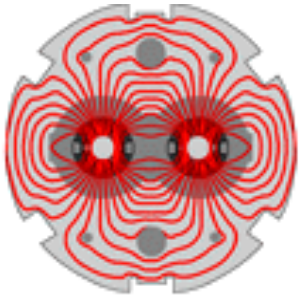

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Weak-Strong Beam-Beam Simulations with Crab Kissing Scheme

A.Valishev (Fermilab/US LARP), S.Fartoukh (CERN)
D.Shatilov (BINP)

LHC-CC13, 6th LHC Crab Cavity Workshop
December 10, 2013

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Outline

- Approach
- Nominal HL-LHC scheme
- Elements of the Crab Kissing case
  - Flat optics and Wire compensator
  - Crab Crossing, Crab Kissing
  - Flat bunches
- Optimization
- Discussion

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Approach

- Motivation: see previous talk by S. Fartoukh
- Here we evaluate the robustness of various collision schemes using weak-strong simulation
  - Well-developed, reliable, and relatively fast approach
  - However
    - Imperfections are excluded
    - No coherent effects – need strong-strong (K.Ohmi, KEK)
- First pass of evaluation, to be refined with more detail

Model

- **Lifetrac** particle tracking code
  - Full detail of machine lattice, element-by-element thin lens
    - Crab cavities
    - 2nd harmonic RF
  - Weak-strong beam-beam with all collisions. IR8 (LHCb) is included in all further results full head-on & β^*=10m
    - Crabbing of strong bunch
    - Arbitrary longitudinal strong beam profile
    - Wire compensators
- Evaluated quantities:
  - Dynamical Aperture, FMA for resonance identification
  - Multiparticle beam parameters (intensity, luminosity, emittance lifetimes)

Nominal HL-LHC Scheme

- Round optics, full crabbing, leveling with β^*
  - For now forget about pileup density
- Beginning of fill is 'trivial' despite large ξ – 3 head-on IPs, very weak long-range (>16 σ separation, compensated IR1-IR5)
- Middle of fill – significant head-on and long range
- End of fill – weak head-on
- Question: how low can the CC voltage be?

Leveling at L=5E34 (except * case)

β^* (cm)	Np (10^{11})	x-angle (μrad)	bb sep. (σ)	CC (MV)	ξx	ξy
69	2.2	360	16	7.7	0.0306	0.031
40	1.65	360	12	7.7	0.023	0.024
40	2.2*	360	12	7.7	0.0306	0.031
15	1.06	590	12.5	12.5	0.015	0.016
15	1.06	440	9	9	0.015	0.016

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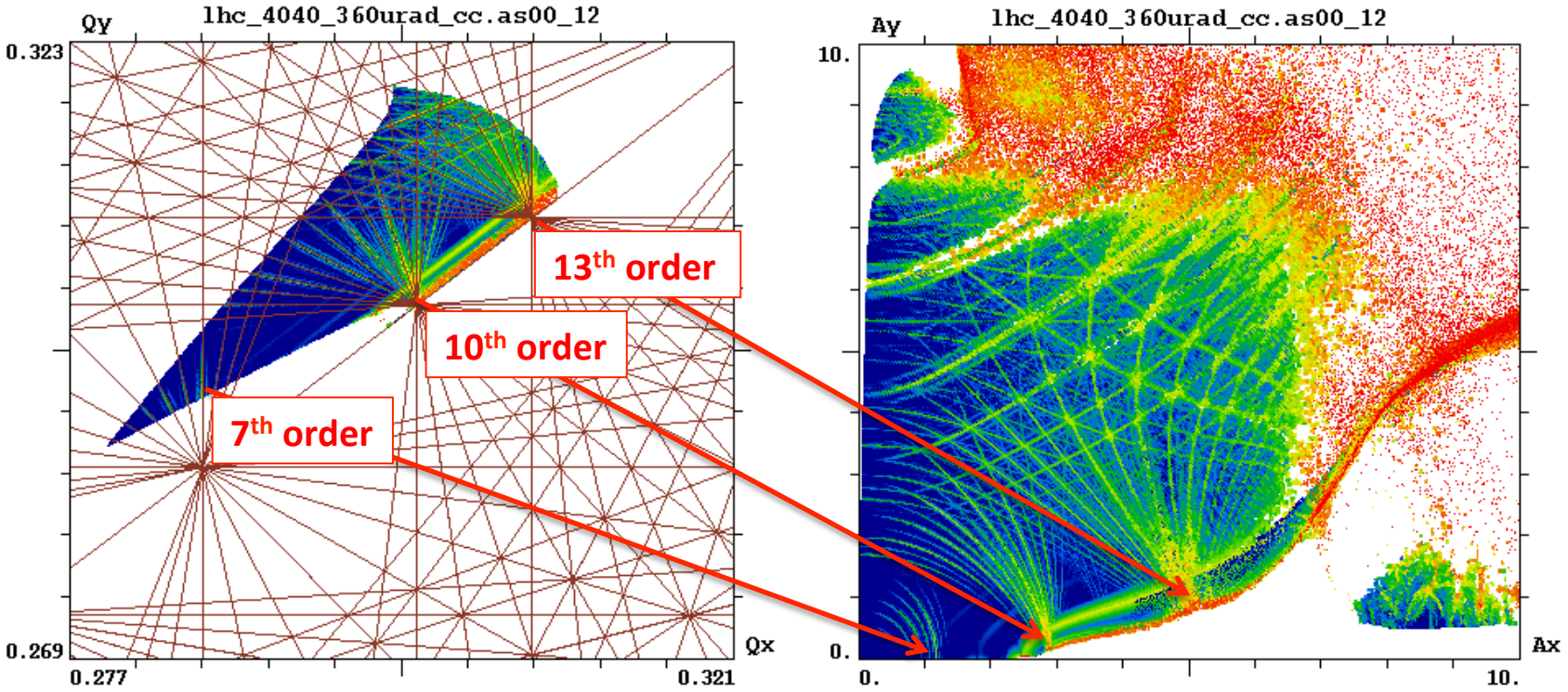
Nominal HL-LHC Scheme Results

b=40 Np=2.2* x=360 A=12 CC=7.7MV ξx=0.0306 ξy=0.031



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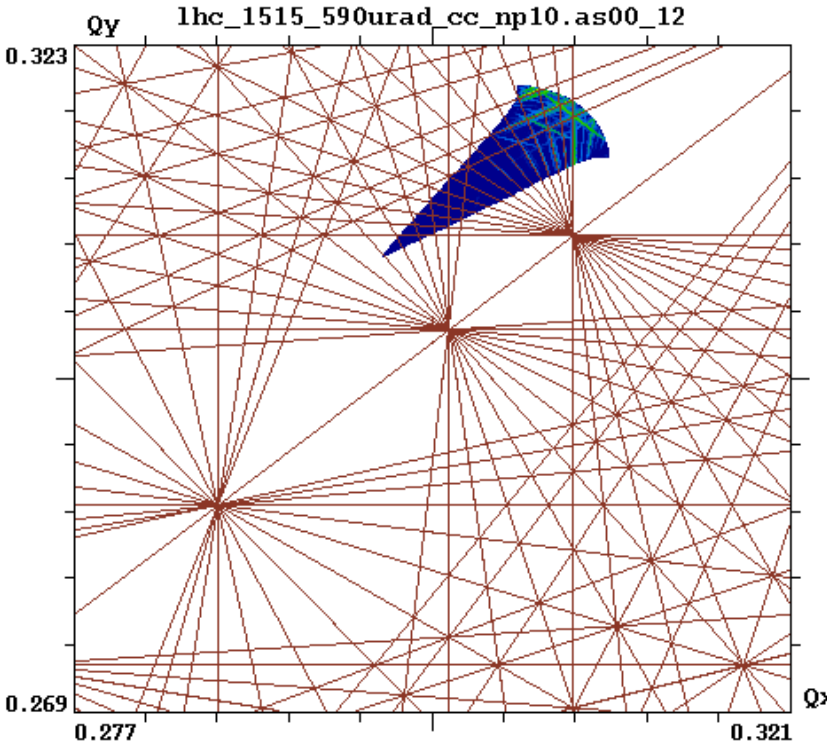
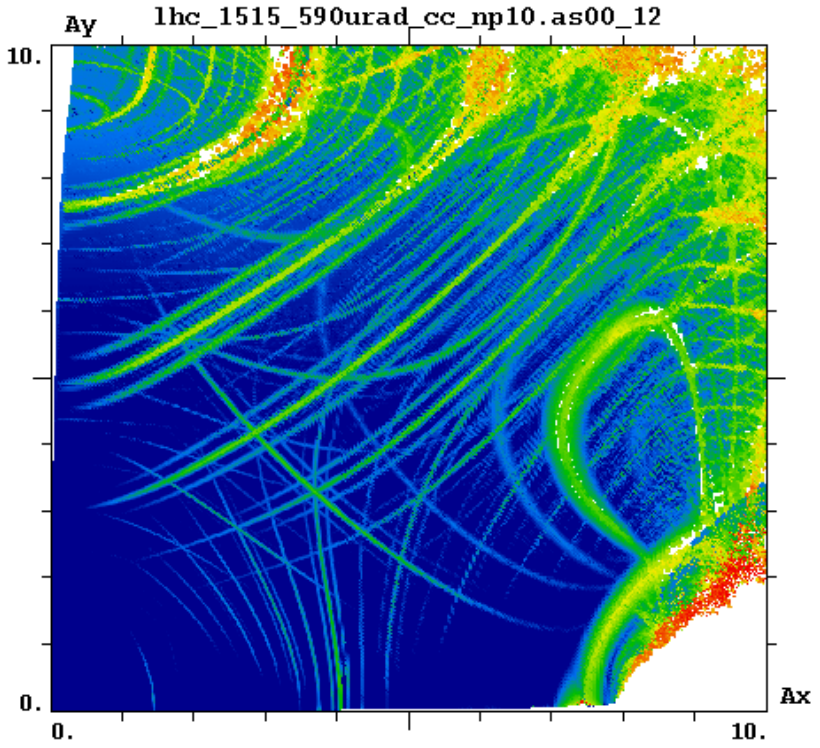
Nominal HL-LHC Scheme Results

b=15 Np=1.0* x=590 A=12.5 CC=12.5MV ξx=0.015 ξy=0.016





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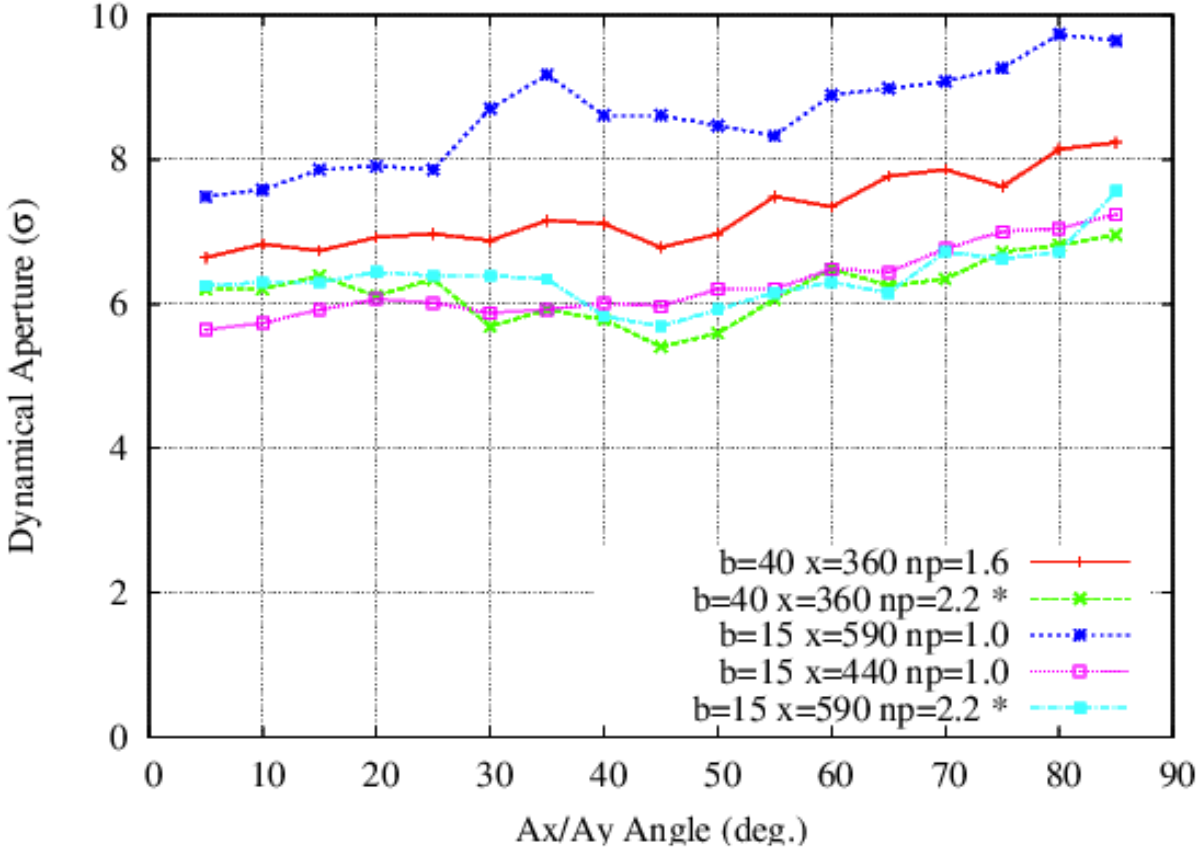
Nominal HL-LHC Scheme Results



- Conclusion: baseline HL-LHC with CC is robust (nb: pileup density is a problem). The CC voltage requirement may be re-visited (However, the emittance growth must be accounted for and effect of imperfections must be studied)

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Ingredients of 'Crab Kissing' Scheme

- Flat optics
- Wire beam-beam compensator (BBW)
- Crab-Crossing, Crab-Kissing
- Flat bunches

- But can take advantage of individual ingredients even with incomplete set

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Flat Optics and BBW

- Flat optics 40/10 cm, σ_z=10cm
  - Small Piwinski angle to reduce luminosity loss
    - L/L_0=0.71 @ θ=340 μrad (11.7σ separation) σ_z=7.5cm – compare to 0.34 in nominal
    - L/L0=0.62 @ θ=340 μrad σ_z=10cm
  - Pileup density without CC depends on Piwinski angle
    - ϕ=1.1 (and less with β* leveling) vs. ϕ=3.1 in nominal
  - Non-compensated long-range in IR1-IR5
- Wire compensator to mitigate long-range?
- <u>Can we operate without Crab Cavities at all (forgetting the still high pileup density)?</u>

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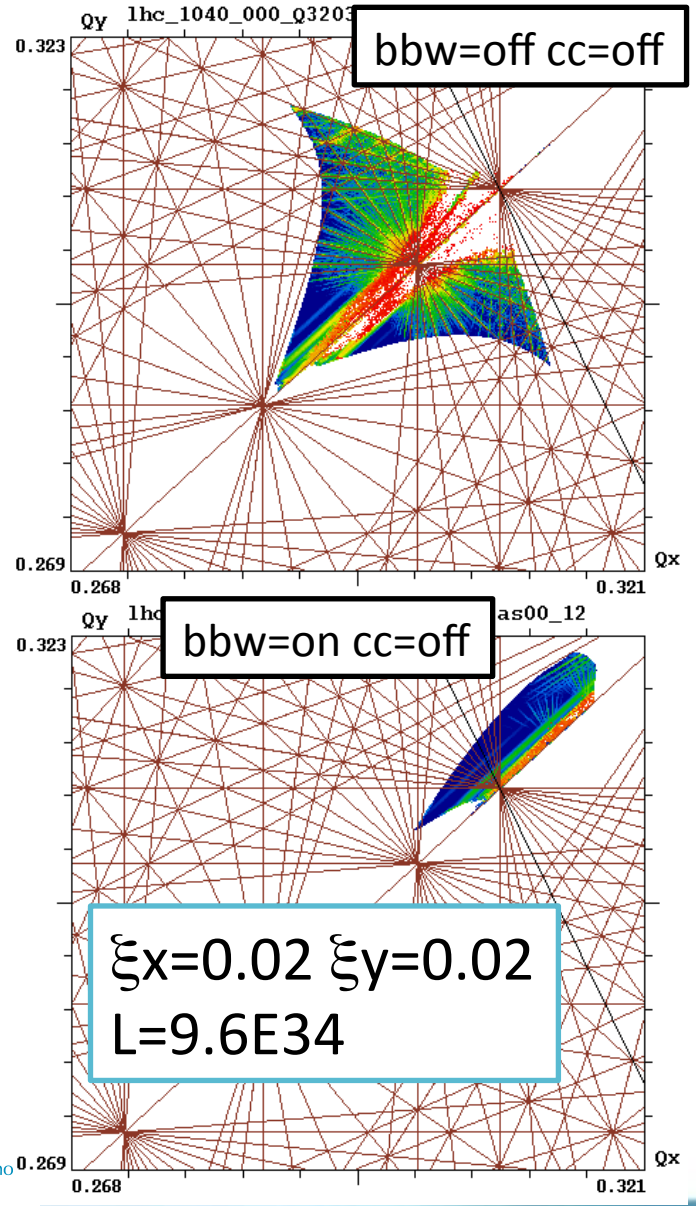
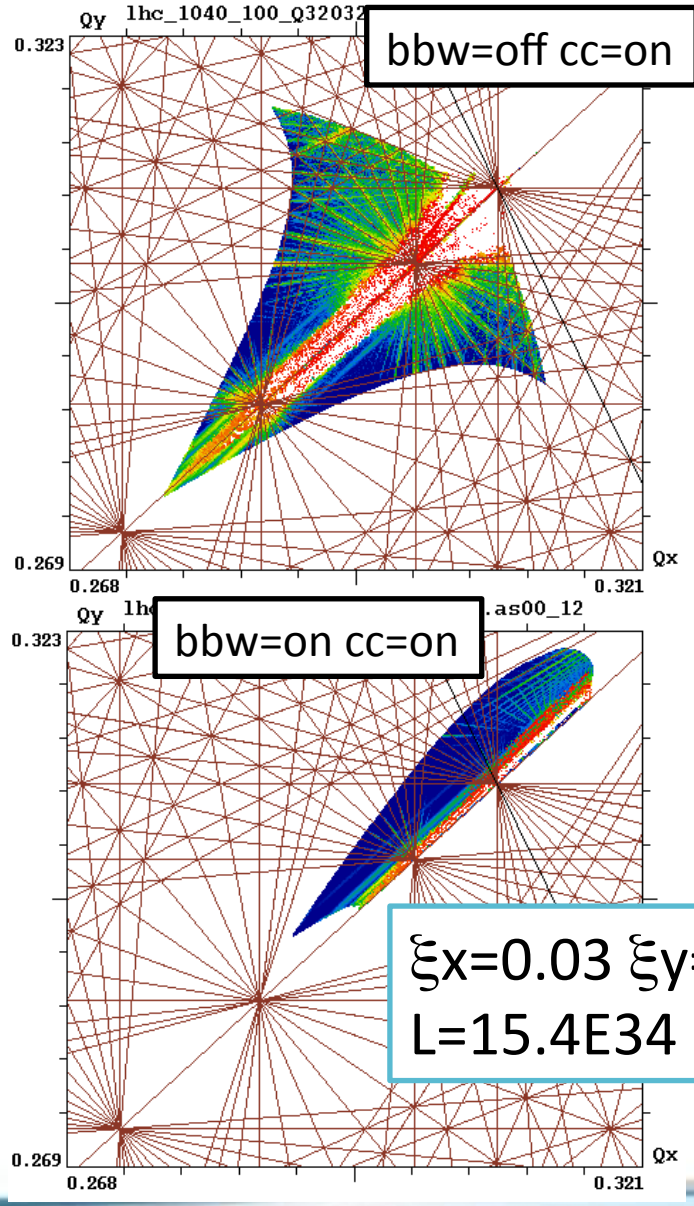
Flat Optics and BBW Results





x-angle 340 μrad, 11.7σ sep.,
σz=10cm, Np=2.2E11

ξx=0.02 ξy=0.02
L=9.6E34

ξx=0.03 ξy=0.031
L=15.4E34

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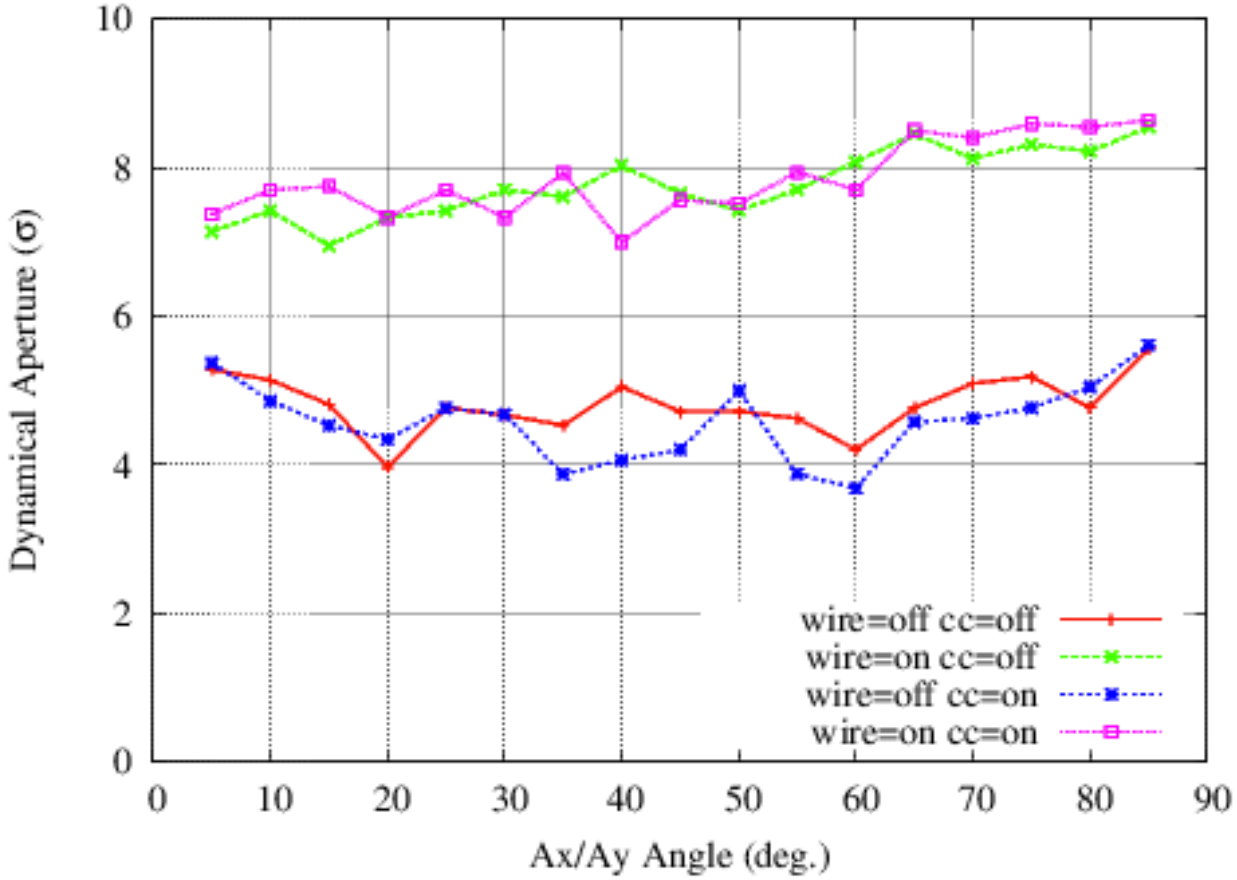
Flat Optics and BBW Results



- Can operate without Crab Cavities but the pileup density is at the same level as in nominal scheme

Crab Kissing

- Flat optics 40/10 cm, 340 μrad
- Wire compensator
- Crab Kissing (7MV in parallel separation plane – θ=165 μrad) – mitigate the pileup density
- Crab Crossing (up to 7MV in crossing plane) – recover luminosity loss due to CK

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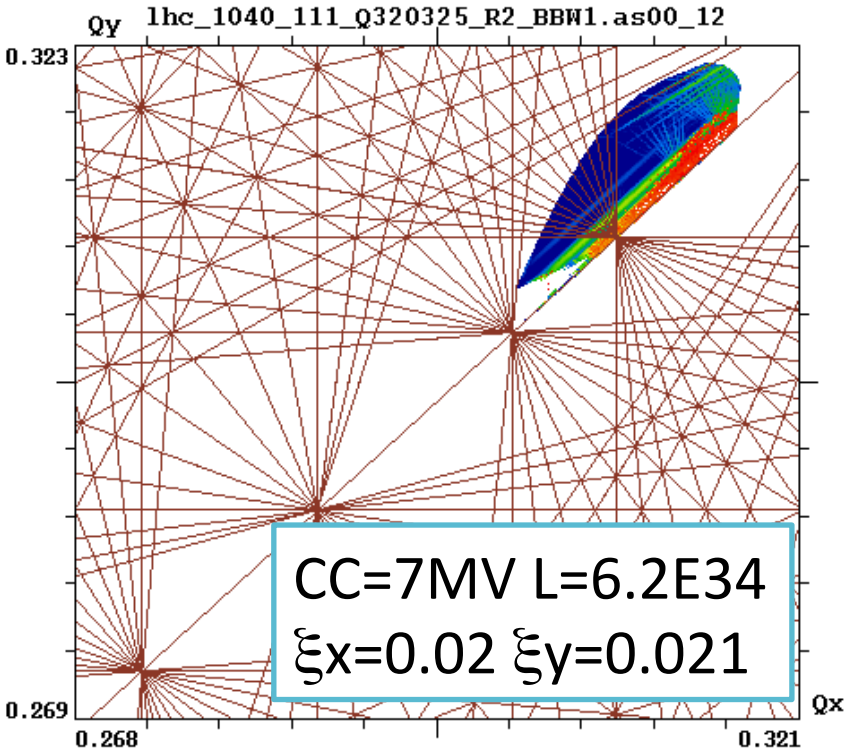
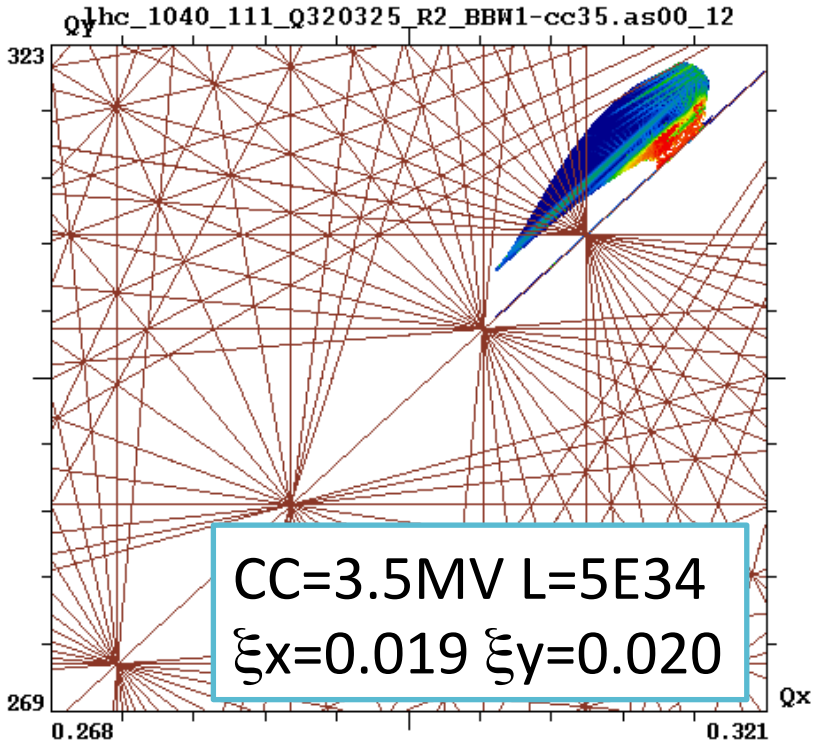
Crab Kissing Results

b=40/10 Np=2.2 x=340 A=11.7 CK=7MV, σz=10cm Gaussian





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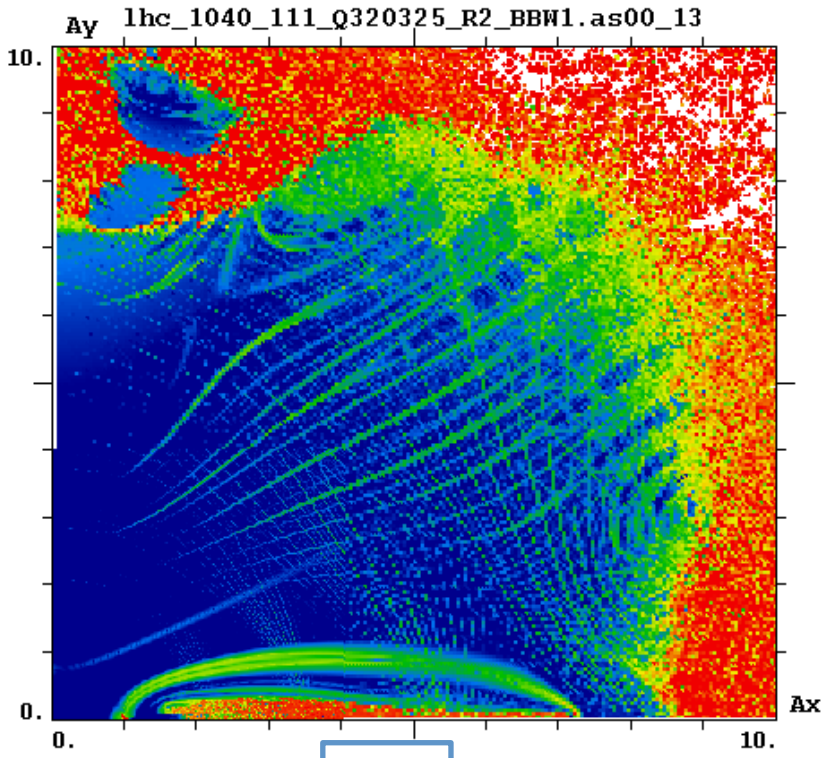
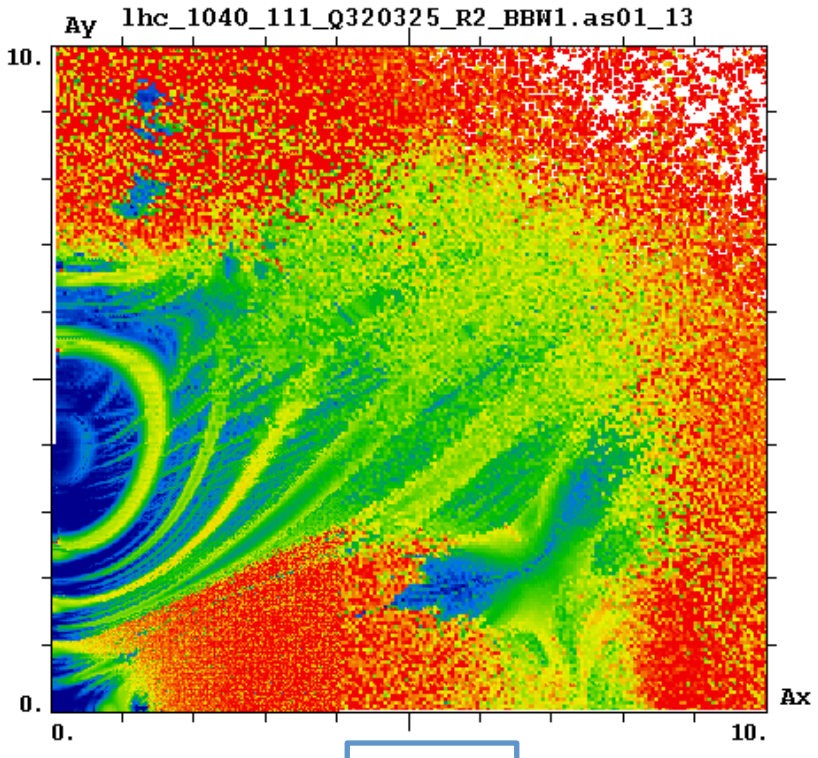
Crab Kissing Results

b=40/10 Np=2.2 x=340 A=11.7 CK=7MV CC=7MV



$A_s=0$



$A_s=1\sigma$

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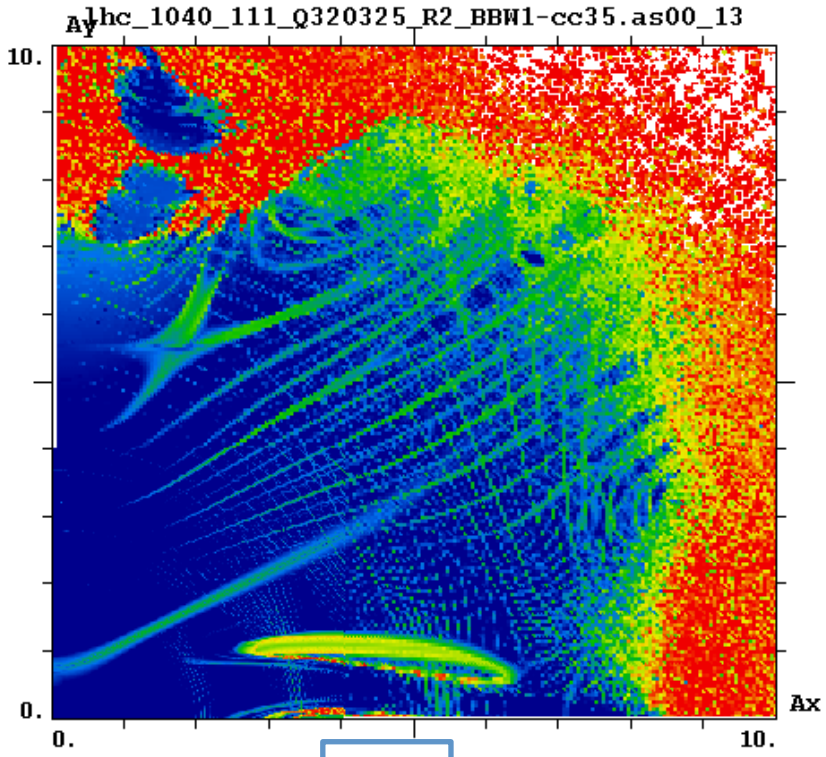
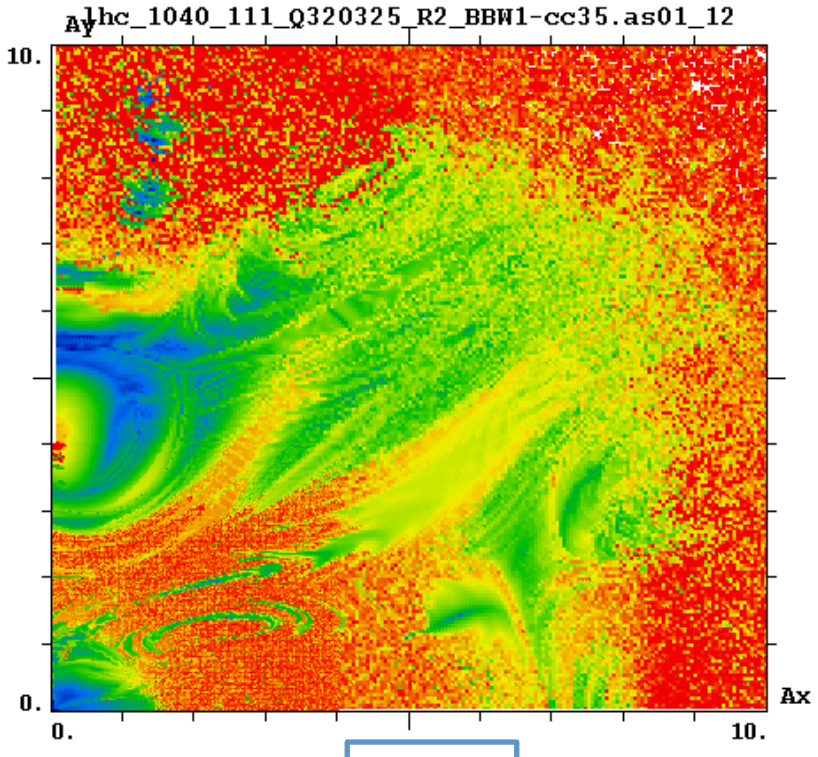
Crab Kissing Results

b=40/10 Np=2.2 x=340 A=11.7 CK=7MV CC=3.5MV



$A_s=0$



$A_s=1\sigma$

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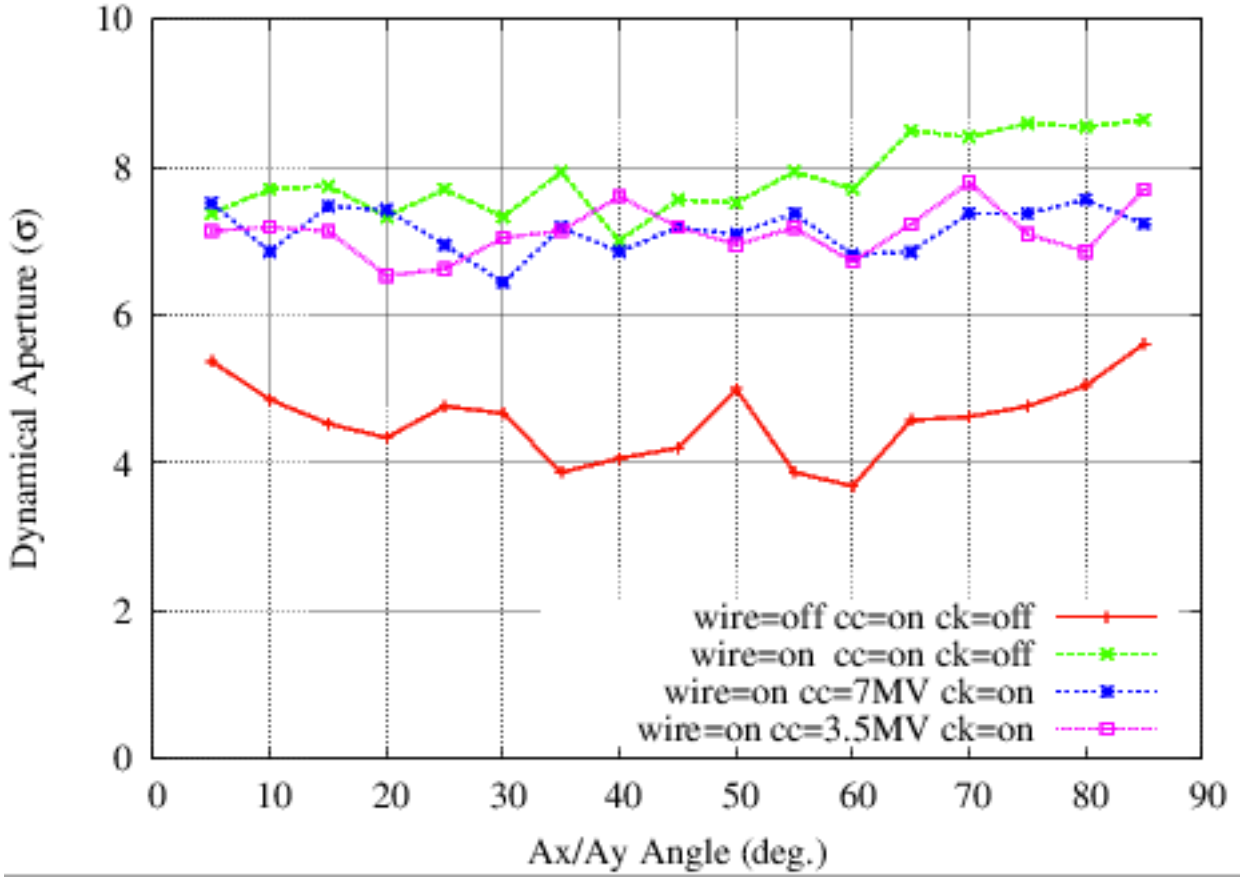
Crab Kissing Results



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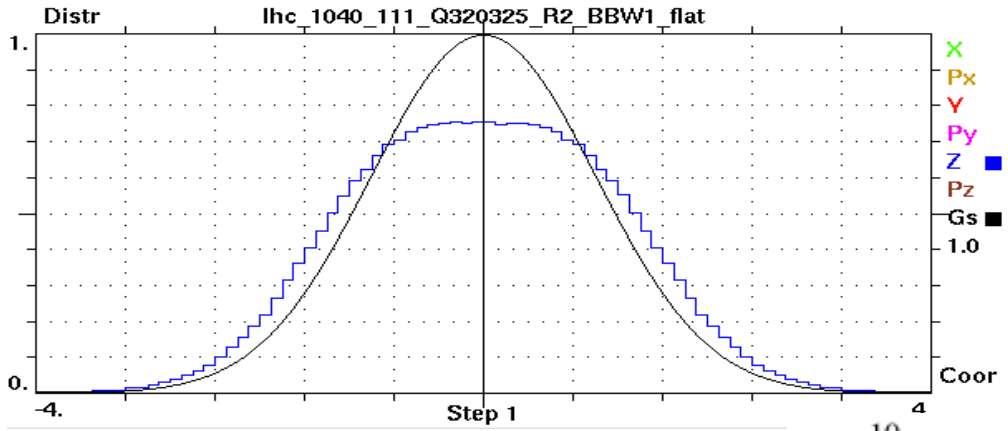
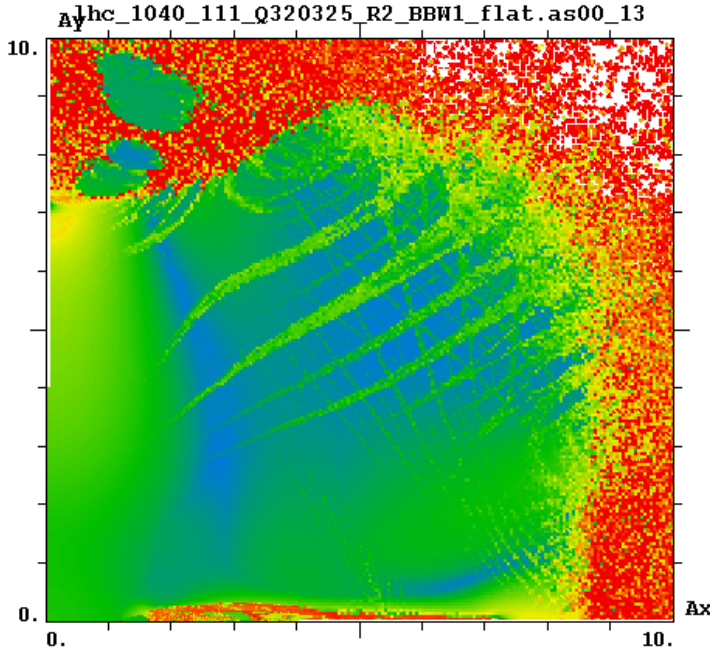
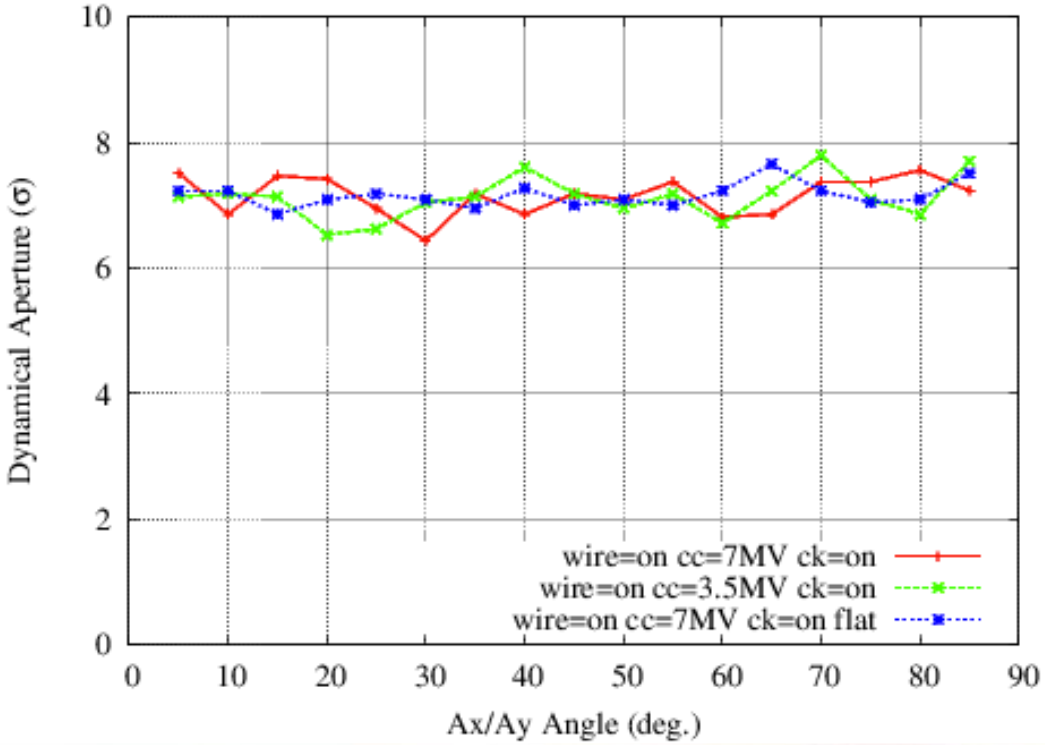
Crab Kissing with Flat Bunches







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Optimization of Parameters – Omitted

- Distance to wire with 340 μrad in the presented optimized case is 10 σ beam (8.5 σ collimation)
  - Alternative solution exists to place wire at 11.5σ (10σ collimation)
- Resonance Driving Terms to cancel with wire
  - Position of the wire
  - Importance of IR8 – adds 0.01 tune shift and enhances 10×Q_x resonance
  - Optimization of tune working point

Electron Lens as BBW

R. Steinhagen, 3rd Joint HiLumi LHC-LARP Annual Meeting, Daresbury 2013

- No limit on the distance from circulating beam
- Easy position adjustment, no mechanical moving parts

A.Valishev and G.Stancari, `http://arxiv.org/abs/1312.1660`

- In the simplest case wire must compensate the kick of N_{LR} collision points $\mathcal{L}_1 = eN_p c(1+\beta) \cong 2ecN_p = 2ec \times 2.2 \cdot 10^{11} = 21\ A \cdot m$
- Current wire produces kick through magnetic field

$$\Delta p_r = \int e\beta c B_\varphi dt = (L \cdot I) \times \frac{e}{2\pi\varepsilon_0 c^2}\frac{1}{r} \qquad \mathcal{L}_{LR} = N_{LR}\mathcal{L}_1 = 18 \times \mathcal{L}_1 = 378\ A \cdot m$$

- Electron Lens produces kick through electrical and magnetic field: gain factor 6 in current! $\Delta p_r = \int e\left(E_r + \beta c B_\varphi\right)dt = (L \cdot I)\frac{1 \pm \beta\beta_e}{\beta\beta_e} \times \frac{e}{2\pi\varepsilon_0 c^2}\frac{1}{r}$

L_{EL}=63 A m

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Summary and Discussion

- Baseline HL-LHC scheme presents no problem w.r.t. weak-strong beam-beam
- A risk reduction solution without CC based on BBW is feasible (HL-LHC 'Plan B')
- We found a robust solution with Crab Kissing in combination with BBW and 2nd harmonic RF that allows to halve the pileup density ➔ may open way to increase of leveled luminosity beyond 5E34
- Preliminary strong-strong results from K.Ohmi do not indicate any showstoppers for CK
- Further optimization and investigation of imperfections is required