HL-LHC Beam-Beam Notes and Plan

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Outline

- Approach
- Tools and methods
- Work plan and issues

Approach

- Evaluate HL-LHC scenarios and options to identify potential limitations from beam-beam
- Criteria / observables
  - Dynamical aperture > 6(7?)σ
    - Nominal LHC design based on 7σ (real)
    - Collimators at 6σ (3.75μm) -> 7.3σ ('real' 2.5μm)
  - Simulated emittance growth / luminosity life
    - Large DA is necessary but not sufficient for successful machine operation
  - Bunch-by-bunch (PACMAN) effects
    - Orbit, Q, Q'
    - Same as nominal bunches: DA & Lumi lifetime

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Tools

- Lifetrac
  - ✓ Full element-by-element lattice
  - ✓ 6D weak-strong beam-beam
  - ✓ Crab Cavity
  - ✓ Wire compensator
  - ✓ FMA, DA, multi-particle

- SixTrack
  - ✓ Full element-by-element lattice
  - weak-strong beam-beam
    - ✓ 4D
    - ? 6D
  - ? Crab Cavity
  - ? Wire compensator
  - DA
  - ? FMA

Tools

- Bunch-by-bunch (PACMAN) effects
  - TRAIN

Lifetrac/SixTrack without beam-beam

slhcv3.1b, 7 TeV, β^*=10 cm, beam-beam off

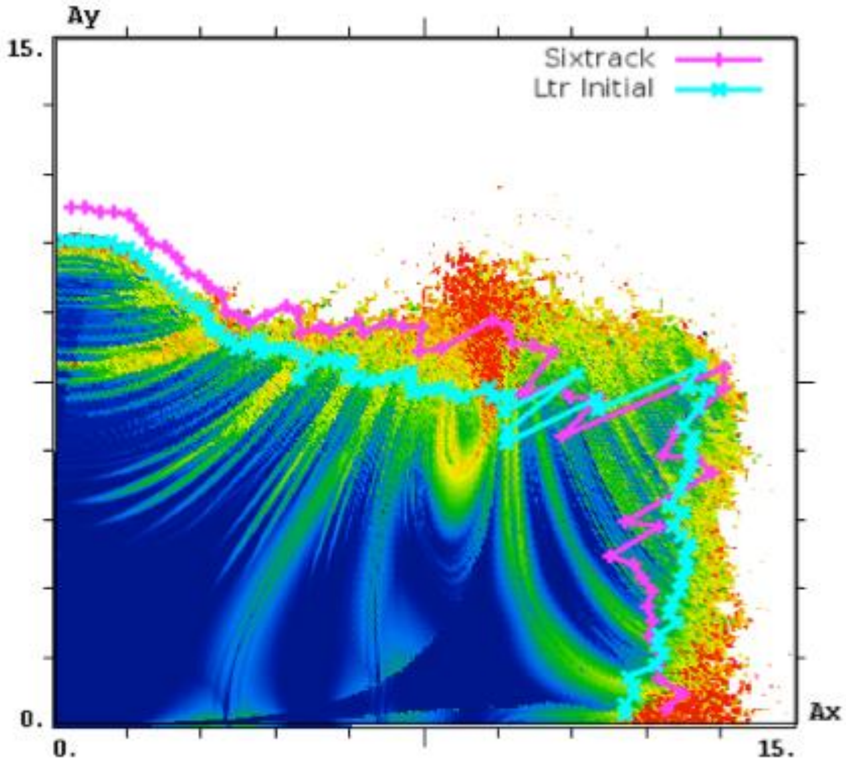
- emittance 3.75 μm, Δp/p=2.7E-4, 10^5 turns DA

- Sixtrack data provided by Task 2.3 M.Giovannozzi
  - 60 seeds
  - 59 angles
  - 30 particle pairs for 2 sigma intervals

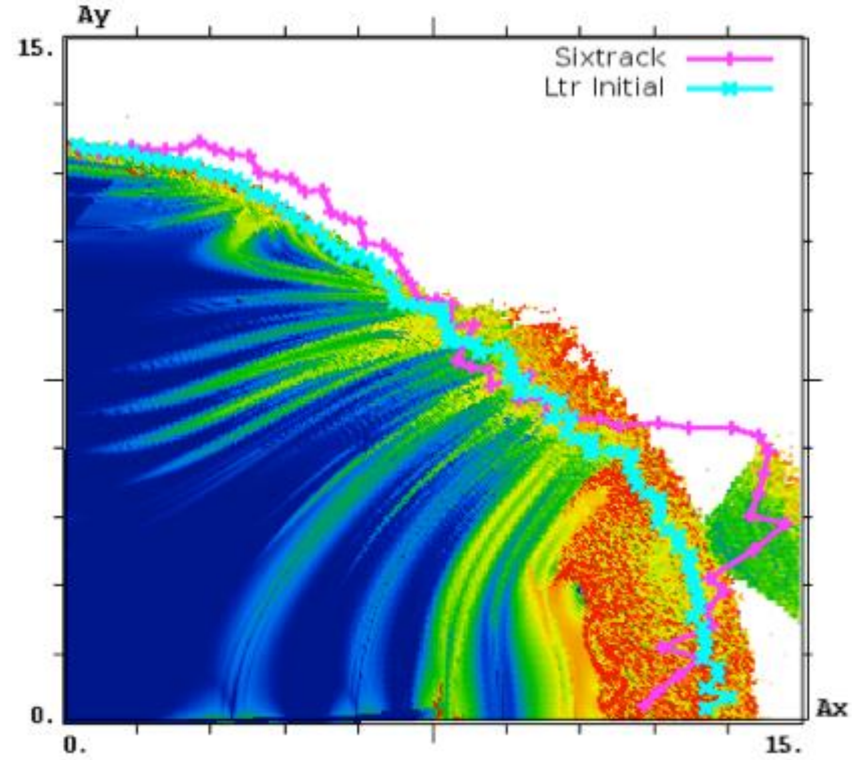
- Lifetrac
  - Same seeds
  - 90 angles
  - 22 particle pairs for 2 sigma intervals

Lifetrac/SixTrack without beam-beam 10^5 turns DA: very good agreement

Seed #1



Seed #2



Agreement based on 10 seed comparison better than 5%

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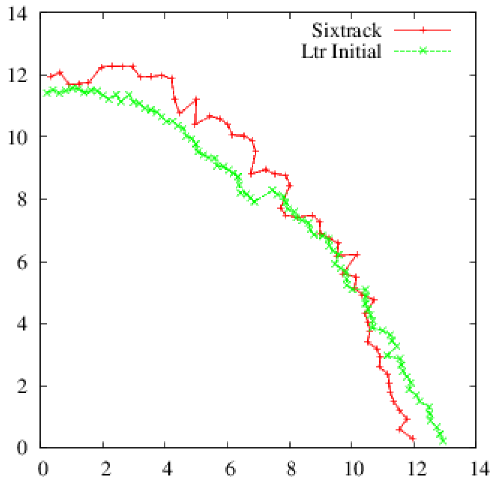
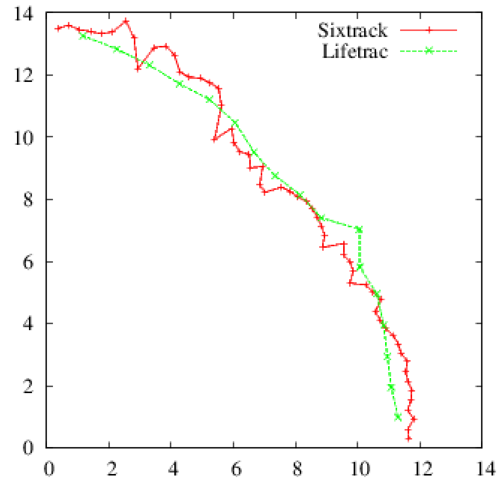
Lifetrac/SixTrack without beam-beam 10^5 turns DA: very good agreement

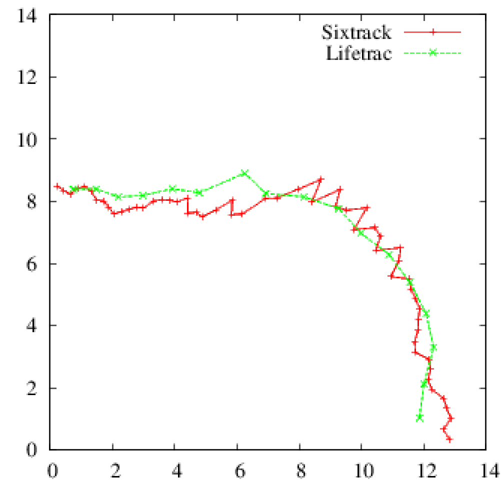
seed #3



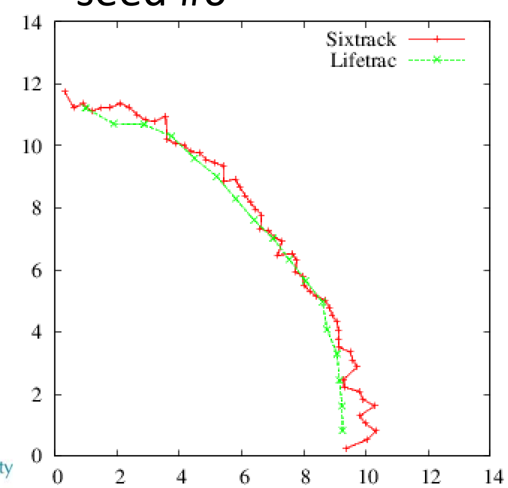
seed #4



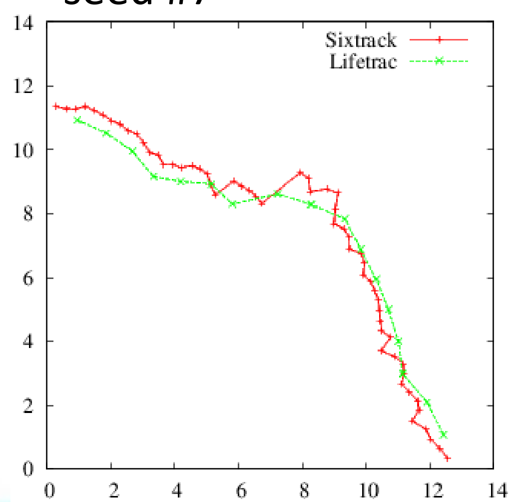
seed #5



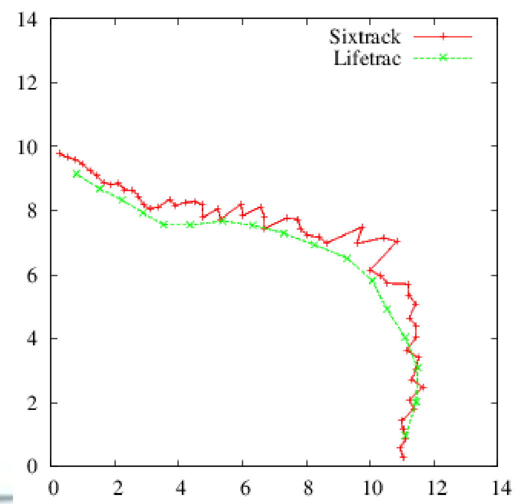
seed #6



seed #7



seed #8



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Lifetrac/SixTrack with beam-beam

slhcv3.1b, 7 TeV, multipole errors off

- emittance 2.5 μm, $\Delta p/p$=2.7E-4, 10^6 turns DA

- Sixtrack
  - 17 angles
  - 30 particle pairs for 2 sigma intervals

- Lifetrac
  - 17 angles
  - 22 particle pairs for 2 sigma intervals
  - averaging over initial betatron phase

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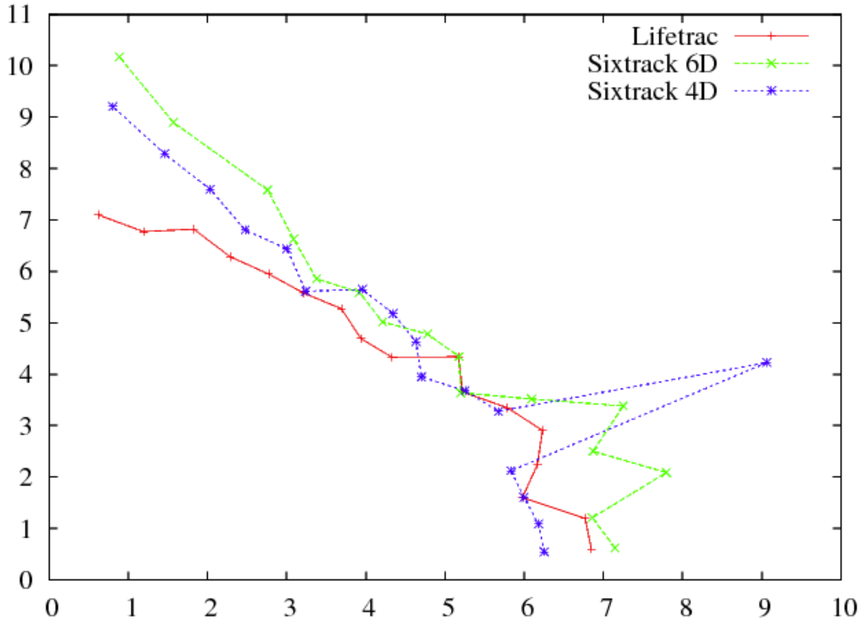
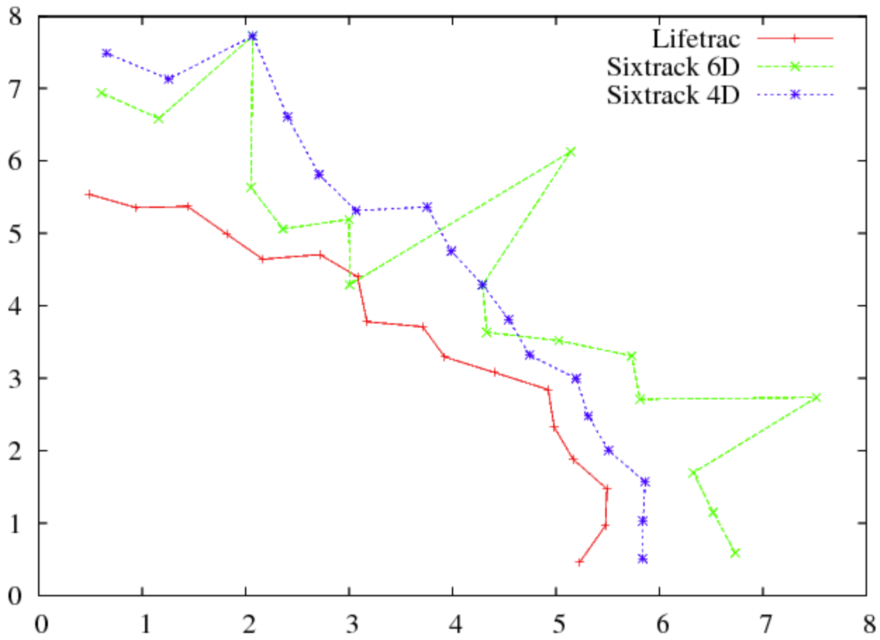
Lifetrac/SixTrack with beam-beam

10^6 turns DA: β^*=15cm, 590 μrad

Np=2.2E11



Np=2.8E11

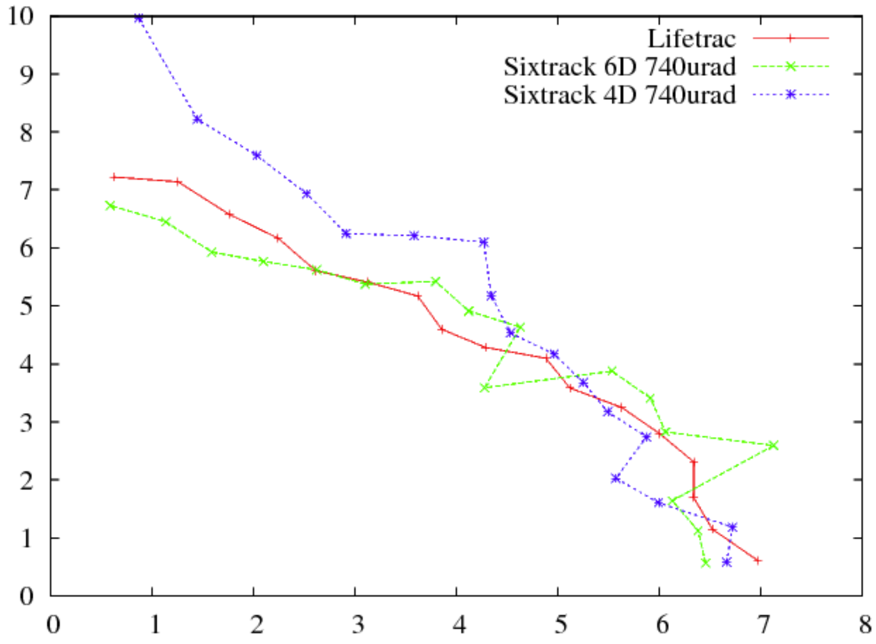


TODO: repeat with Lifetrac without phase averaging, to establish that the difference is not from different DA definition in two codes

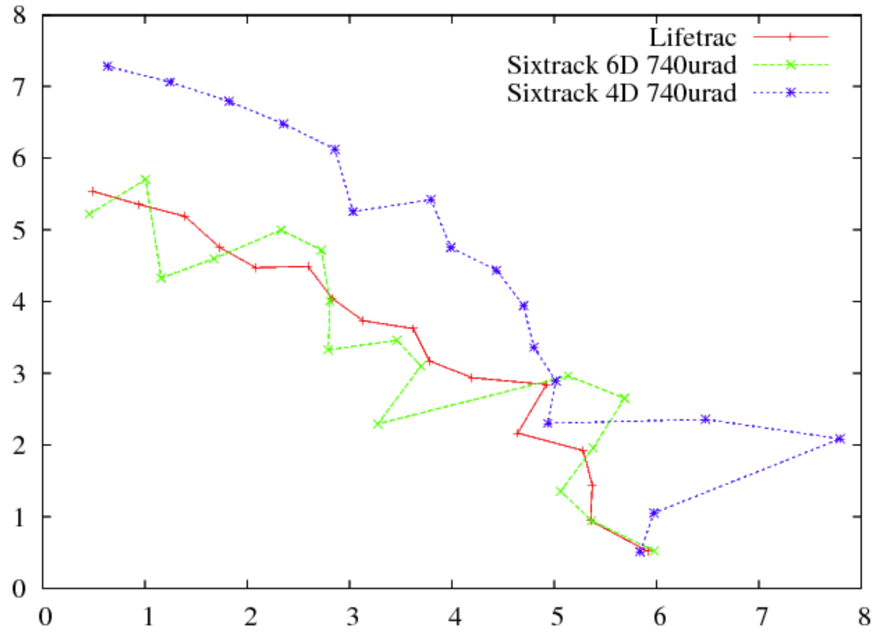
Lifetrac/SixTrack with beam-beam

10^6 turns DA: β^*=10cm, 720 μrad

Np=2.2E11



Np=2.8E11



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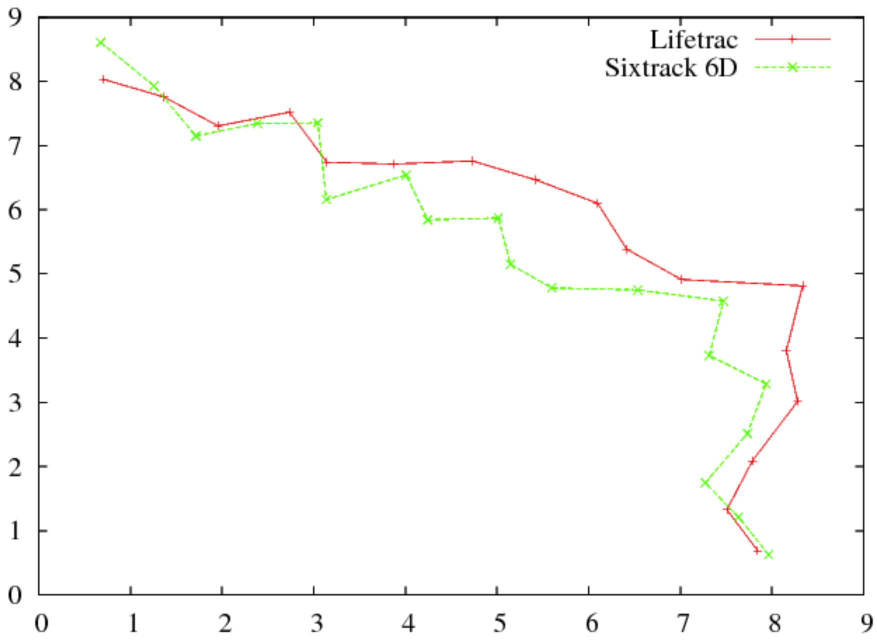
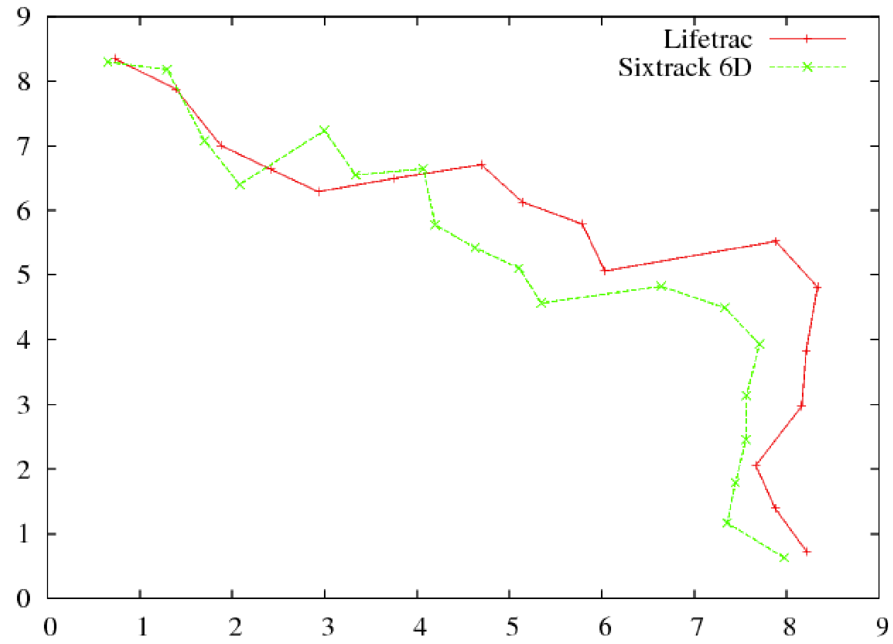
Lifetrac/SixTrack with beam-beam

10^5 turns DA: Np=2.2E11, δ=0

β^*=15cm, 590 μrad



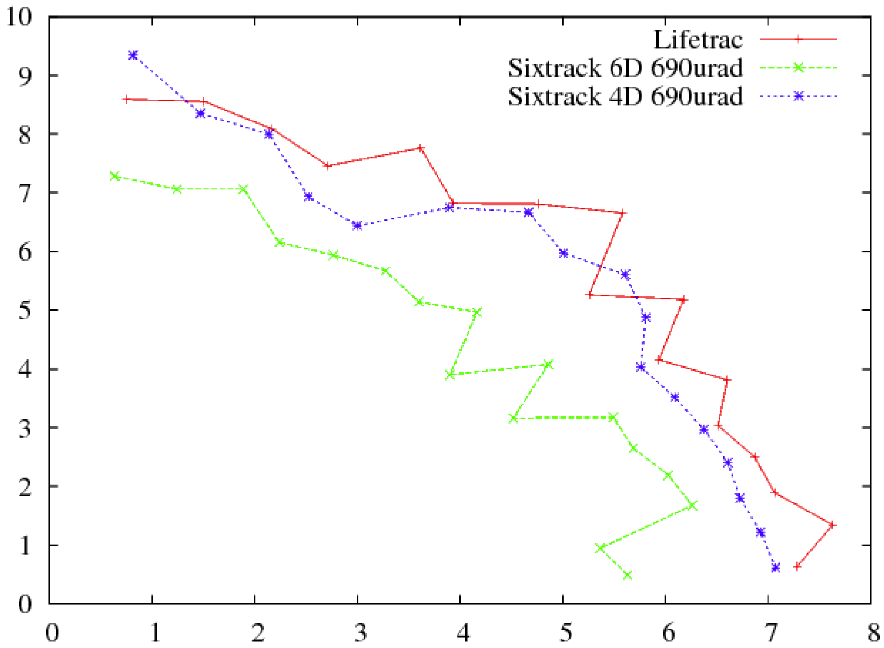
β^*=10cm, 720 μrad



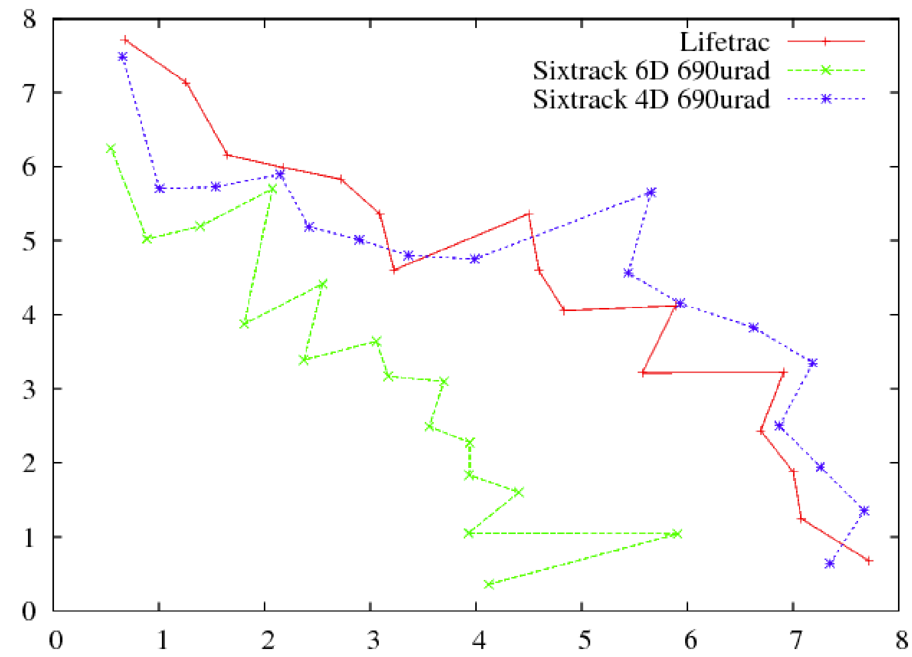
Lifetrac/SixTrack with beam-beam

10^6 turns DA: β^*=5/20cm, 670 μrad

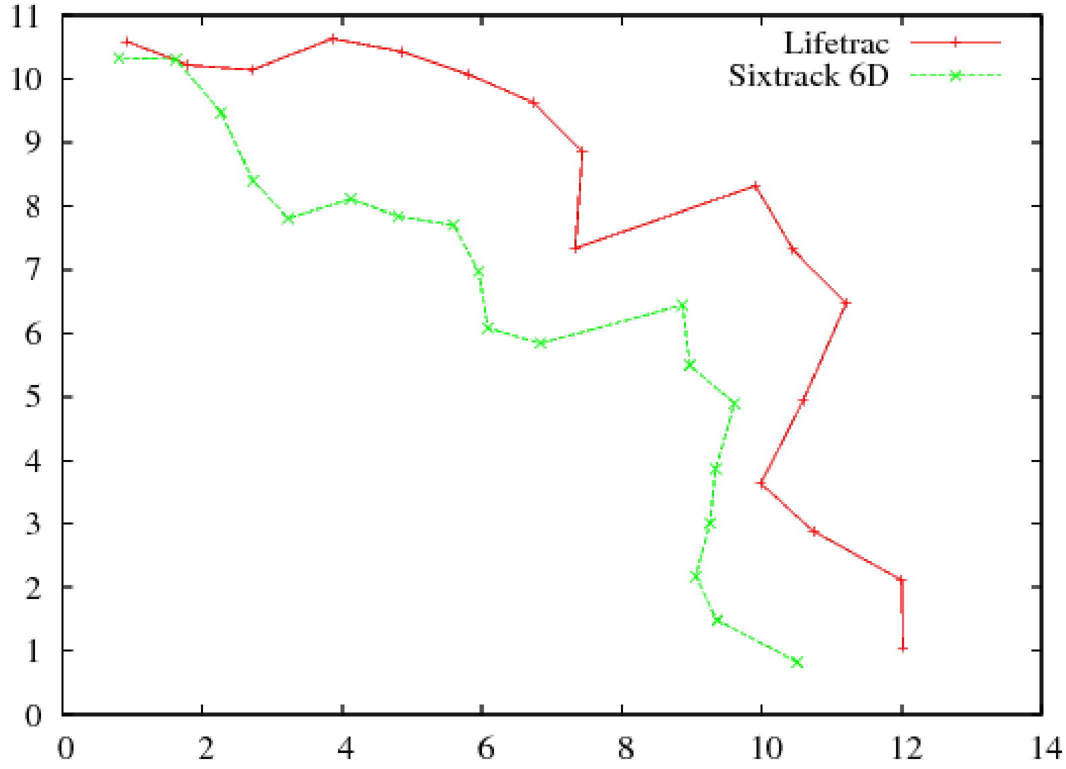
Np=2.0E11



Np=2.8E11



10^5 turns DA: Lifetrac vs. Sixtrack
β^*=5/20cm, 670 μrad, Np=2.2E11, δ=0



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Lifetrac/SixTrack with beam-beam

- Need to understand the in origin of discrepancy between Ltr./Sx.4D/Sx.6D
- Observation: difference for particles with $\Delta p/p=0$ is small – synchrobetatron effects?
- TODO
  - More elaborate benchmarking: turn off long-range, etc.

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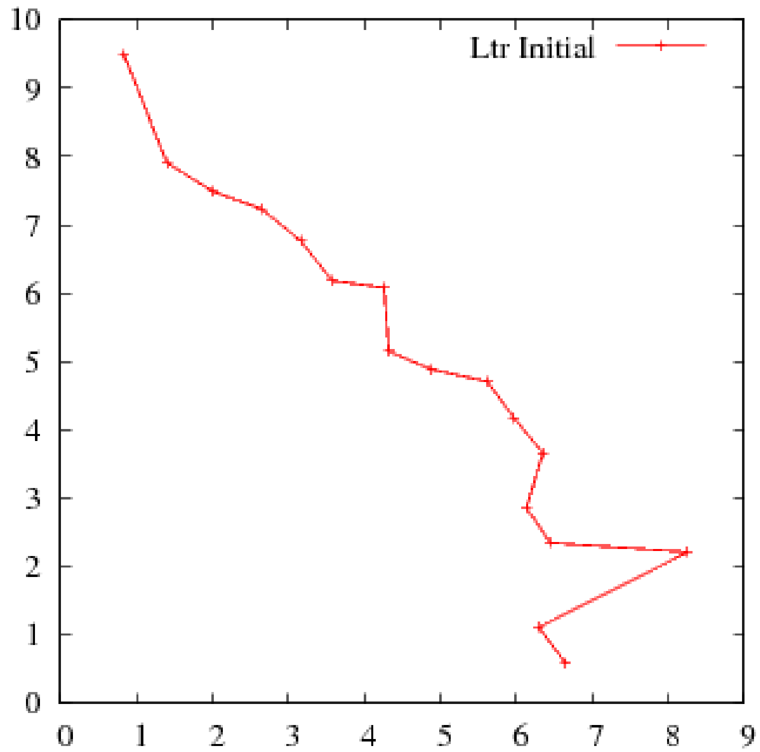
Importance of multiparticle simulation:
Nominal LHC: DA

10^6 turns DA: β^*=55cm, 285 μrad, Np=1.12E11

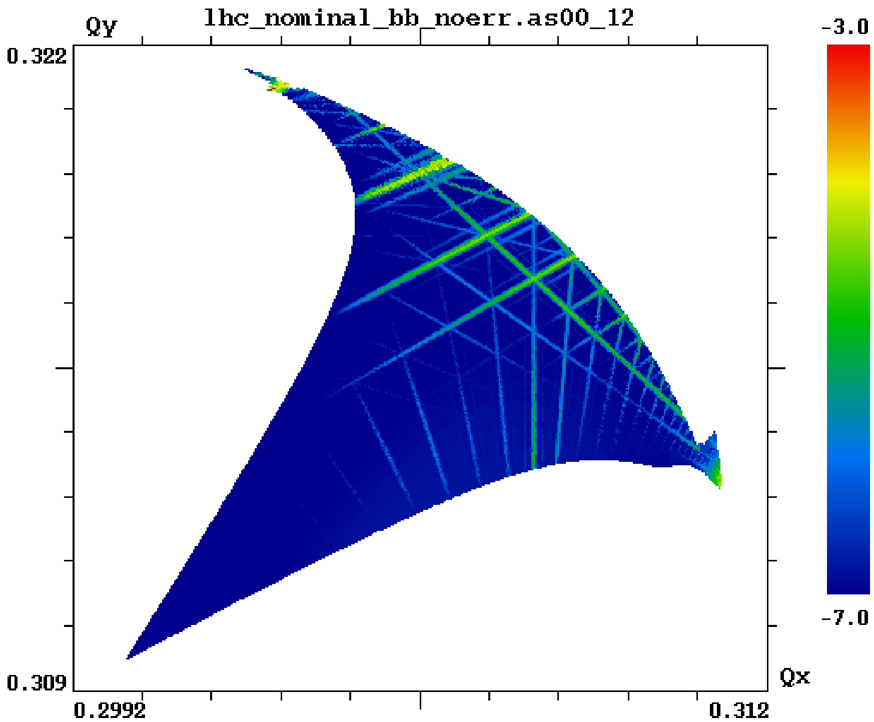
DA>7σ - consistent with LHC design

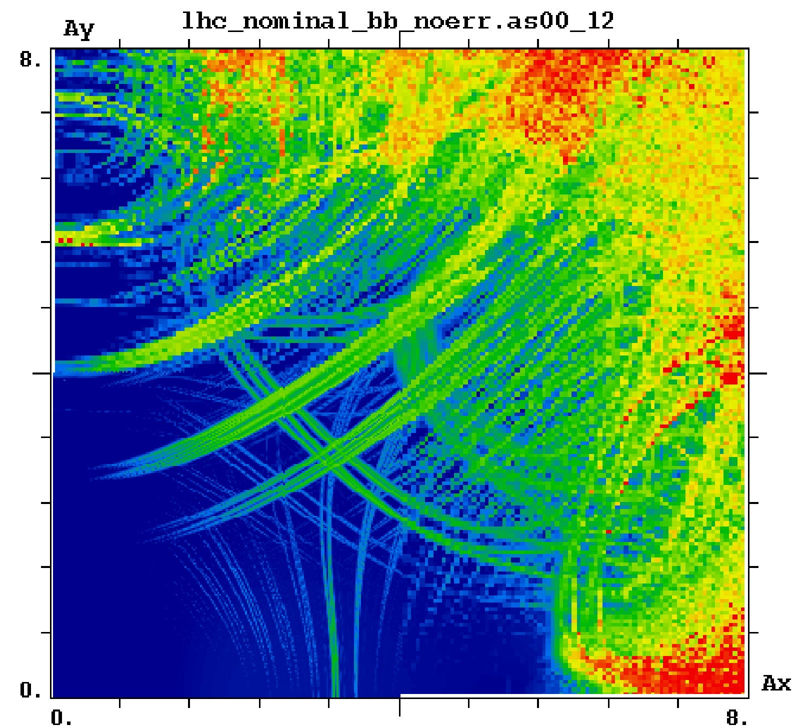


Importance of multiparticle simulation:

Nominal LHC: FMA

2^{12} turns FMA: β*=55cm, 285 μrad, Np=1.12E11, δ=0





Tune spread is ~0.01, no strong resonances. No beam-beam?

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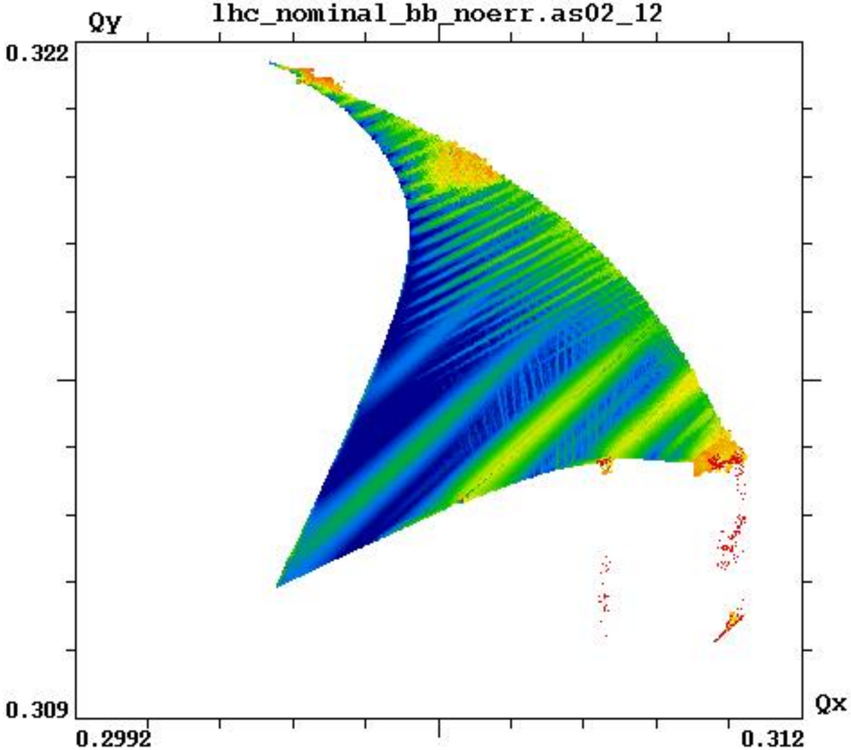
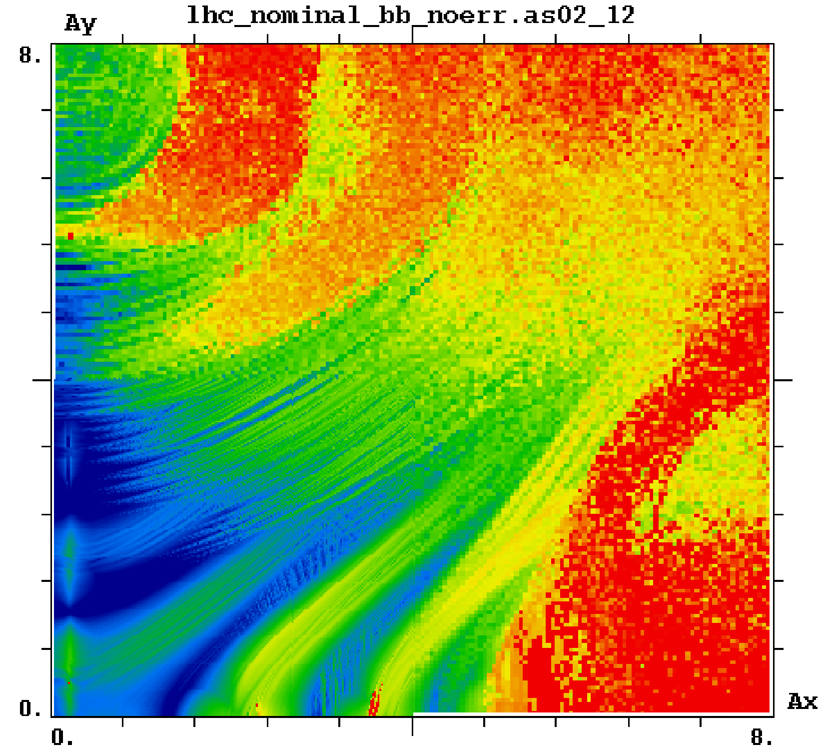
Importance of multiparticle simulation:
Nominal LHC: FMA

2^{12} turns FMA: β^*=55cm, 285 μrad, Np=1.12E11, δ=2σ



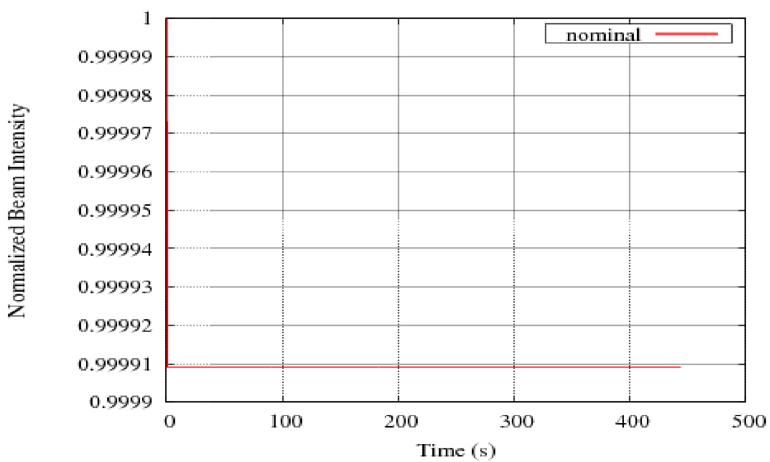


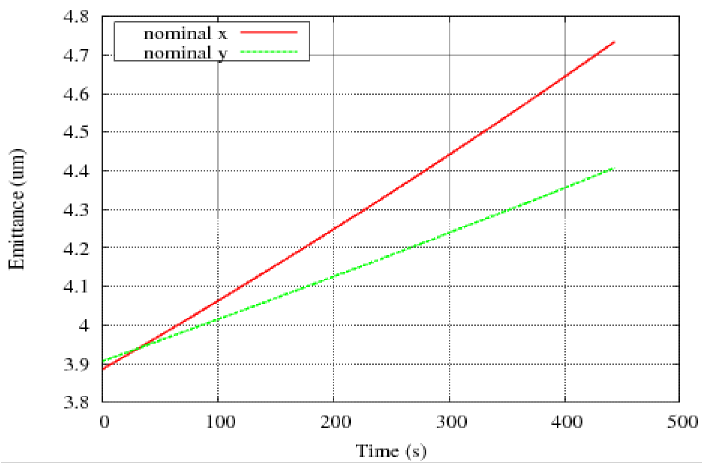
FMA for off-momentum particles shows significant synchrobetatron resonances!

Importance of multiparticle simulation:

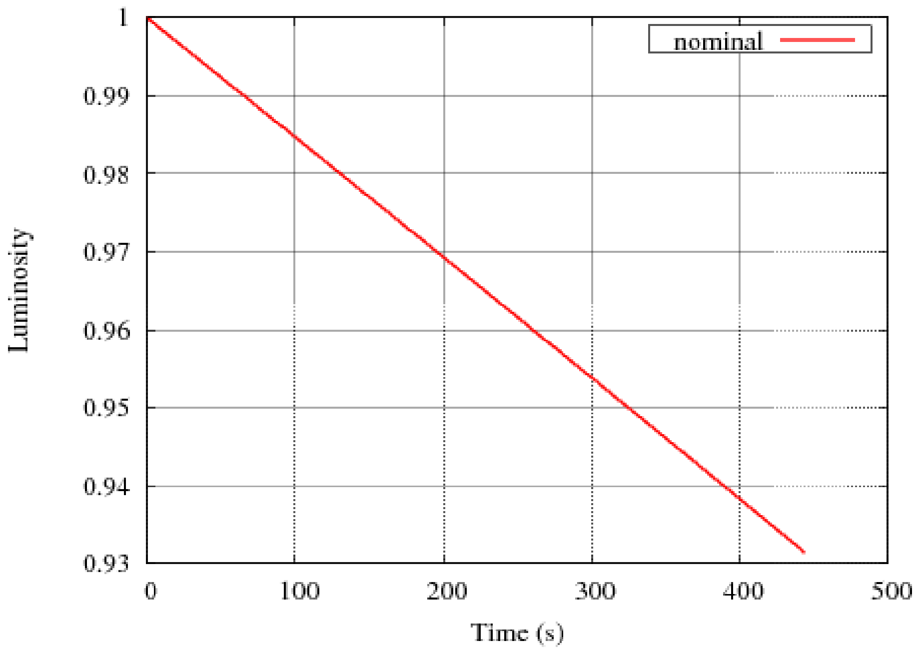
Nominal LHC: multiparticle

5 10^6 turns, 10,000 particles: β^*=55cm, 285 μrad, Np=1.12E11





τ_L=1.8 hours !!!*



* probably overestimated by a factor 2 due to constant strong beam

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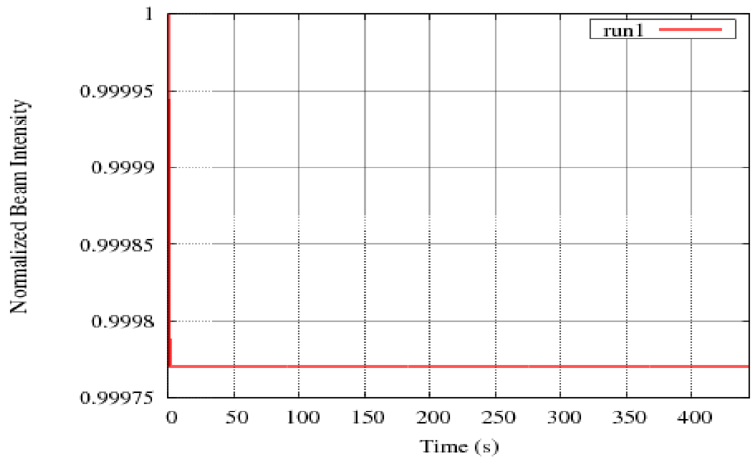
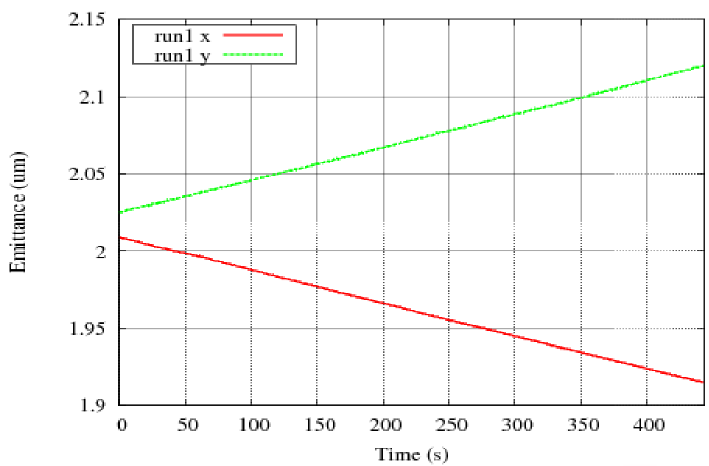
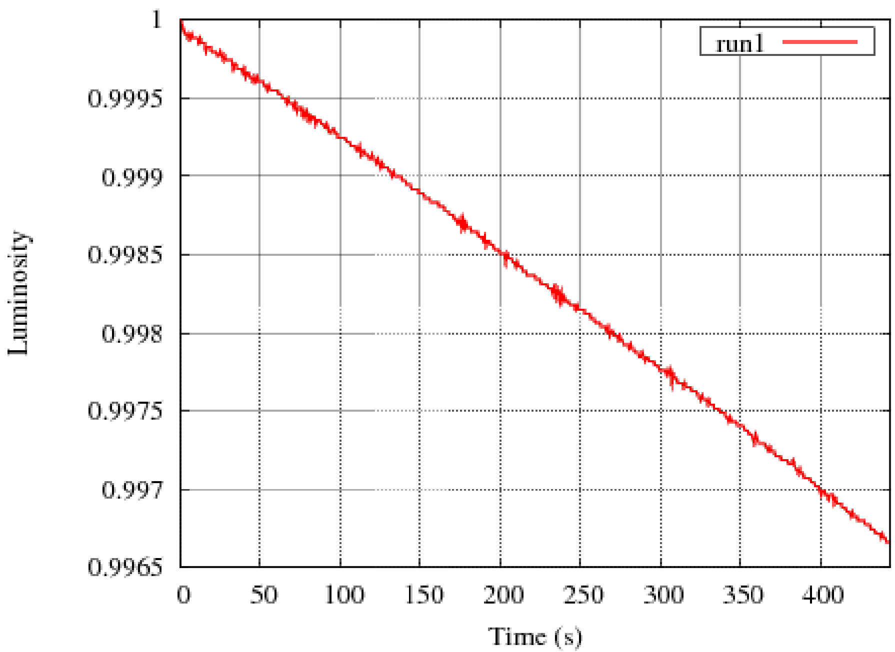
Multiparticle simulation:
2012 LHC

5 10^6 turns, 10,000 particles: β^*=60cm, 285 μrad, Np=1.6E11, 50 ns spacing, 4TeV





τ_L=36 hours - OK*



* probably underestimated by a factor 2 due to constant strong beam

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Work plan

- Code consolidation
- Old Baseline (β*=15cm, θ=590μrad, leveling with CC)
- Baseline HL-LHC (round optics, θ=590μrad, CC fully on, leveling with β*)
- Plan B (Flat optics, BBLR, leveling with β*)
- Plan B with Crab Kiss

Work plan: code consolidation / development

- SixTrack/Lifetrac
  - create simplified test case: turn off all long-range, perform intensity scan
  - verify CC in SixTrack
  - verify BB wire in SixTrack
- Simulations vs. Run 1 data
  - collect data for a number of “good” high luminosity fills in 2012
    - luminosity, intensity, bunch length, transverse emittances for b1 & b2
  - calculate *non-luminous* luminosity, intensity and emittance lifetimes
    - subtract IBS, gas lifetimes from actual data
  - simulate DA and luminosity evolution for these fills
- bunch-by-bunch orbits
  - fix the code

Work plan: Old Baseline

- Simulate: DA, Luminosity lifetime
- Break points along fill

1 Np=2.2E11, crab off

✓ DA ok

✓ Lumi lifetime <u>NOT OK : 12.5 hours</u>

2 Np=??, crab=50%

? DA

? Lumi lifetime

3 Np=0.95E11, crab=100%

? DA

? Lumi lifetime

Work plan: Baseline

- Simulate: DA, Luminosity lifetime
- Break points along fill

1 Np=2.2E11, β^*=70m

✓ DA ok with β^*=40m

✓ Lumi lifetime ok

2 Np=??, β^*=?

? DA

? Lumi lifetime

3 Np=0.95E11, β^*=15cm

✓ DA ok

? Lumi lifetime

Work plan: Plan B

- So far for this option we only established the minimum required crossing angle without bb wire to achieve DA
- Need to implement and optimize bb wire
- Leveling with β*, keeping constant β1/β2 ratio
- Need a number of break-points along fill

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Work plan: Plan B with Crab Kiss

- First results were obtained with CK in crossing plane
  - Need to implement CC in parallel sep. plane in flat optics
- Leveling with β^*, keeping constant $\beta 1/\beta 2$ ratio or CK?
- Need a number of break-points along fill

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