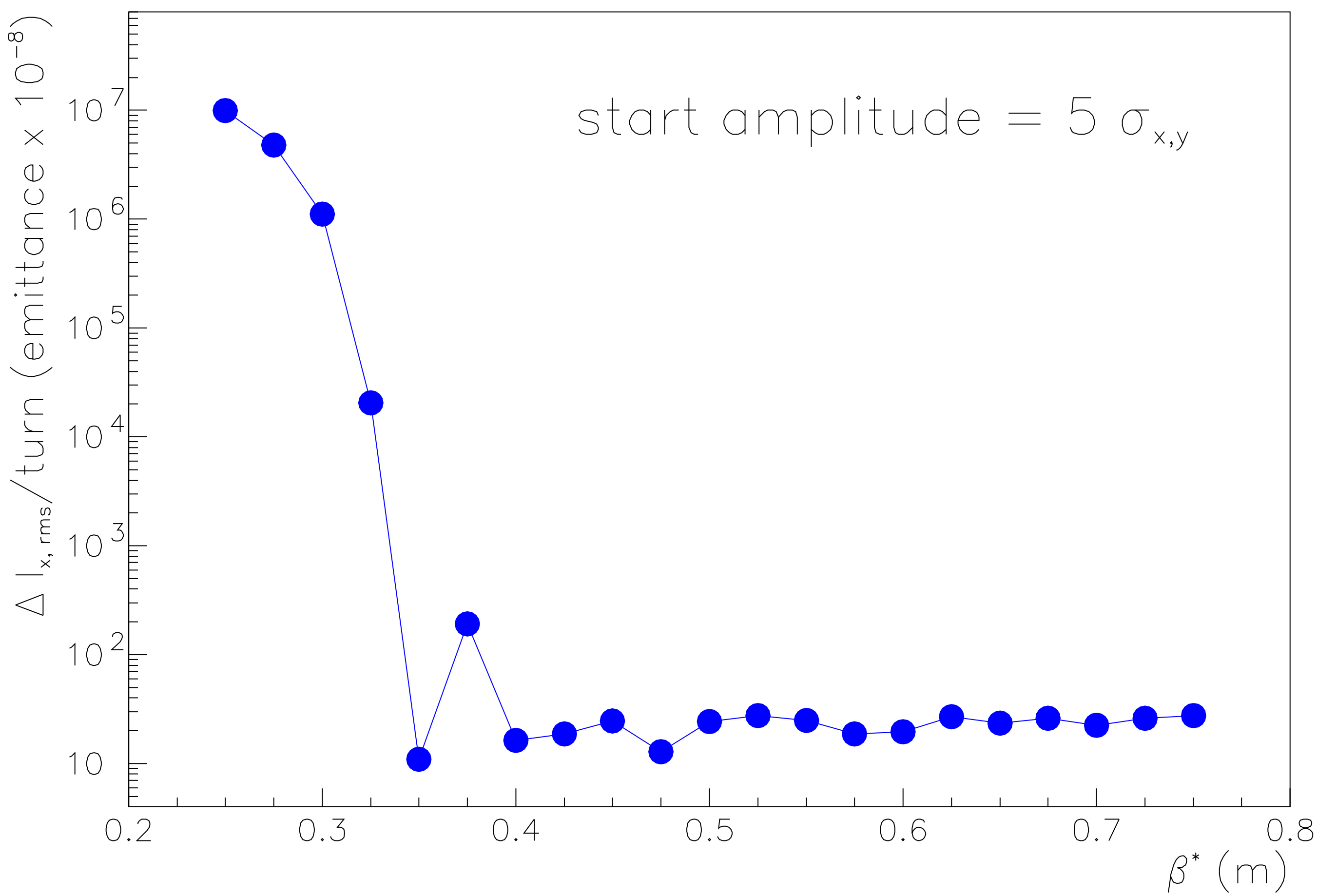
Diffusion vs. Amplitude – Zimmermann



Diffusion vs. Crossing Angle – Zimmermann



Diffusion vs. β^* – Zimmermann



Questions for the Working Group on Weak-Strong Effects II

- Are missing head-on collisions harmful?

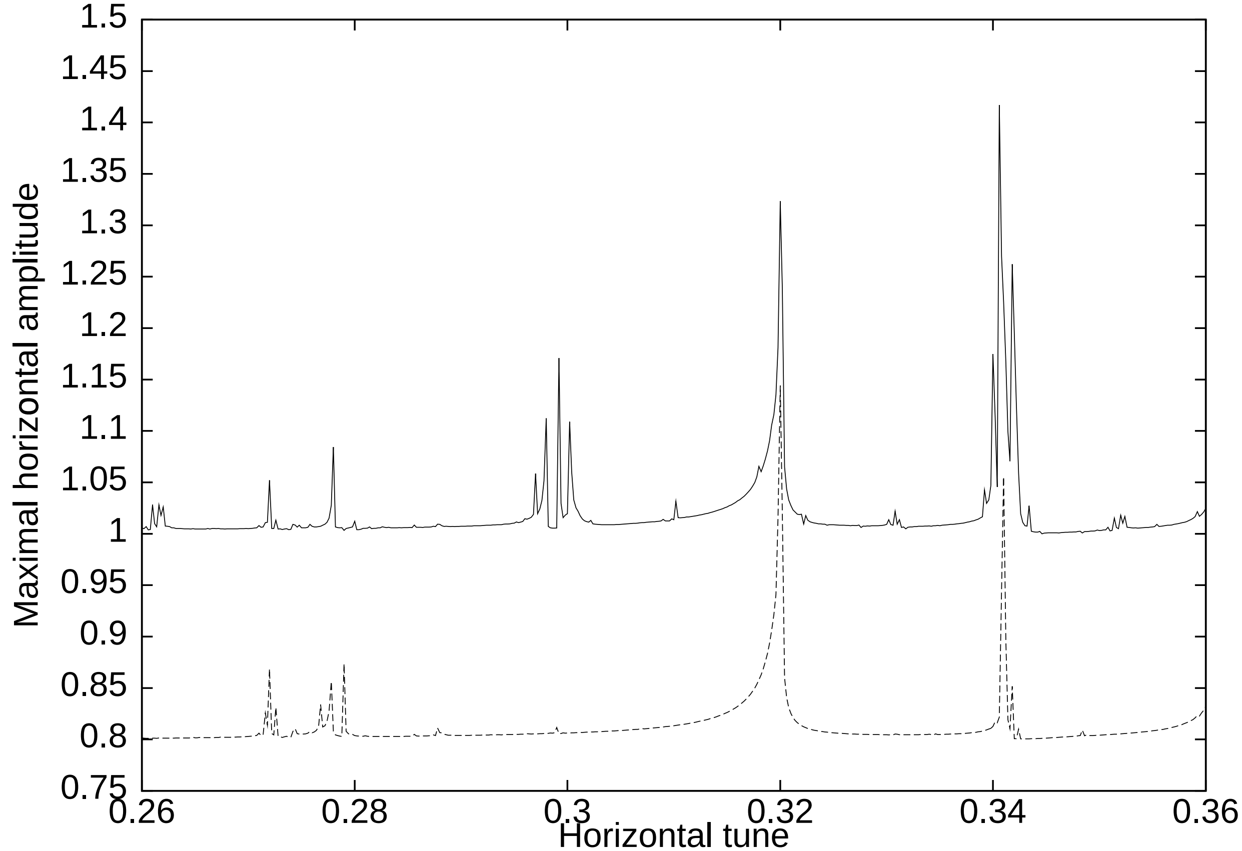
  We hope not. We raised the question whether a bad batch can be dumped and refilled individually, or whether all batches must be dumped and refilled.

- How much dispersion can we expect and tolerate at the crossing points?

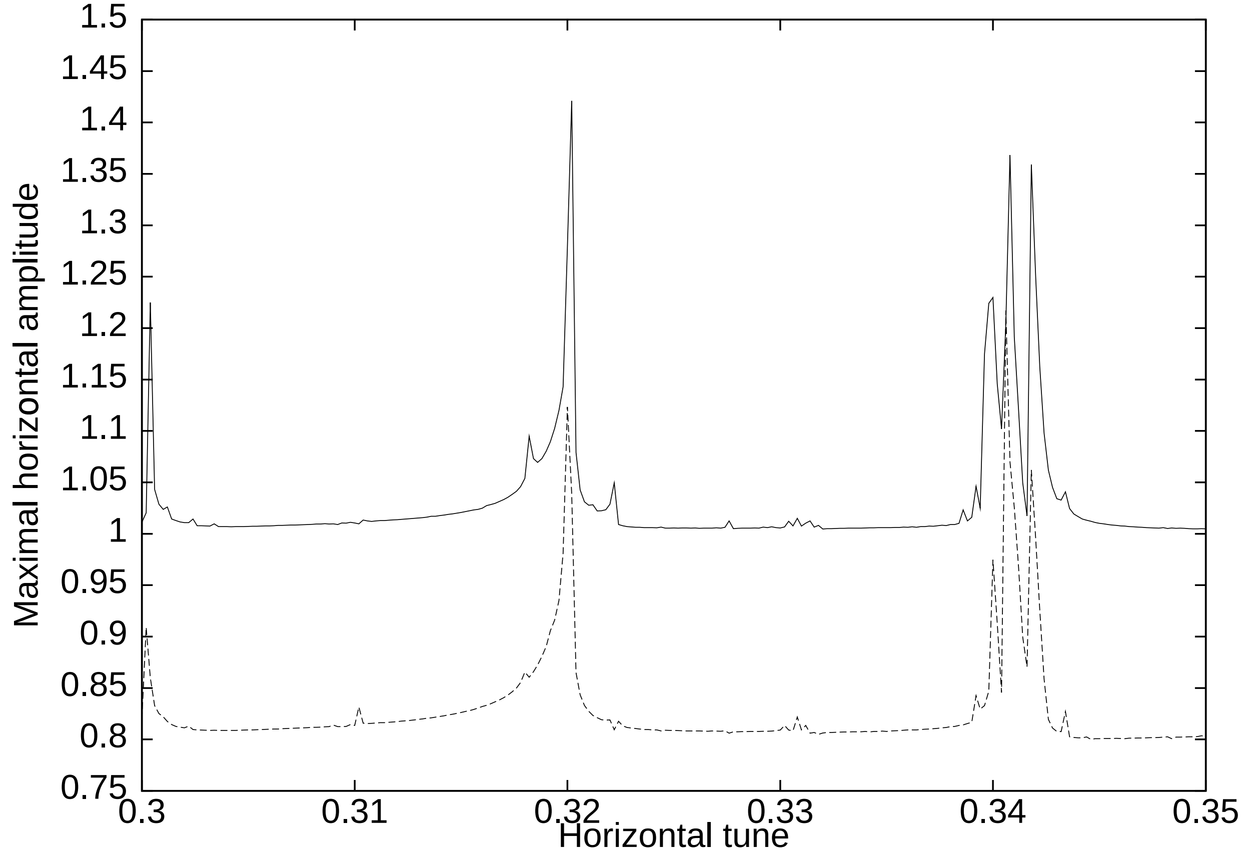
  Given the answer to first question and a knowledge of closed orbit errors, the expected values of dispersion can be computed. Results given by L. Leunissen

  - $|D| \approx 6$ *mm from separation bumps is smaller than* $|D| \approx 25$ *mm from orbit errors*
  - *Find tolerable* D *from analogy with crossing angle for synchro-betaron resonance excitation* $D_y = \alpha C\Theta/4\pi Q_s$
  - *Correct* D *and orbit around LHC simultaneously as now done in LEP*
  - *Side effects of* D *compensation by either launching forced* D *oscillation through arcs or by coupling* D_x *into* D_y *by skew quadrupoles in arcs unknown*

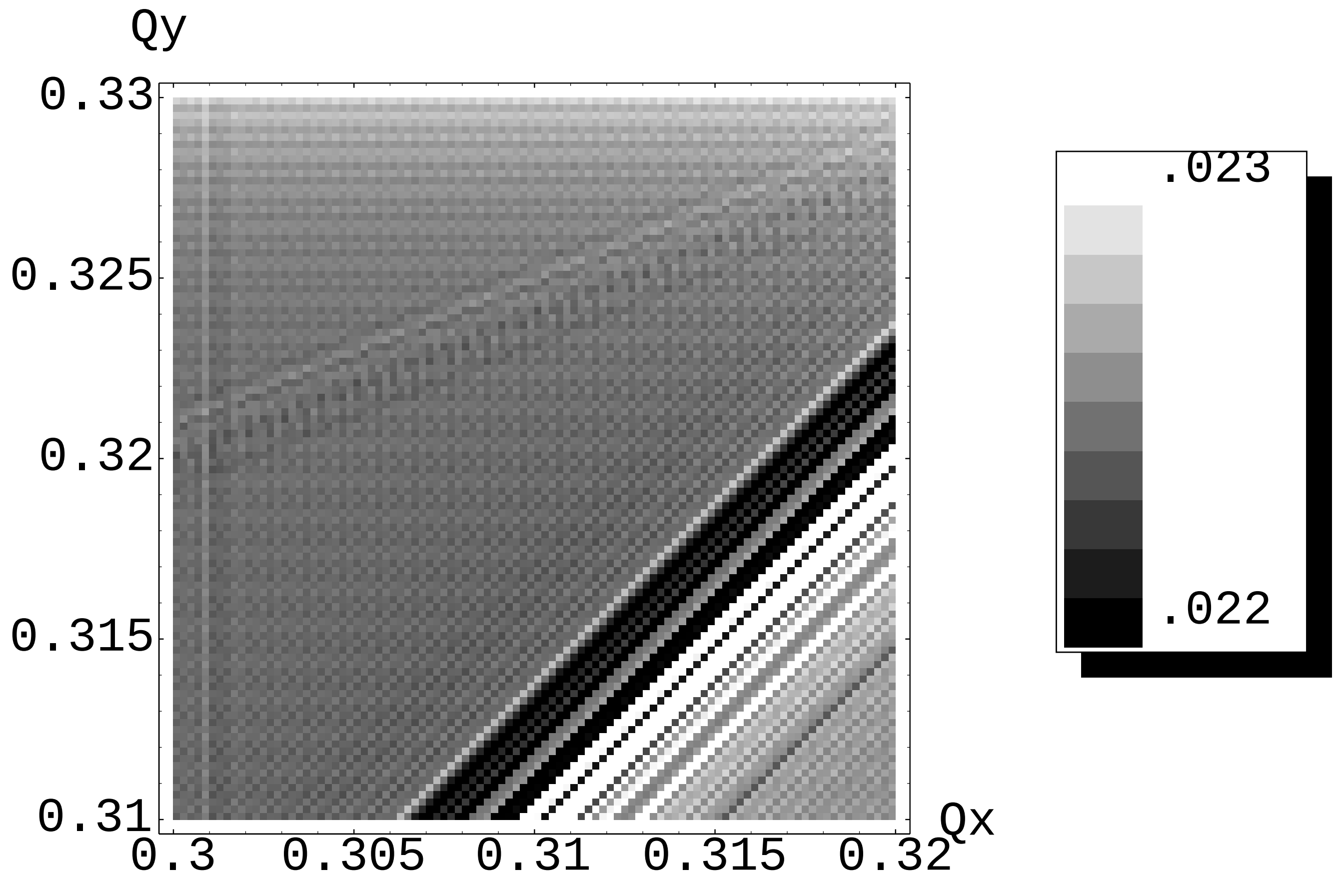
Synchro-Betatron Resonances due to Crossing Angle



Synchro-Betatron Resonances due to Vertical Dispersion

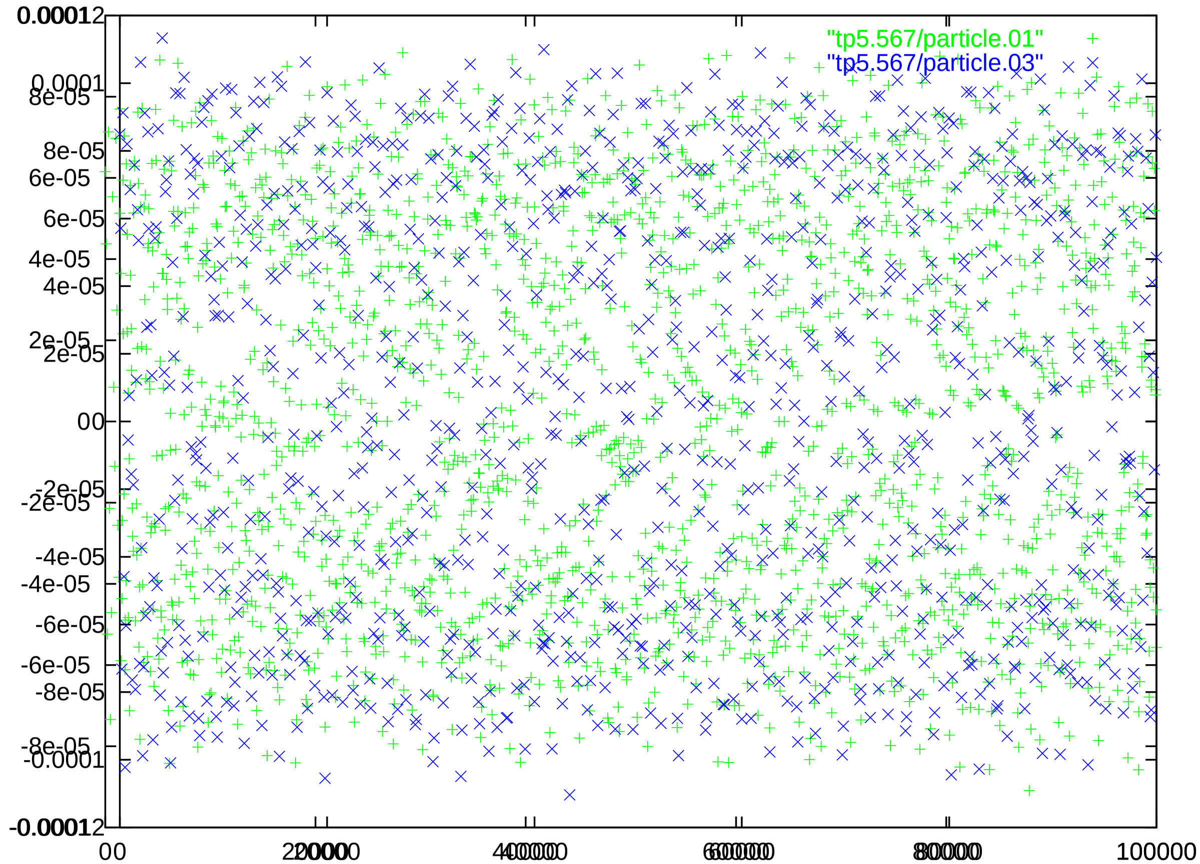


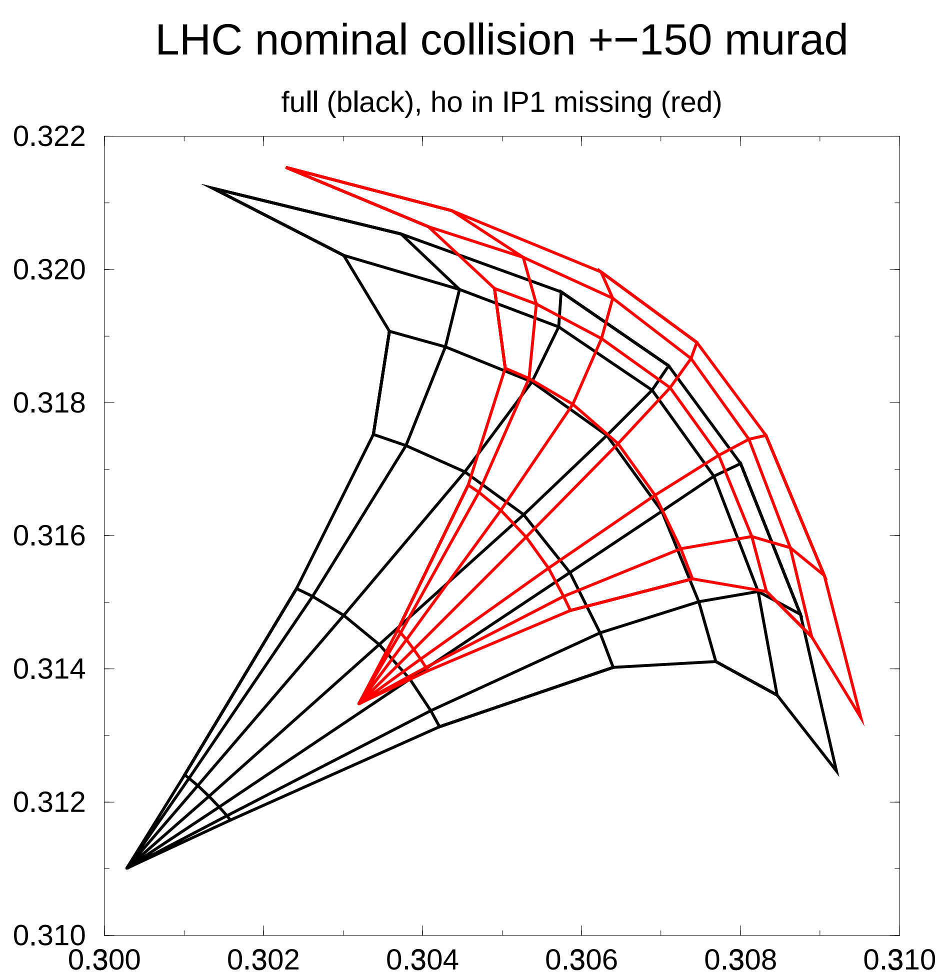
Luminosity Change due to Vertical Dispersion



Several questions arising during the workshop are answered below (at least in part).

- Is there an emittance blow-up beyond 10000 turns? Tracking with:
  - LHC collision at $\pm 150\mu$r, all 4D beam-beam elements present
  - full error table for triplet quadrupoles including systematic and random, KEK at IP1 and IP8, FNAL at IP2 and IP5
  - tracking one particle at 5σ and 7σ each, $\Phi = 45^\circ$, $\Delta_p = 2\sigma$ over 100000 turns
  - resulted in no observable emittance growth (see slide)
- Do the triplet errors allow angles higher than $\pm 150\mu$r? Tracking with the LHC above, particle amplitudes 7σ, showed loss of the particles above $\Phi = 45^\circ$ for $\pm 175\mu$r (and for $\pm 200\mu$r). However, with the fractional tunes swapped, i.e. $Q_x = 63.32$, $Q_y = 59.31$ the particles survived at $\pm 175\mu$r and were only lost at $\pm 200\mu$r above $\Phi = 45^\circ$.
- What effect has a missing head-on collision? The footprint (see slide) shows that at least the tune shift poses no problem.


"tp5.567/particle.01"
"tp5.567/particle.03"
0.00012
0.0001
8e-05
6e-05
4e-05
2e-05
0
-2e-05
-4e-05
-6e-05
-8e-05
-0.0001
-0.00012
0
20000
40000
60000
80000
100000


LHC nominal collision +−150 murad
full (black), ho in IP1 missing (red)
0.322
0.320
0.318
0.316
0.314
0.312
0.310
0.300
0.302
0.304
0.306
0.308
0.310

Conclusions

- Effectes of crossing angle and multi-pole errors in triplet quadrupoles more clear
- Progress in simulation codes that hopefully continues
- Opportunity for interacting with colleagues whom one sees too rarely
- Thanks to all participants in the Working Group on Weak-Strong Beam-Beam Effects for their contribution