SixTrack
&
Crab Cavities

A. Marsili
R. Bruce, S. Redaelli, B. Yee Rendon

Introduction

- Adding Crab Cavities (CC) to SixTrack simulations
- Starting point: CC failures studies by B. Yee Rendon
  - HiLumi SLHC v3.1b with 3 CC on each side of the IPs (baseline is now 4)
  - Dynamic CC voltage: free turns, ramp up, plateau, ramp down
    => Not used. Here CC are on or off, no variation, no failure.
- Check of emittance growth: standard bunch over 1000 turns
- Evolution of halo distribution over 1000 turns
- p-p collision debris with CC on or off, and different TCL configurations.

Outline

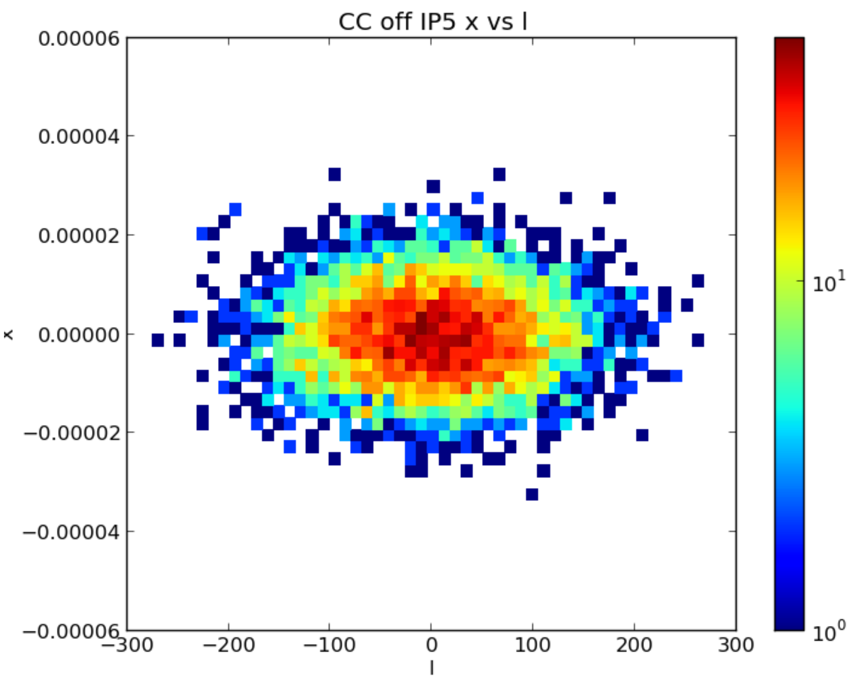
- Introduction
- Changes in SixTrack code
- Single-pass effects of the Crab Cavities
  - Phase advance
  - Bunch distributions
- Multiturn effects of the Crab Cavities
  - Emittance
  - Halo distribution over 1000 turns
- Loss simulations
  - Debris inputs
  - Debris simulations

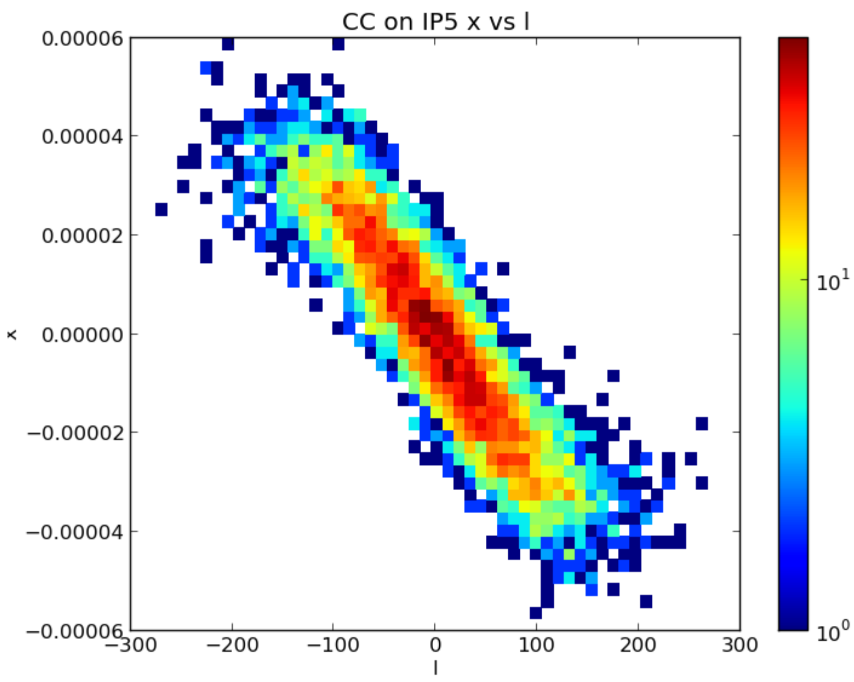
Changes in SixTrack code

- SixTrack can't generate a "tilted" bunch => start simulation at IP2
- Need "checkturns" version to get particle distr. at different elements
  - /!\ Not at all elements (file too big)
  - Element number is hard-coded and counted from start (IP2) !!!
  - Need to recompile every time, new version => should be changed
  - Change: element (or list of element) is an input?
- SixTrack bug: at the CC, all optics functions are 0 (investigating..)
- CC kicks only written in standard output (script to "catch" it)
- New version for debris: starting at IP1, all elements
  $\rightarrow$ SixTrack_CCct_all
- Otherwise usual version from B. Yee Rendon.

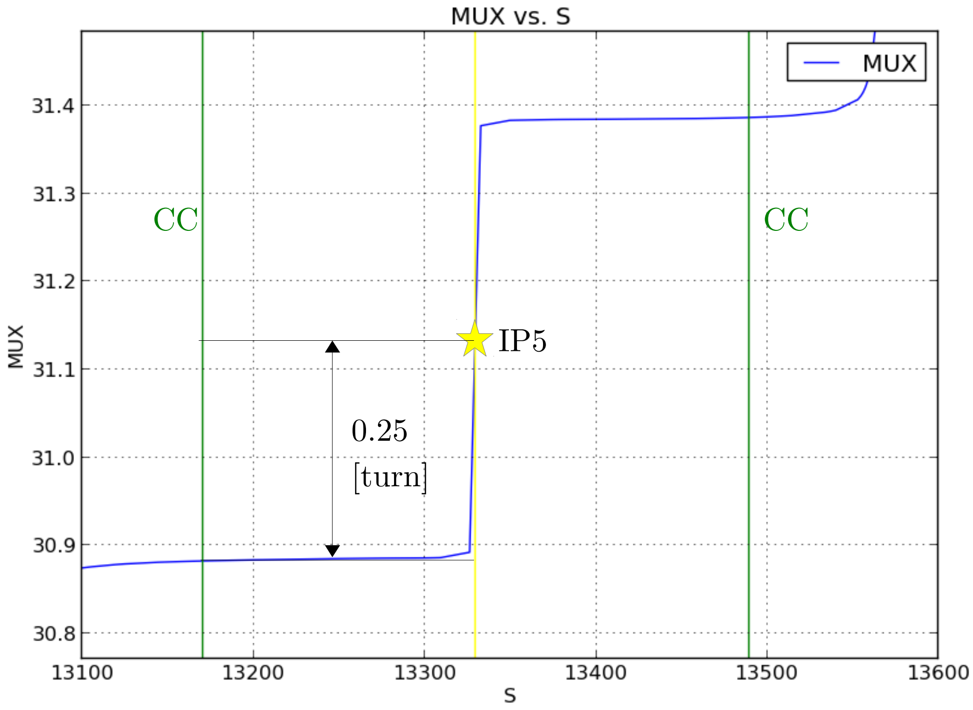
Effect of the Crab Cavities at IP1

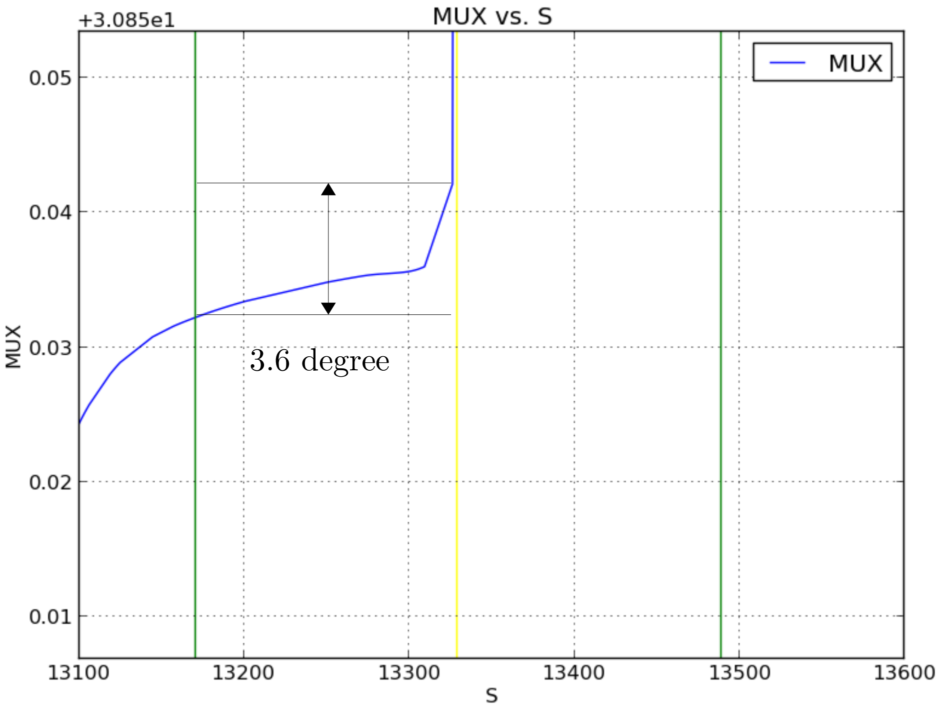
- SixTrack - generated bunch, tracking starting at IP2
- Two cases: CC off / CC on, same random seed
- CC off => “flat” bunch, CC on => “tilted” bunch
- From checkturns.dat: longitudinal tilt of the bunch





Phase advance in IR5





- Phase advance nearly constant (3.6 deg.) from CC up to last element before IP, only changes (by pi/2) at IP
  => can't see the bunch "turn"
- Effect of CC can still be shown inside a bunch

Illustration of the kick of CC

1/ Particles coordinate is plotted versus position in bunch l, in 2D

2/ Colour shows particle displacement y at IP1

3/ Colour is kept for all plots

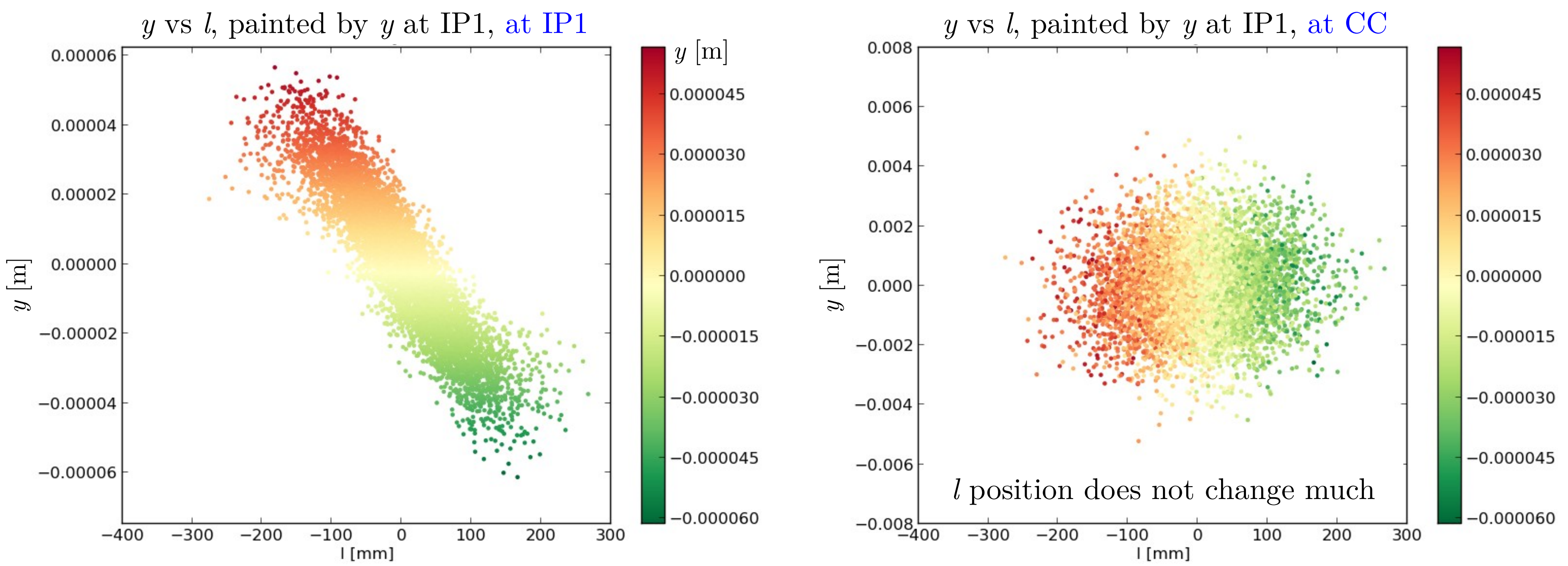


Illustration: kick of CC
y' vs. l, painted by y at IP1, before CC

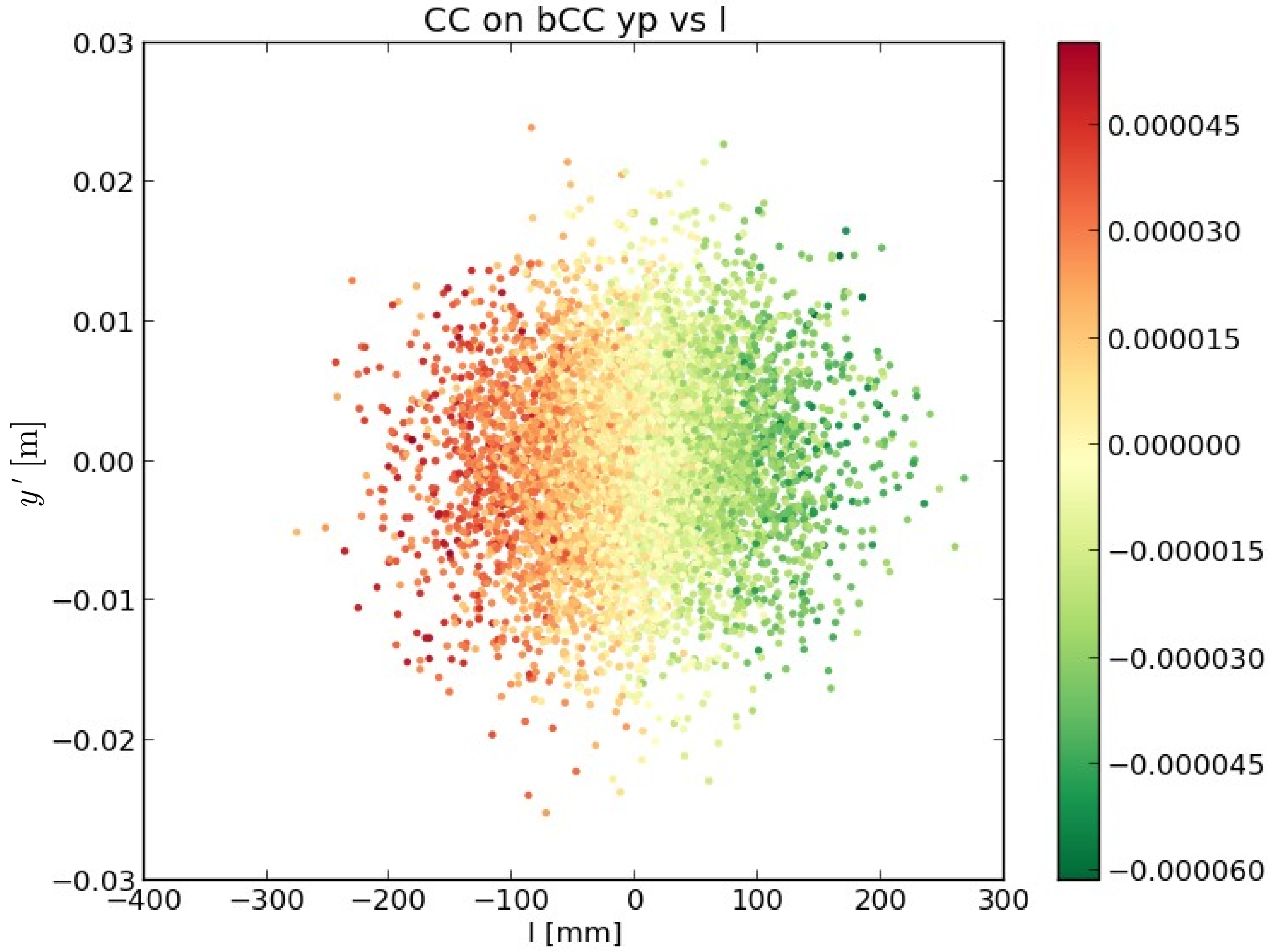


Illustration: kick of CC
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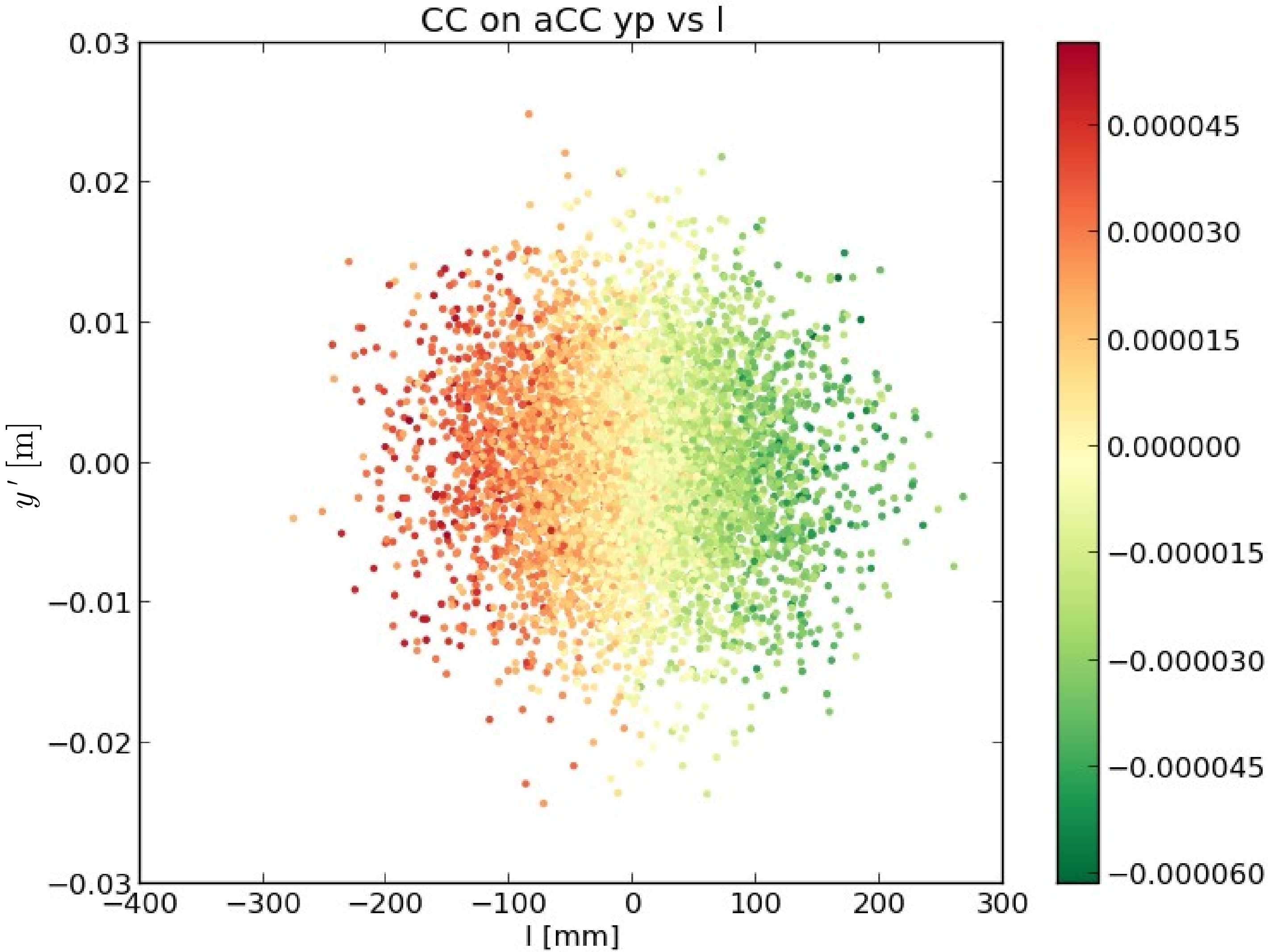
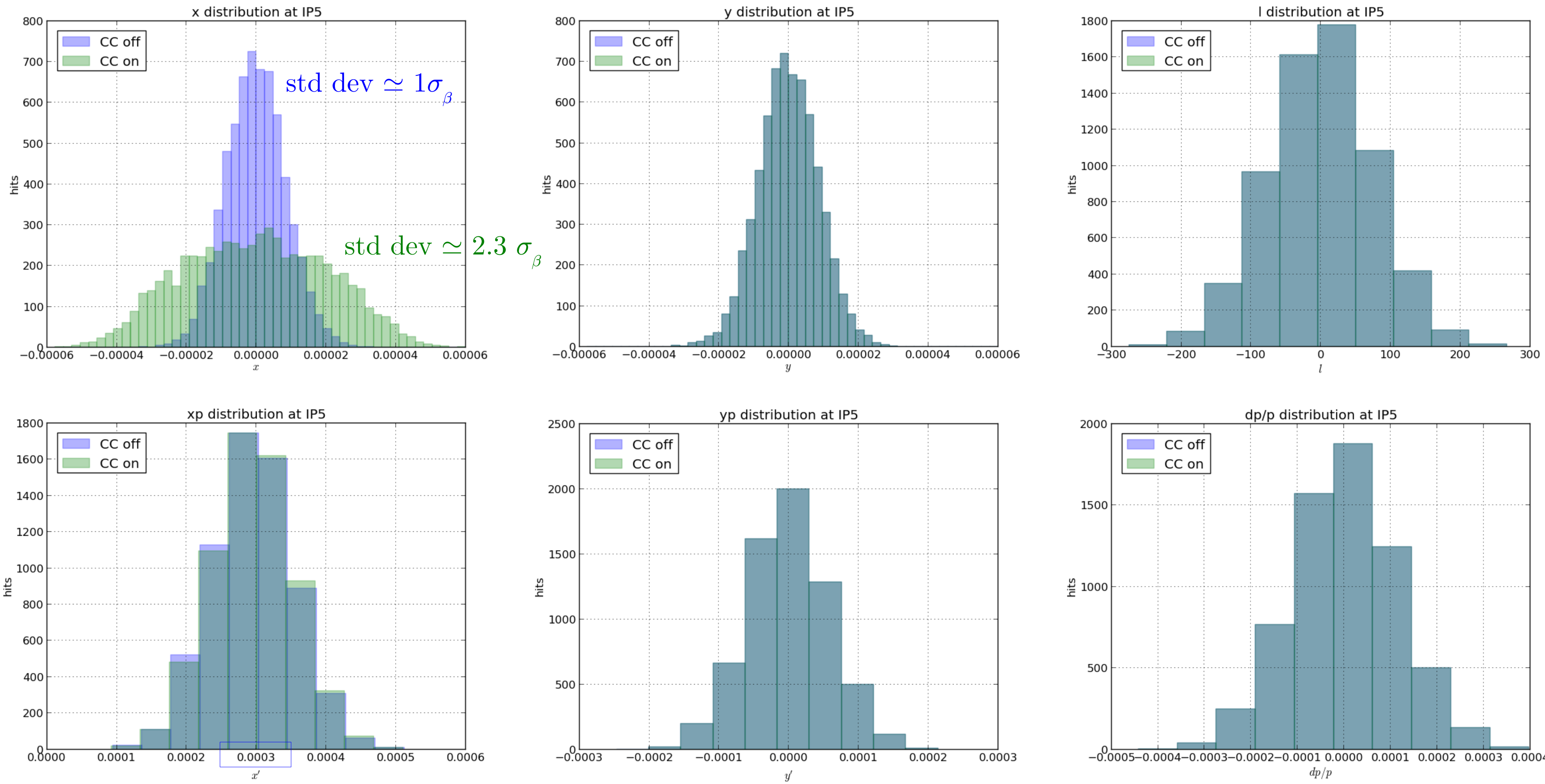


Effect of the Crab Cavities at IP5

- All 6 dimensions (x and y inverted for IP1), from checkturns



x' centred around crossing angle

Important observations on checkturns.dat / dist0.dat / distn.dat

- The value of the orbit is subtracted from dist0.dat / distn.dat
  => $<y'> = 0$ at IP1, $<x'> = 0$ at IP5

- But in the usual referential, the particles' trajectory isn't "flat" but follows the orbit: position = 0 but kick = crossing angle, as seen in twiss file, and in checkturns file.
  => $<y'> =$ Xing at IP1, $<x'> =$ Xing at IP5

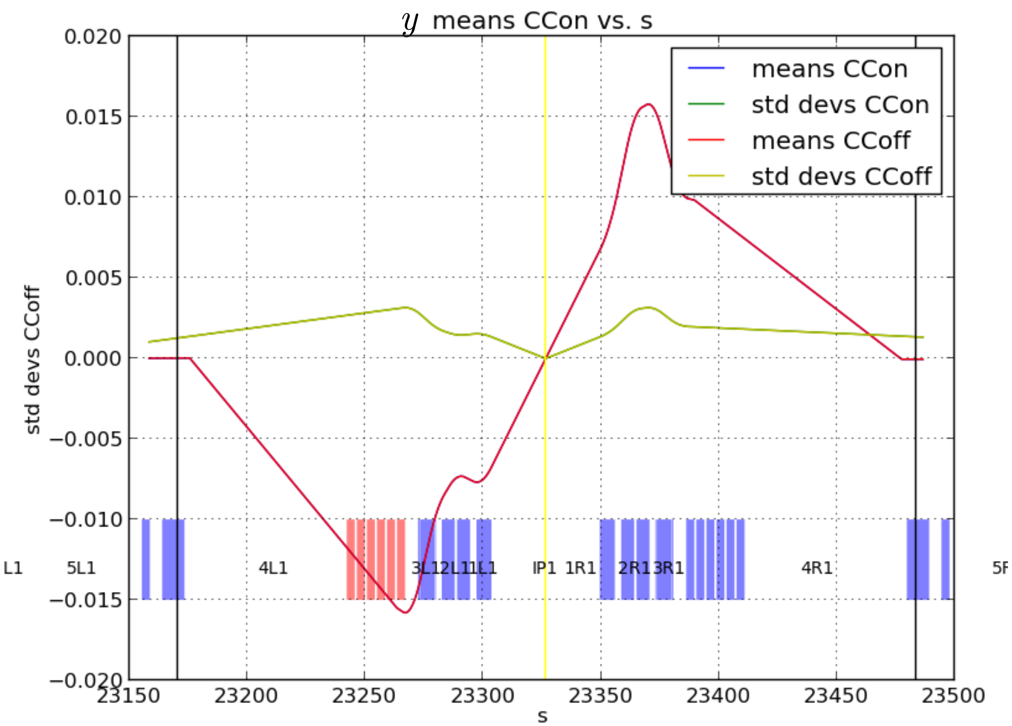
- Only the value of the orbit at the position of the considered element is subtracted from the transverse dimensions: 0 at the IP, not recalculated for each particle.

- The variations due to the position in the bunch l for each proton are not taken into account: $y \simeq l$. Xing

  => bunch is still tilted with or without orbit subtraction.

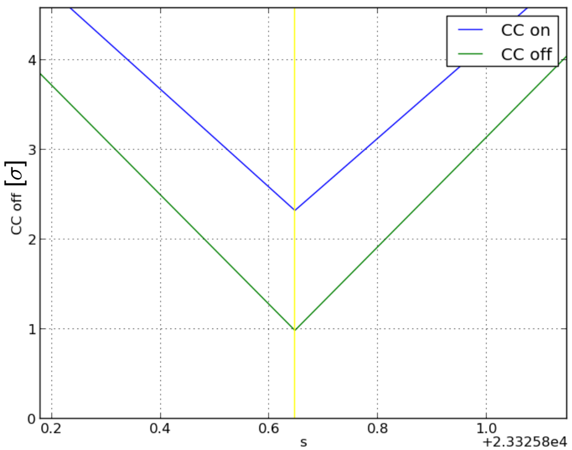
Effect of the Crab Cavities
Introduction

- Calculating mean and standard dev. in y for a bunch around IP1 (vertical crossing angle)
- Same for all other coordinates, and for IR5
- Mean follows crossing angle, std. dev. follows the beta function

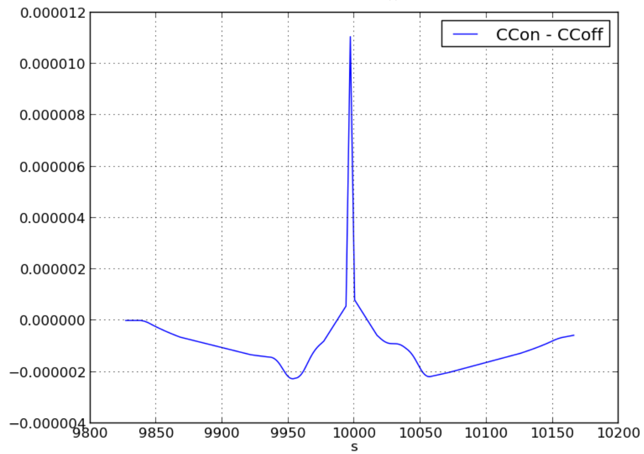


Effect of the Crab Cavities

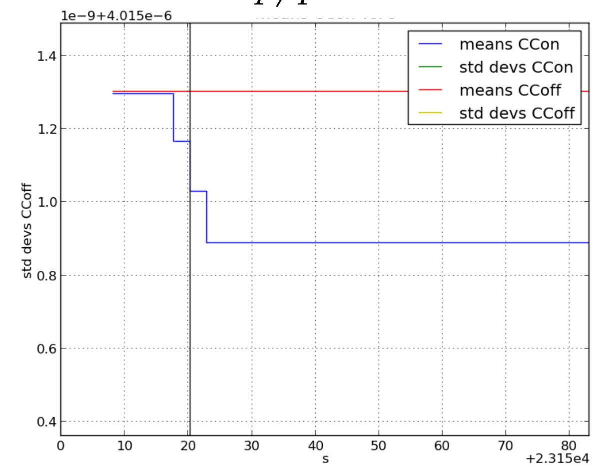
Std. dev. y vs s at IP1



Std dev x_{CCon} - x_{CCoff} vs s at IP1



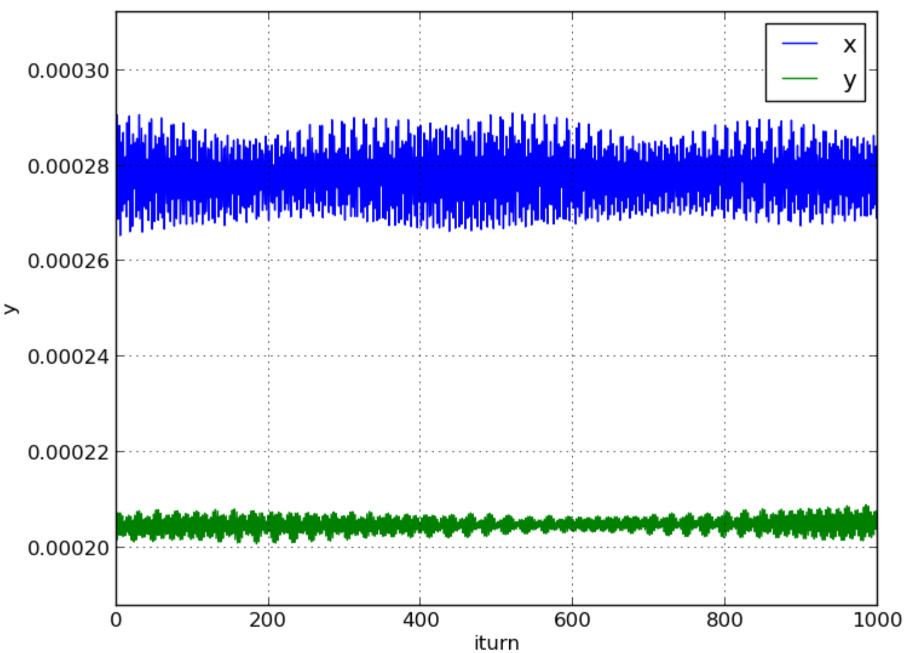
$<dp/p>$ vs s at CC



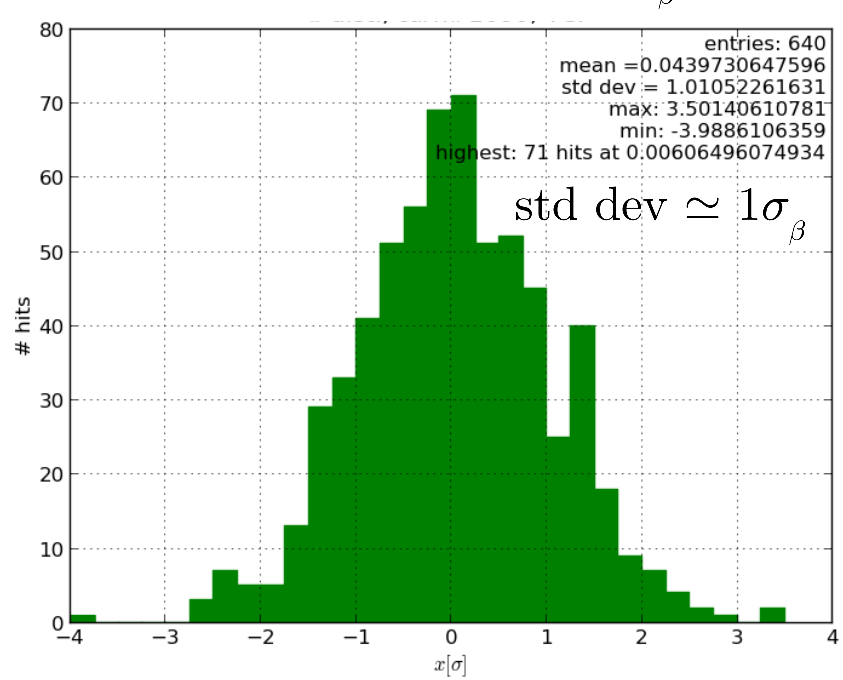
- Std. dev of y is different at the IP: from 1 σ_β to ~2.3 σ_β
- Change is only really noticeable at the IP (phase advance)
- $<dp/p>$ changes slightly at the CC (~452 eV)
- Now on to many turns...

Effect of the Crab Cavities over 1000 turns 6D bunch, observed at TCP IR7

Std. dev. of the bunch at TCP vs. number of turns

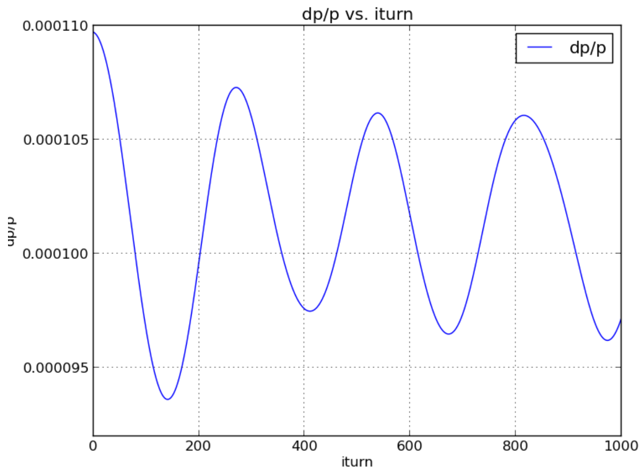


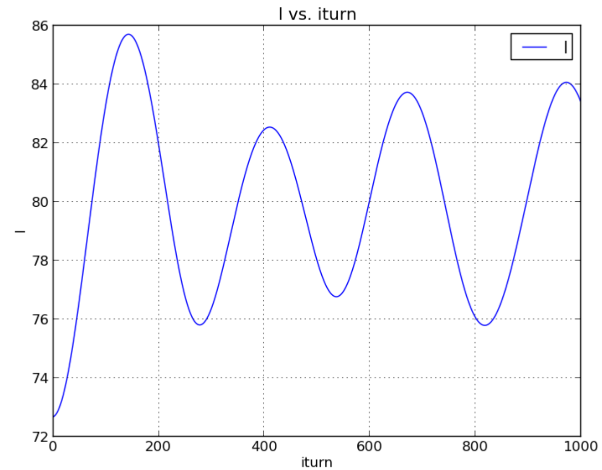
Particle distribution in x after 1000 turns in $[\sigma_\beta]$

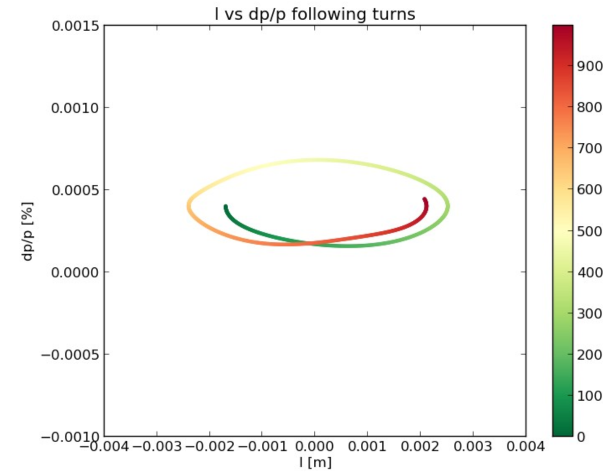


- No emittance growth: after 1000 turns, the bunch size is conserved, its standard deviation is still $1\ \sigma_\beta$

Effect of the Crab Cavities over 1000 turns
Nominal bunch oscillations

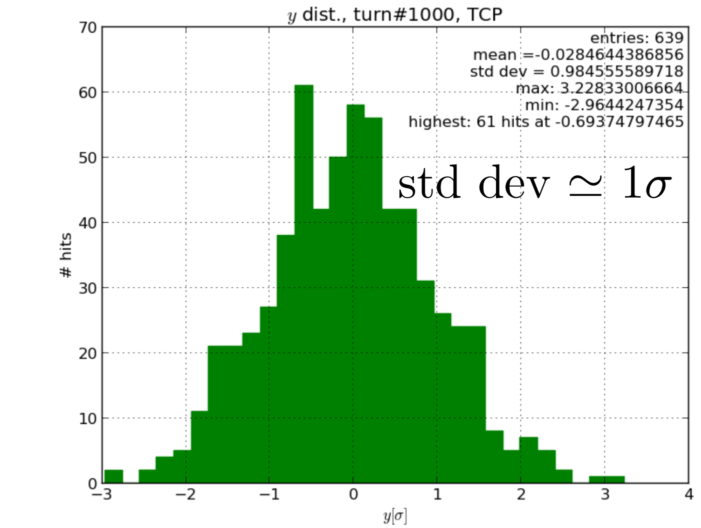




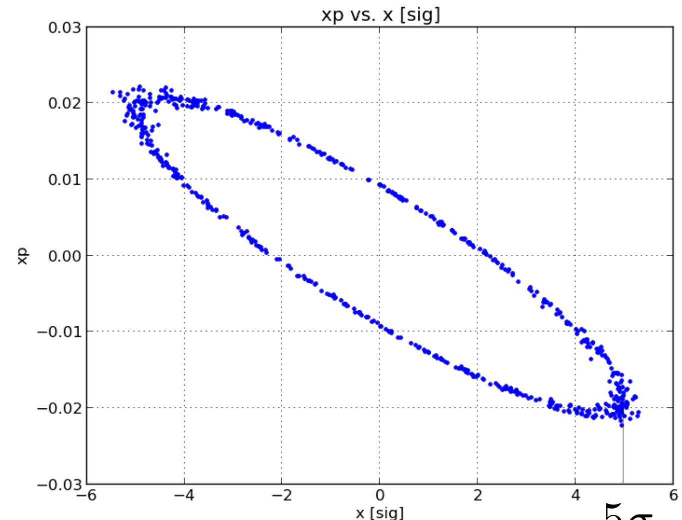


- Illustrating the relation between $<l>$ and $<dp/p>$ over many turns
- Effect of the RF cavities
- Same thing can be shown in the phase spaces, with higher frequency
- Size in phase space stays constant

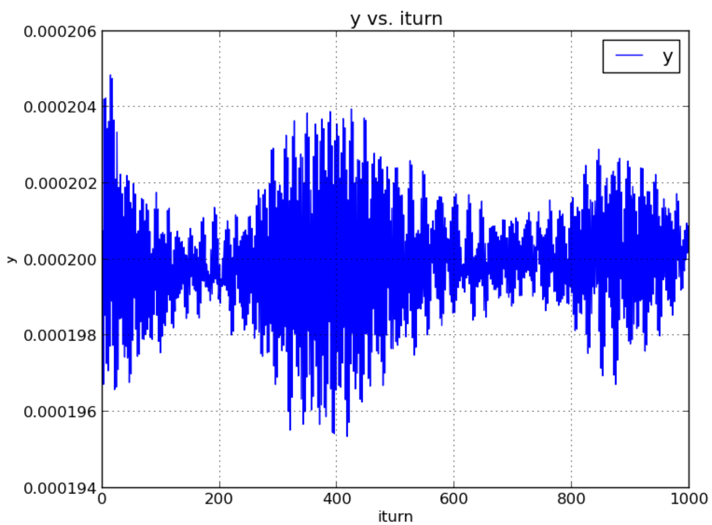
Effect of the Crab Cavities over 1000 turns
5σ halo distribution, at TCP



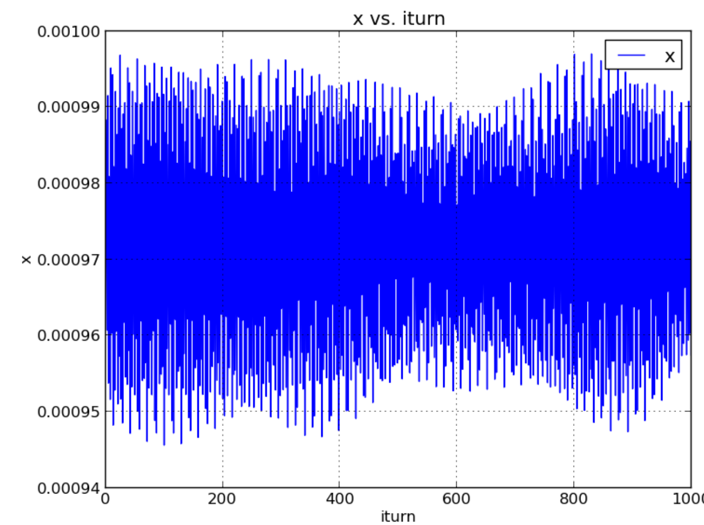
Turn #1000



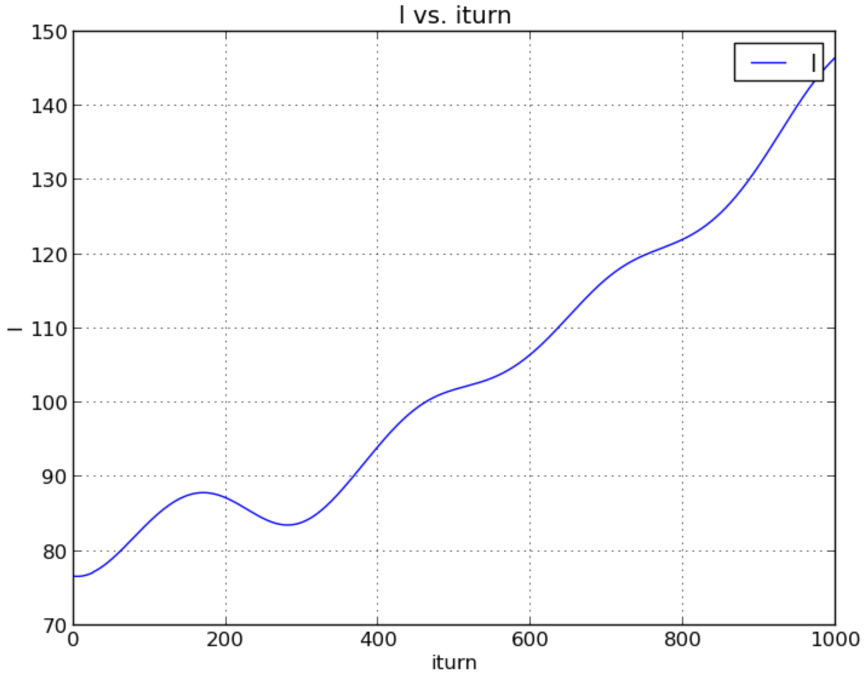
5σ

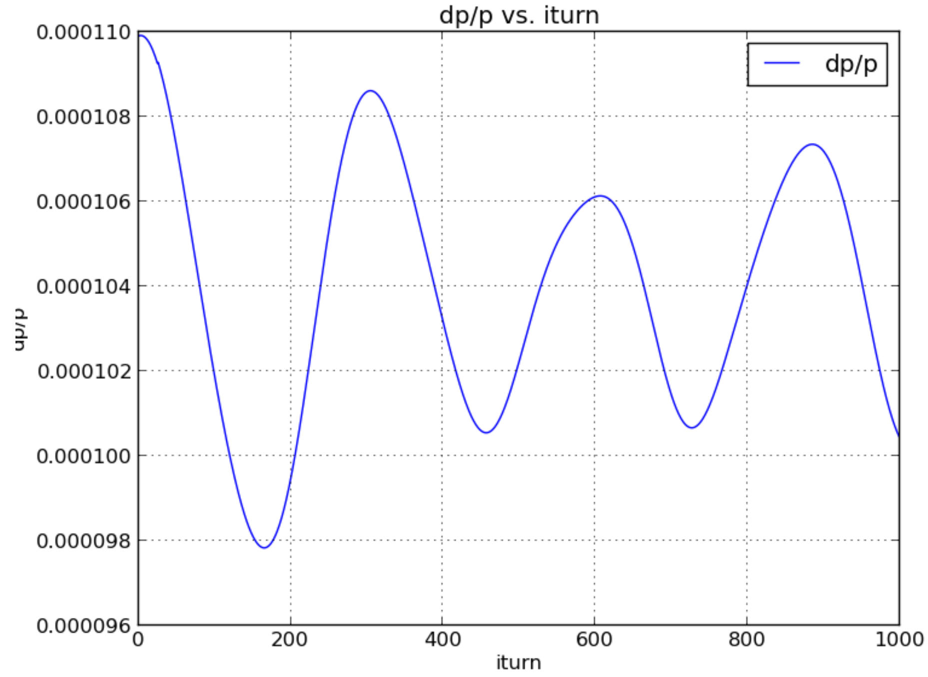


No obvious increase



Effect of the Crab Cavities over 1000 turns
Halo, l and dp/p





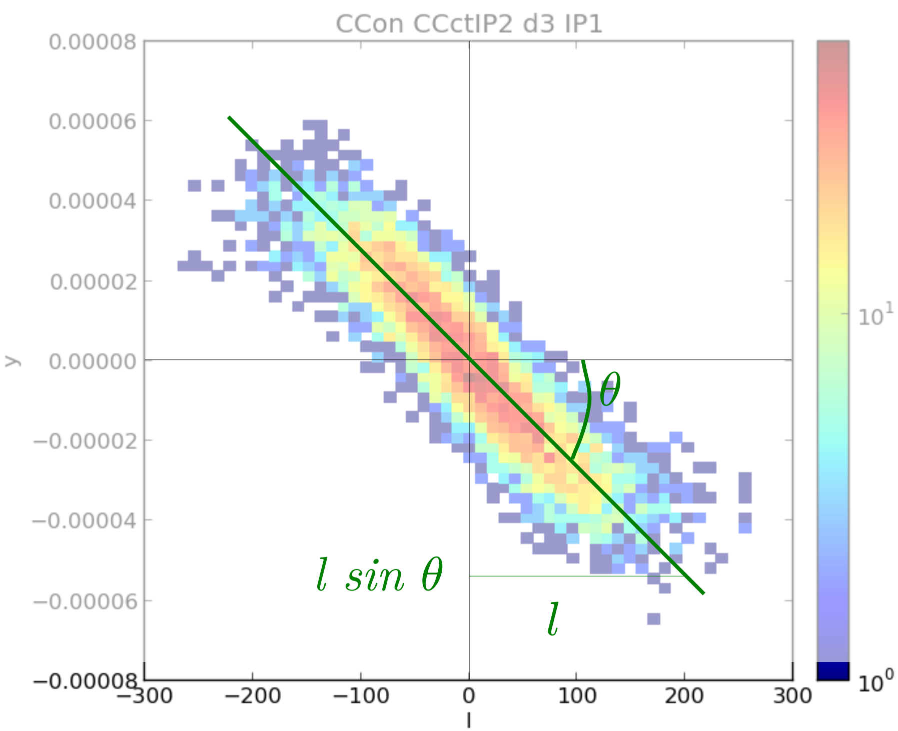
- Average of l distribution increases with time...

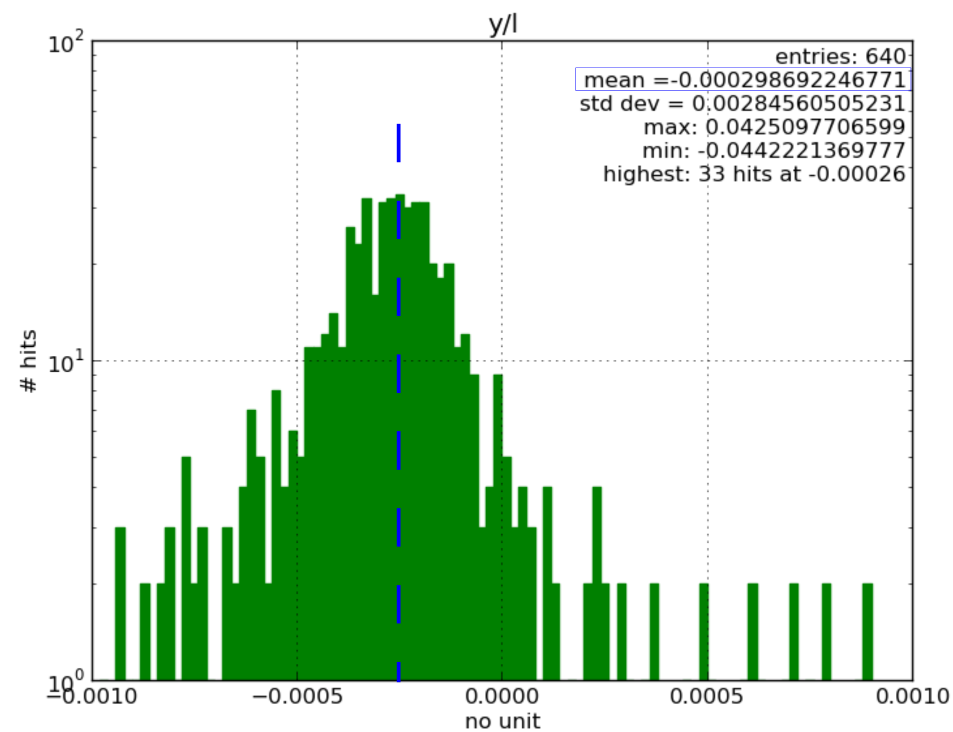
Loss simulations: ongoing work

- Regenerate input for debris, taking CC effect in to account
  - Bunch tilt in crossing angle plane
  - Gaussian distribution in l
- BYR studies performed with SLHC v3.1b
  - Case with CC off give exactly the same results (tracks2.dat) as the case without any CC for the same input and same random seed
- Mad-X script to install CC available $\rightarrow$ do it for HL LHC v1
- Debris loss maps (single pass)
- Halo loss maps: issues with recentering (start from IP2)

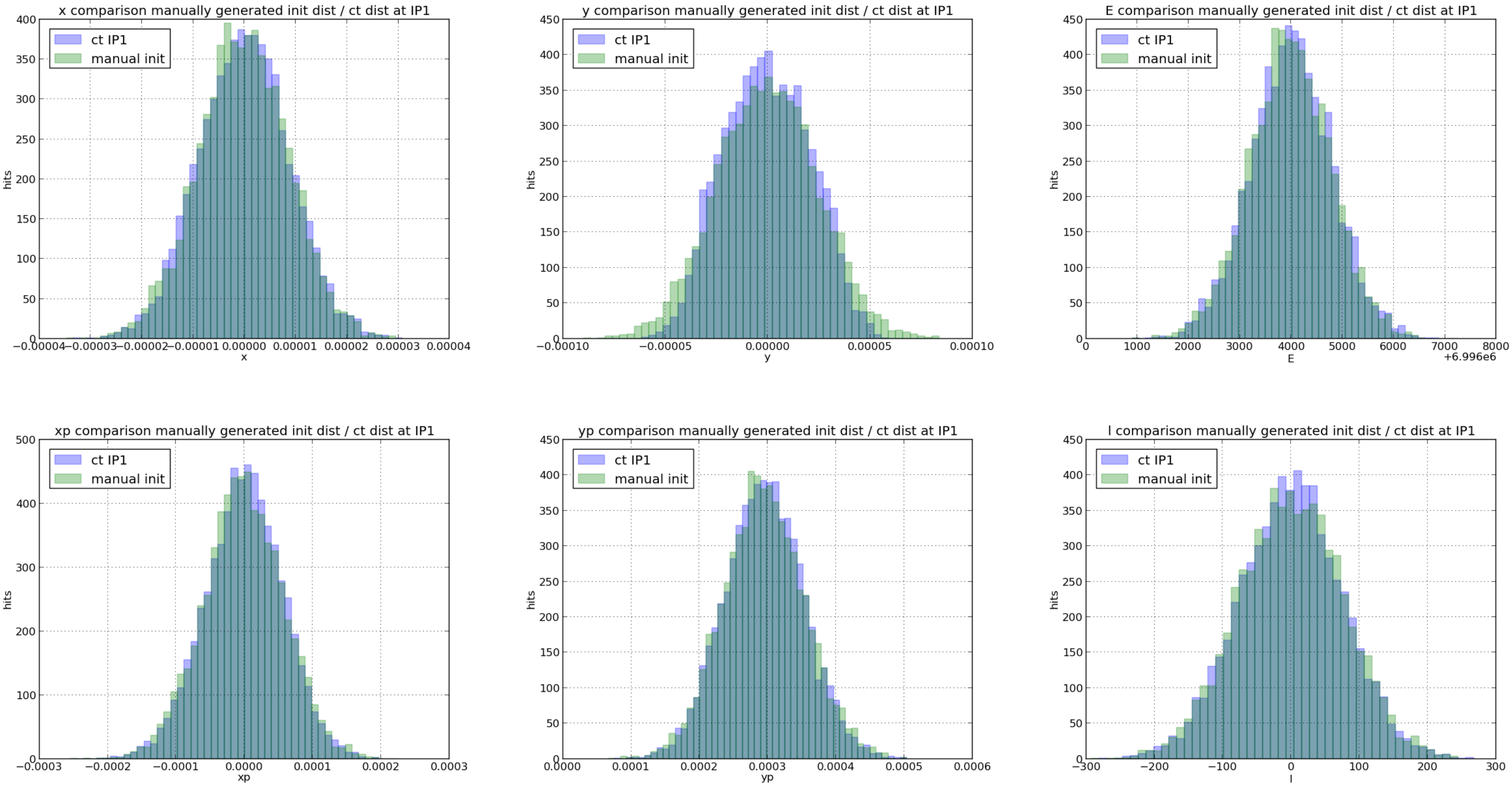
Debris
Initial distribution

- 6D beam distribution + effect of collisions + effect of CC
- 1st order approximation: adding the extra tilt to the y distribution: $(y_0, l) \to (y_0 + l * \sin\theta, l)$
- Distribution of y/l from checkturns is centred around crossing angle





Comparison of checkturns dists. at IP1 with manually-generated initial distributions



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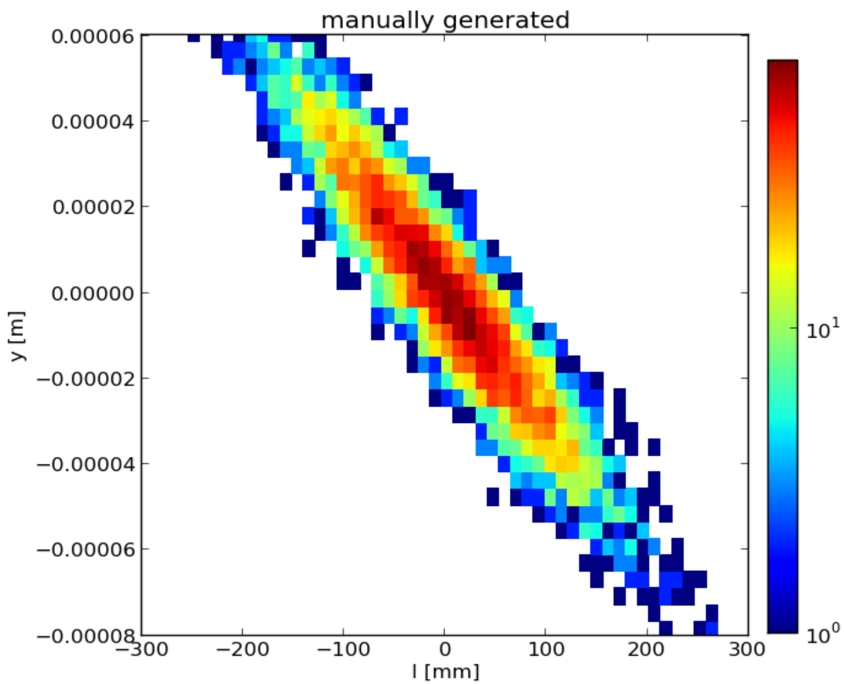
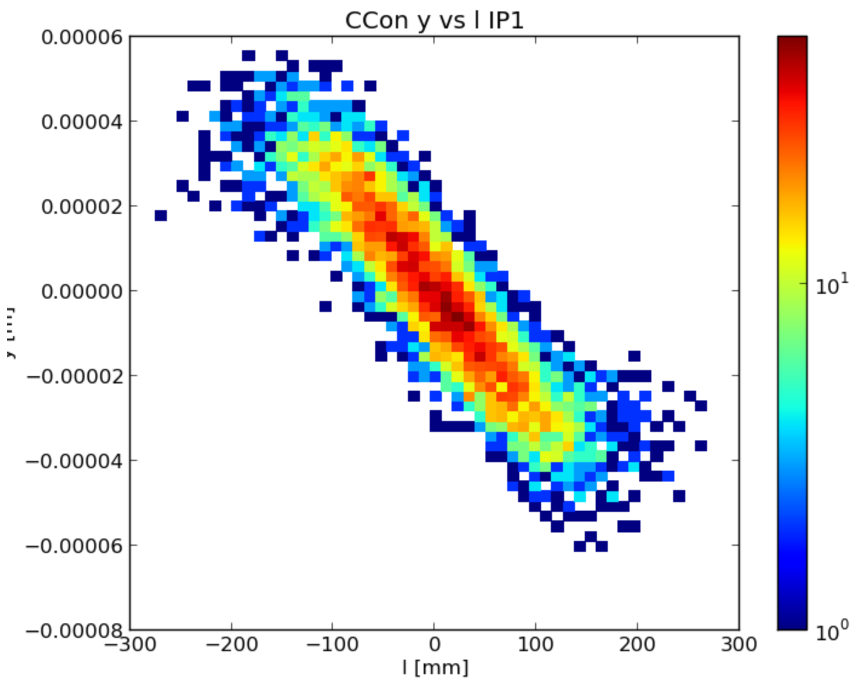
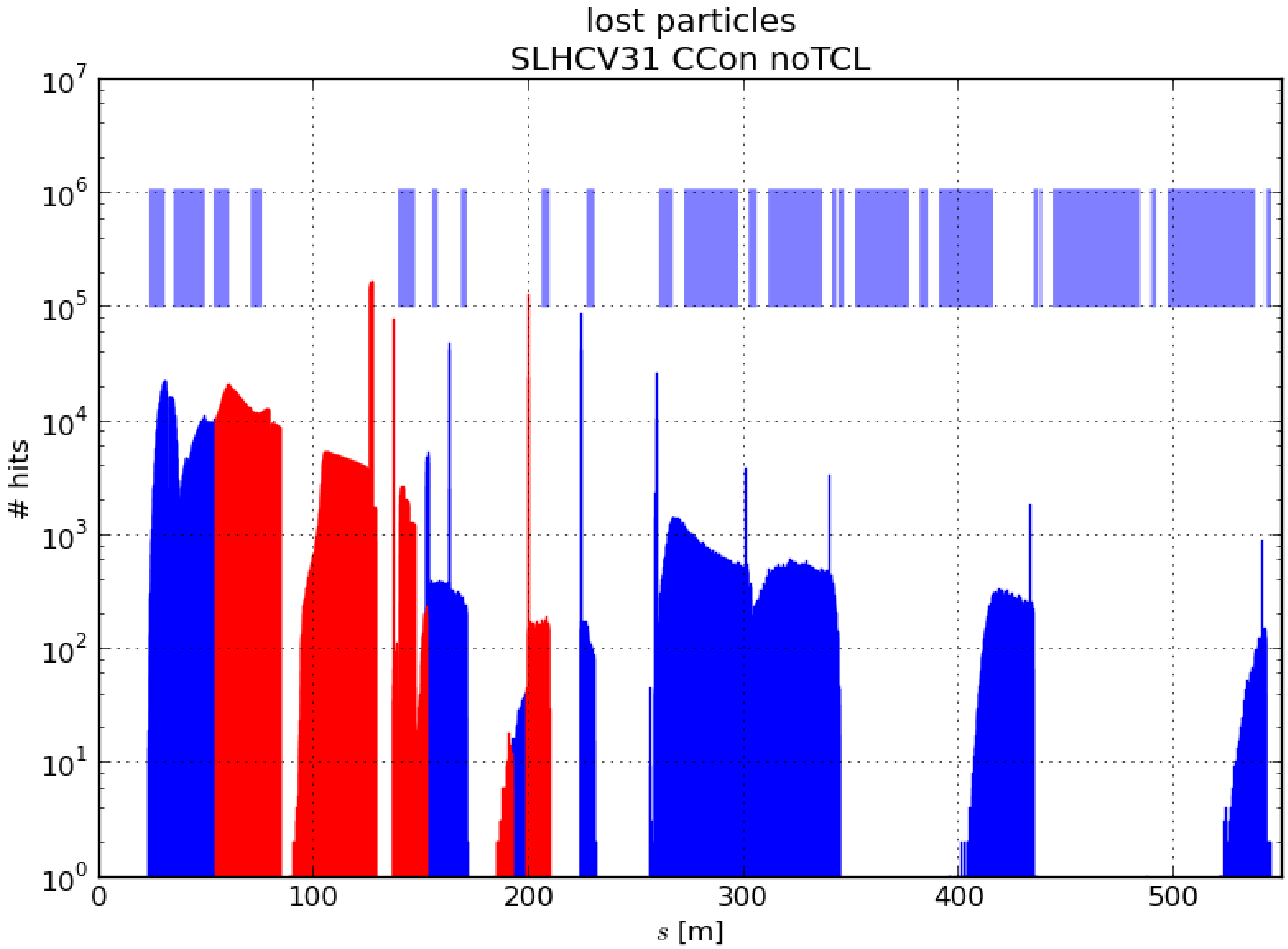


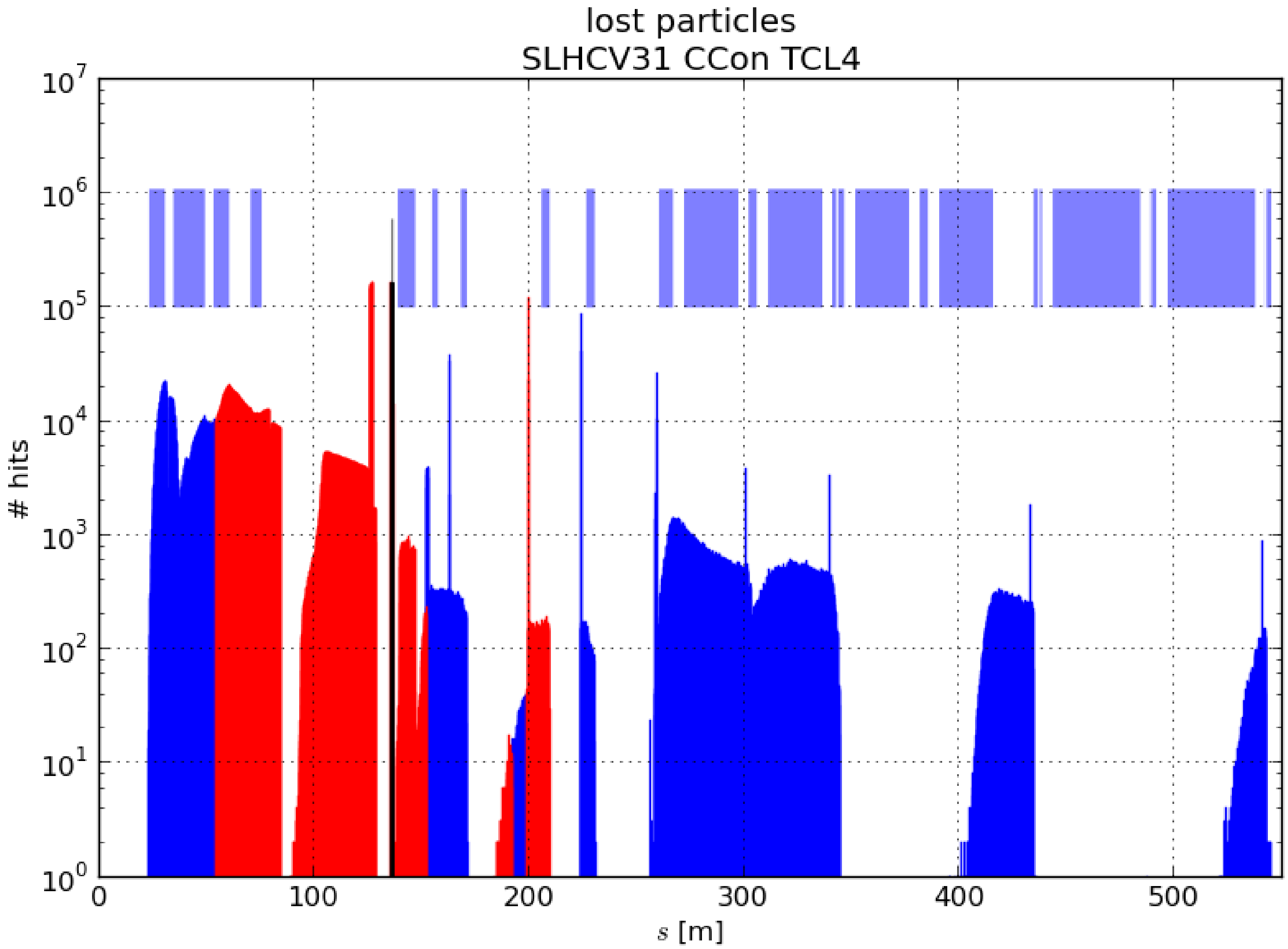


- Difference in the y distribution as shown in previous slide
- 3.2 µm difference in numerical standard deviation (0.37 sig)
- First order not sufficient?

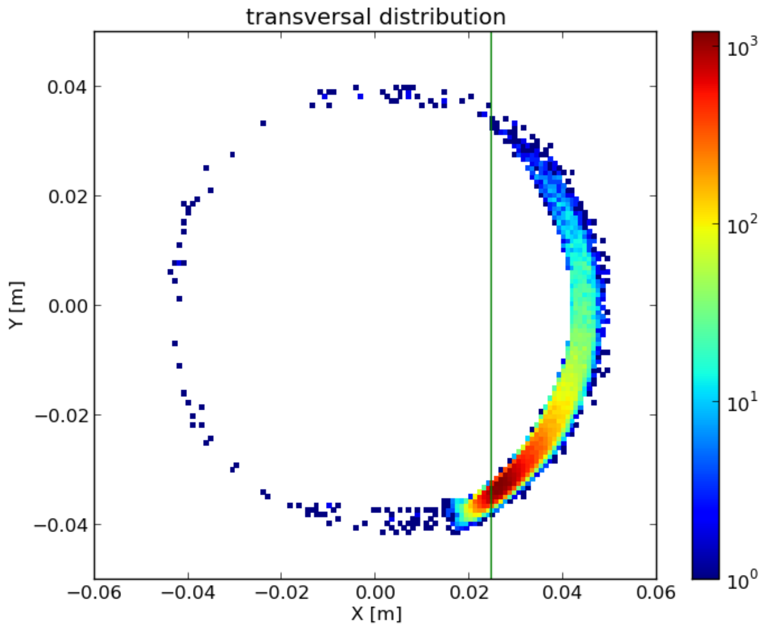
Debris simulations: no TCL

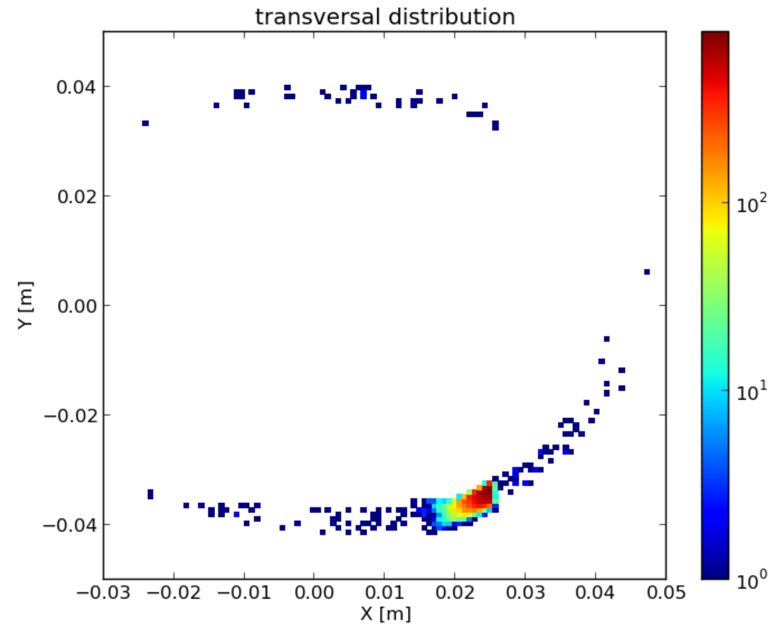


Debris simulation: TCL4



First observations: loss distribution in the peak 137<s<137.5





- Not much difference observed
- Losses not clearly in one plane → not all stopped by collimator
- Collimator at 15 sigma, could be tighter.
- Check trajectories

Conclusion

- Effect of CC in SixTrack studied in depth and is consistent
- Setup ready:
  - Debris with CC generated
  - Emittance is constant
  - Halo is fine over 200 turns (l could be an issue)
- First (slow...) series of simulations revealed small issues:
  - Possible issue with orbit subtraction where relevant
  - Recentering for simulations starting in IP2
  - Small effect of TCL4
- More simulations needed

Thank you!