Electron Lens Simulation Updates

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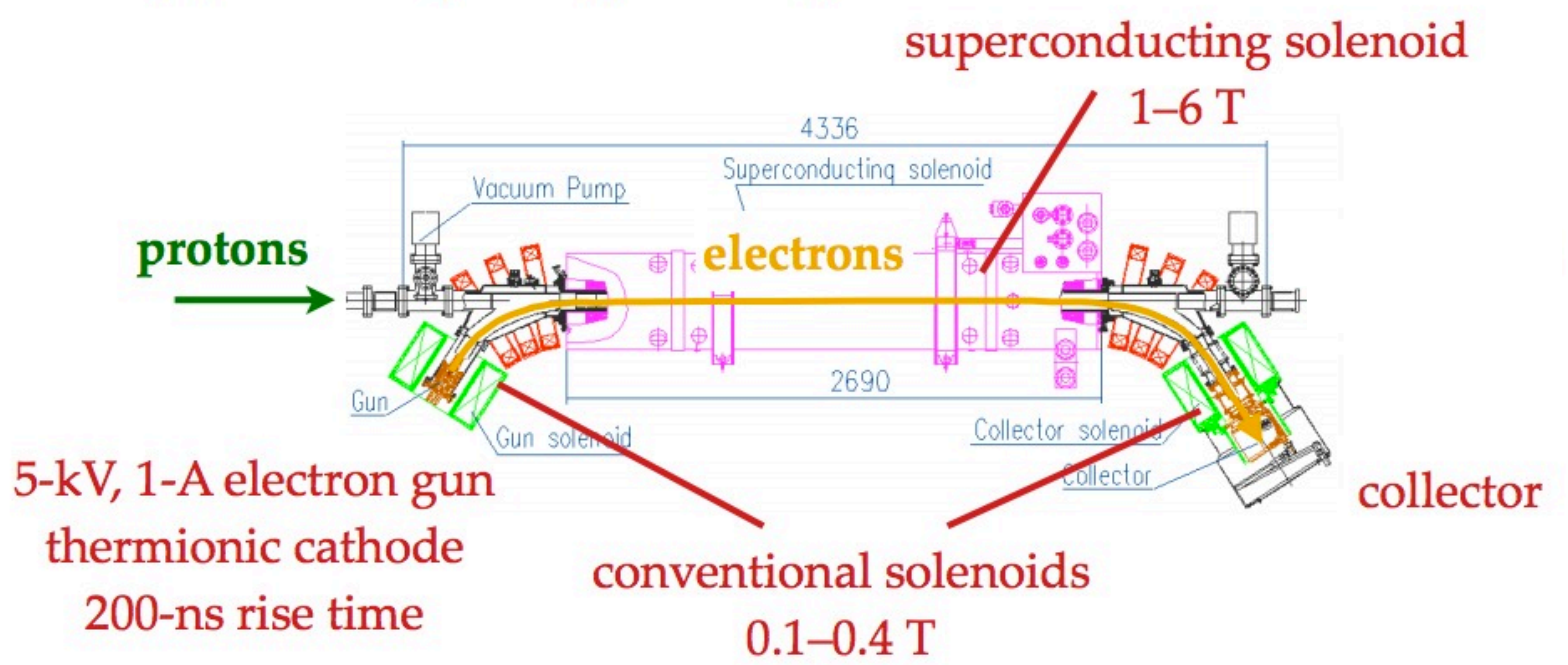
the e-lens: what is it and why is it interesting?

The e-elens is a device generating an electron beam which travels parallel (overlapped) with the p-beam



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A hollow electron beam has been proven (Tevatron experience) to be an effective scraping device (see Giulio's presentations).

the e-lens: what is it and why is it interesting?

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A hollow electron beam has been proven (Tevatron experience) to be an effective scraping device (see Giulio's presentations).

Main advantages w.r.t. conventional scraping:
- no "hard" material close to the beam (MP, impedance)
- size can be easily/quickly changed acting on magnetic fields
- great flexibility:
  - scraping efficiency can be tuned by acting on e-beam current / operation mode
  - device can control groups of bunches individually

The "e-lens for LHC" project so far

- E-lens review in November 2012 @ CERN: outcomes
  - first integration studies: identified possible installation locations in LHC
  - strong experimental evidences from Tevatron measurements
  - first simulation results assessing beneficial effects of the electron lens
- Positive feedbacks, however installation in LS1 is not feasible
- FNAL and CERN have agreed on the roadmap:
  - the device will be responsibility of BI (CERN)
  - integration studies will be carried out by ME group (CERN)
  - the Physics study is to be lead by FNAL -> delivery of a conceptual design by next collaboration meeting (Oct-Nov 2013)

plan for conceptual design study

- identify expected scraping efficiency

Scraping efficiency:
First answers by SixTrack simulations

- implication on beam dynamics

Realistic e.m. field computation & non linear map for proton beam core

- integration (not covered here)

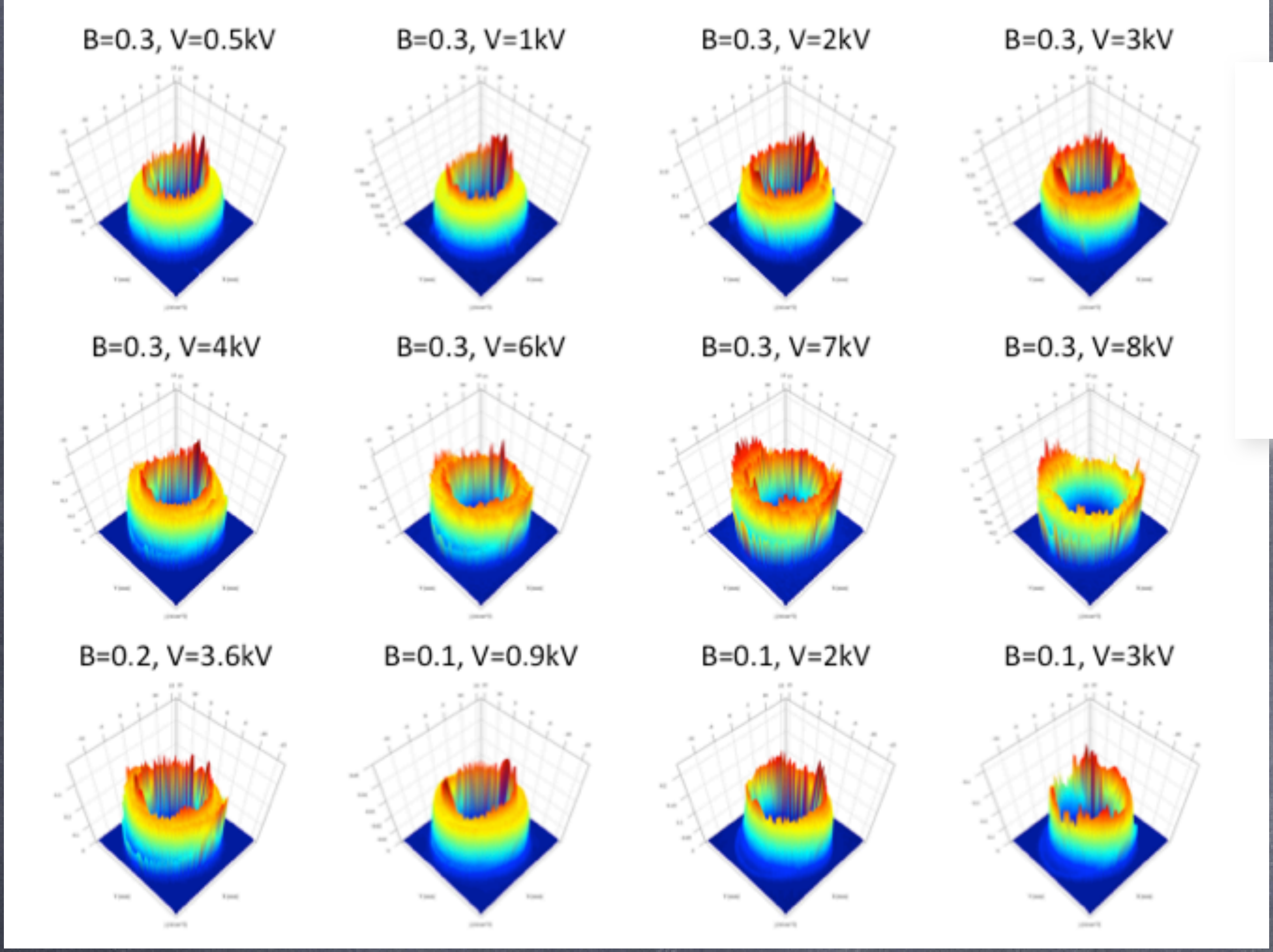
WARP calculations

Vince Moens, CERN technical student, now @FNAL

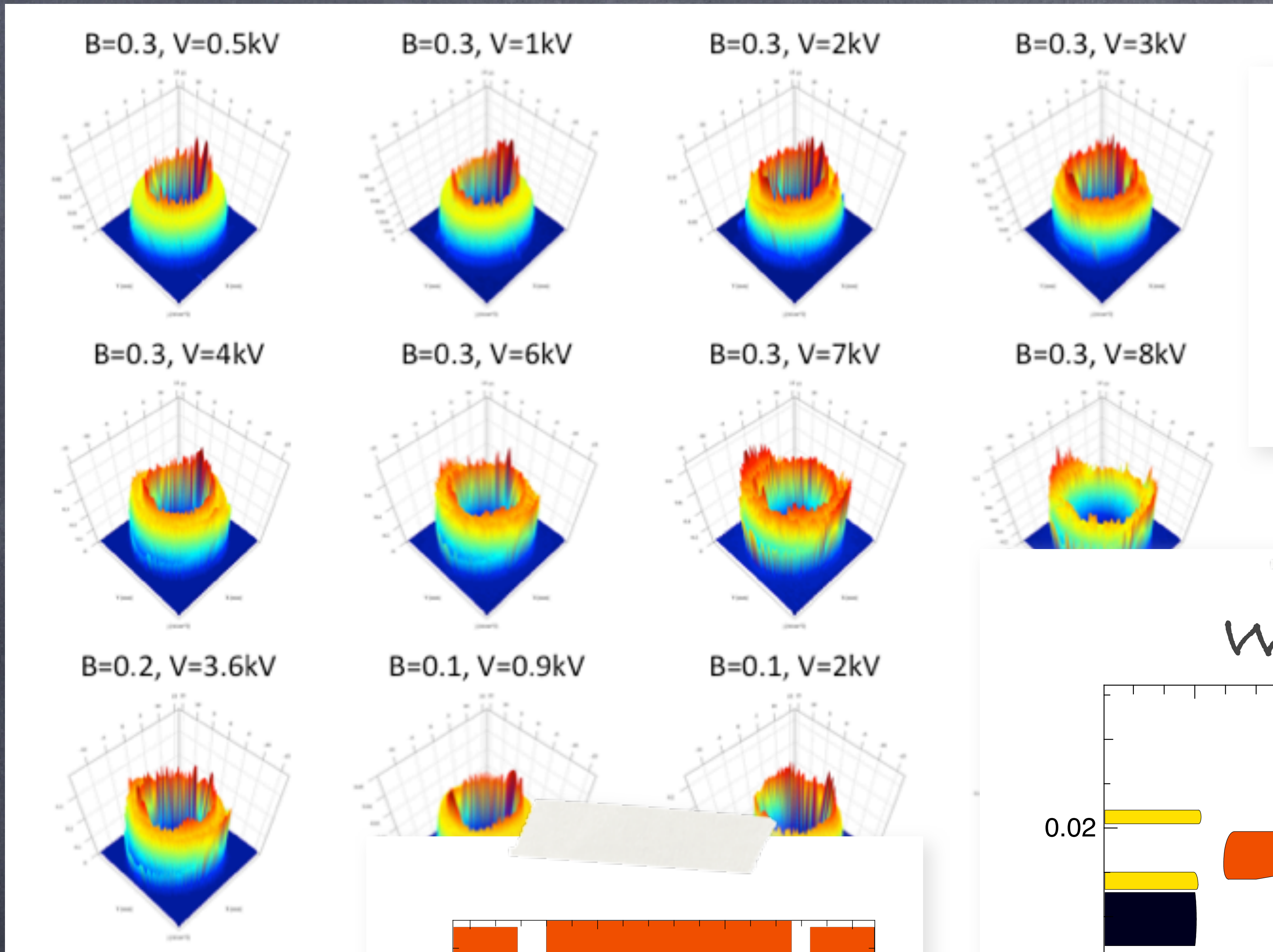
possible e-lens issues

Realistic e.m. field computation & non linear map for proton beam

- WARP: particle in cell plasma 3D code which computes the e-beam evolution in space and the associated e.m. fields.
- Detailed geometry & electron beam evolutions included
- experimental data on measured profiles on the new high-current 1 in gun are used as benchmark
- Evaluation of e.m. magnetic fields along the p trajectory and creation of a non linear map to be inserted in a tracking code. Detailed evaluation of the e-lens effect on the beam core.
- Identify possible issues related to the e-lens use in the LHC
- code setup is done, results coming soon!



new 1-in cathode measurements used for benchmark



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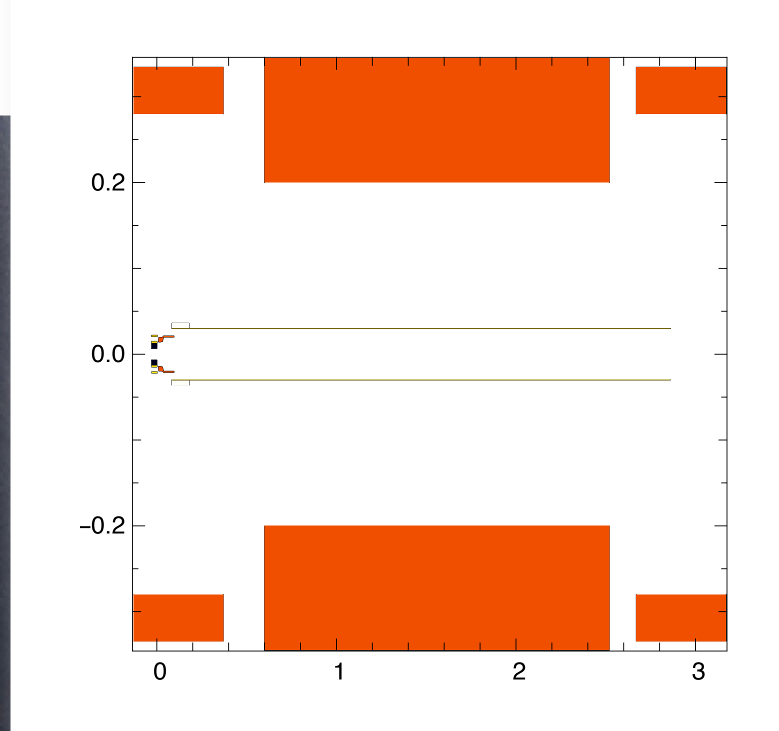
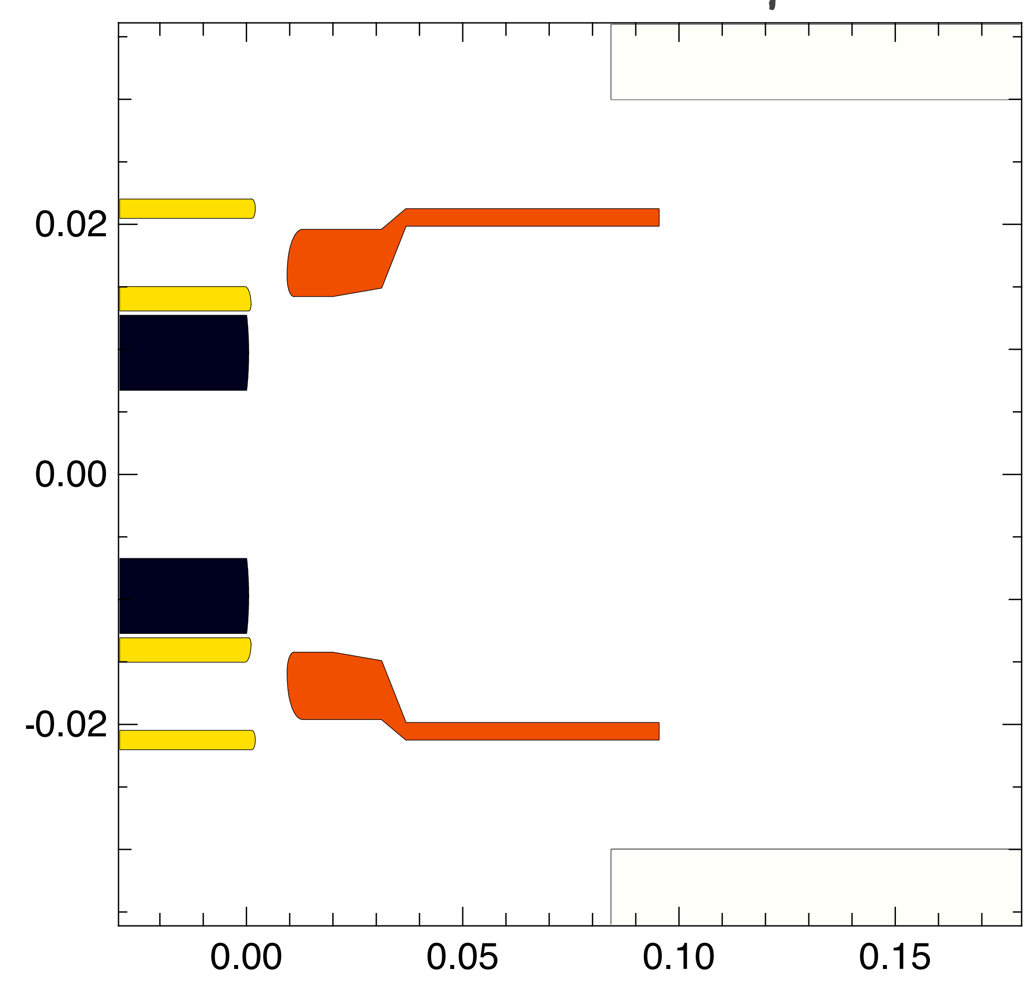


WARP setup



Latest SixTrack results

Valentina Previtali, TOOHIG fellow@FNAL

e-lens advantages

Scraping efficiency: answers by SixTrack simulations

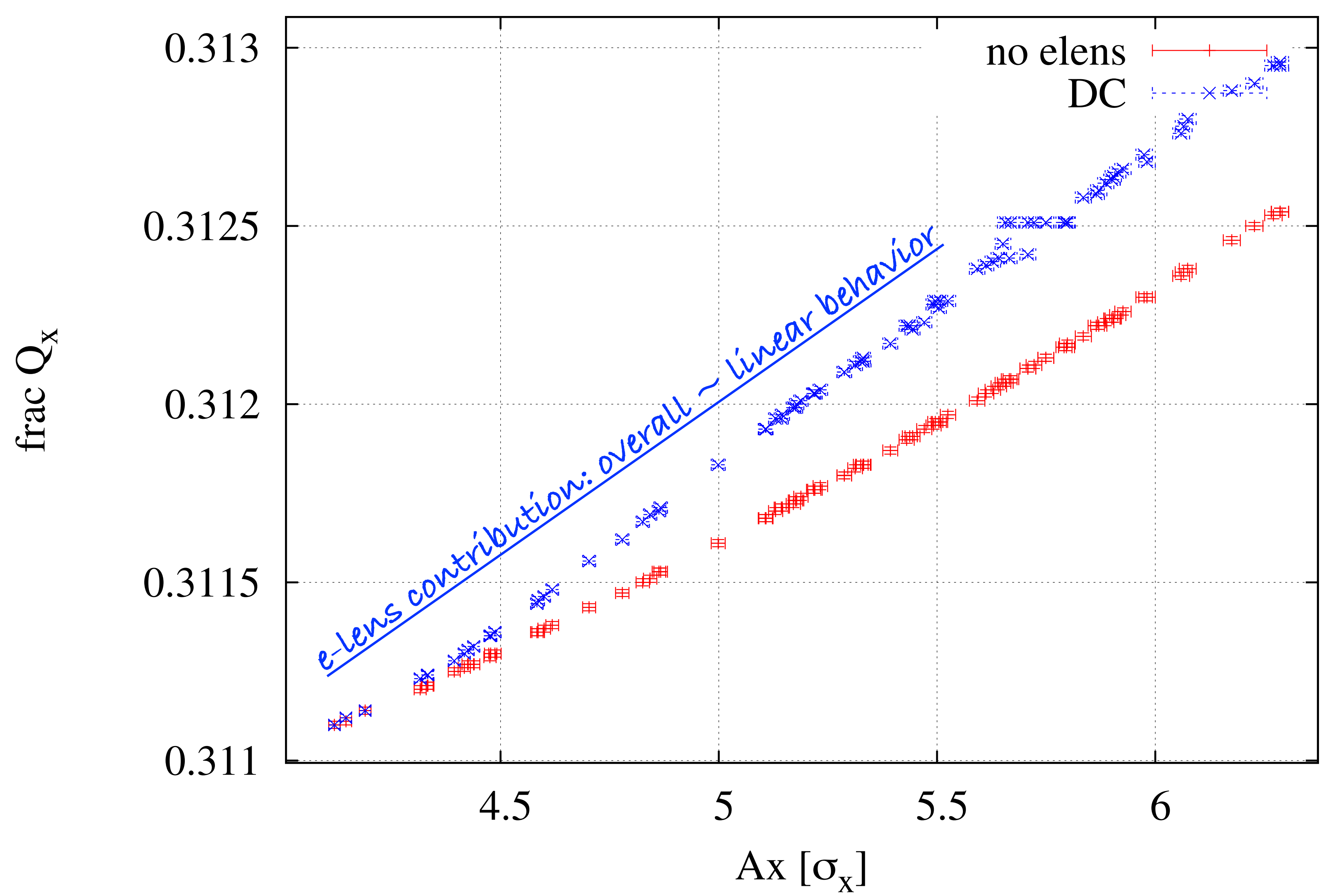
Simulation inputs

- collimation version of SixTrack + elens
- particle number: 6400
- turns: up to 200K
- optics: nominal squeezed LHC 7 TeV
- e-lens inputs: 1,2 A - inner radius 4 σ_x
- collimation inputs: only primary collimators at 6 σ_x
- initial distribution: horizontal distribution between 4 and 6 σ_x, no off momentum

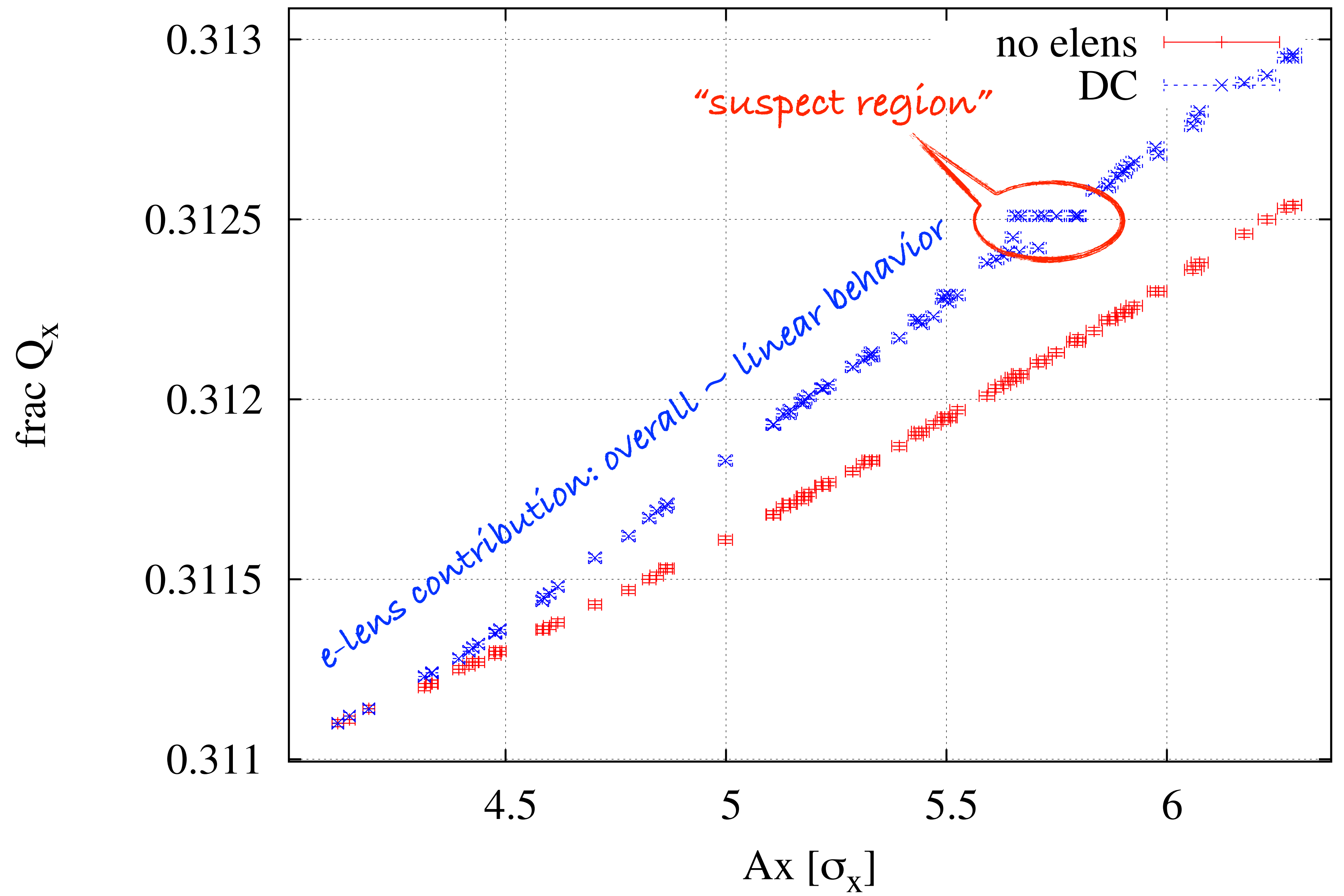
Latest SixTrack results

- 3 operation modes have been identified so far:
  - **DC mode:** e-lens is ON (scraping relies on the strong non linearity of lens field)
  - **AC mode:** e-beam is modulated with particle tune (improved from last presentation, see details later)
  - **diffusive mode:** e-beam current is randomly switched off or on on turn-by-turn basis

DC mode

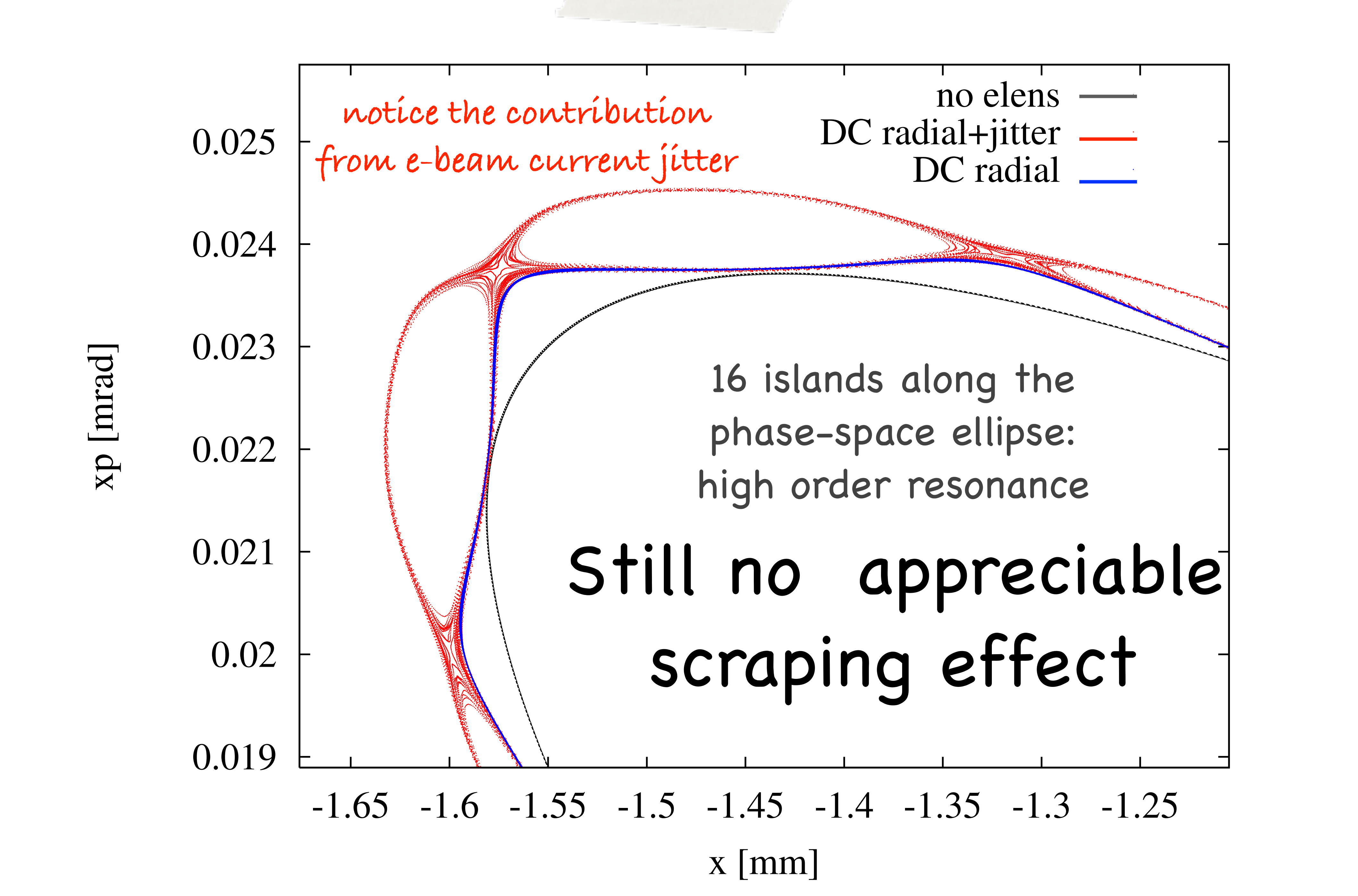

0.313
0.3125
0.312
0.3115
0.311
frac Q_x
4.5
5
5.5
6
Ax [σ_x]
no elens
DC
e-lens contribution: overall ~ linear behavior

DC mode



no elens
DC
"suspect region"
e-lens contribution: overall ~ linear behavior
0.313
0.3125
0.312
0.3115
0.311
frac Q_x
4.5
5
5.5
6
Ax [σ_x]

resonance at about 5.7 σ_x



AC mode

- trying to attack the problem analytically:
  - Harmonic oscillator with a driving force which depends on time and position.
    The problem is solvable for non-hollow elens, uniform e-beam (landau, parametric resonance)

$$m\ddot{x} + \left[k + k_{DC}(1 + \sin\omega_e t)\right] x = 0$$

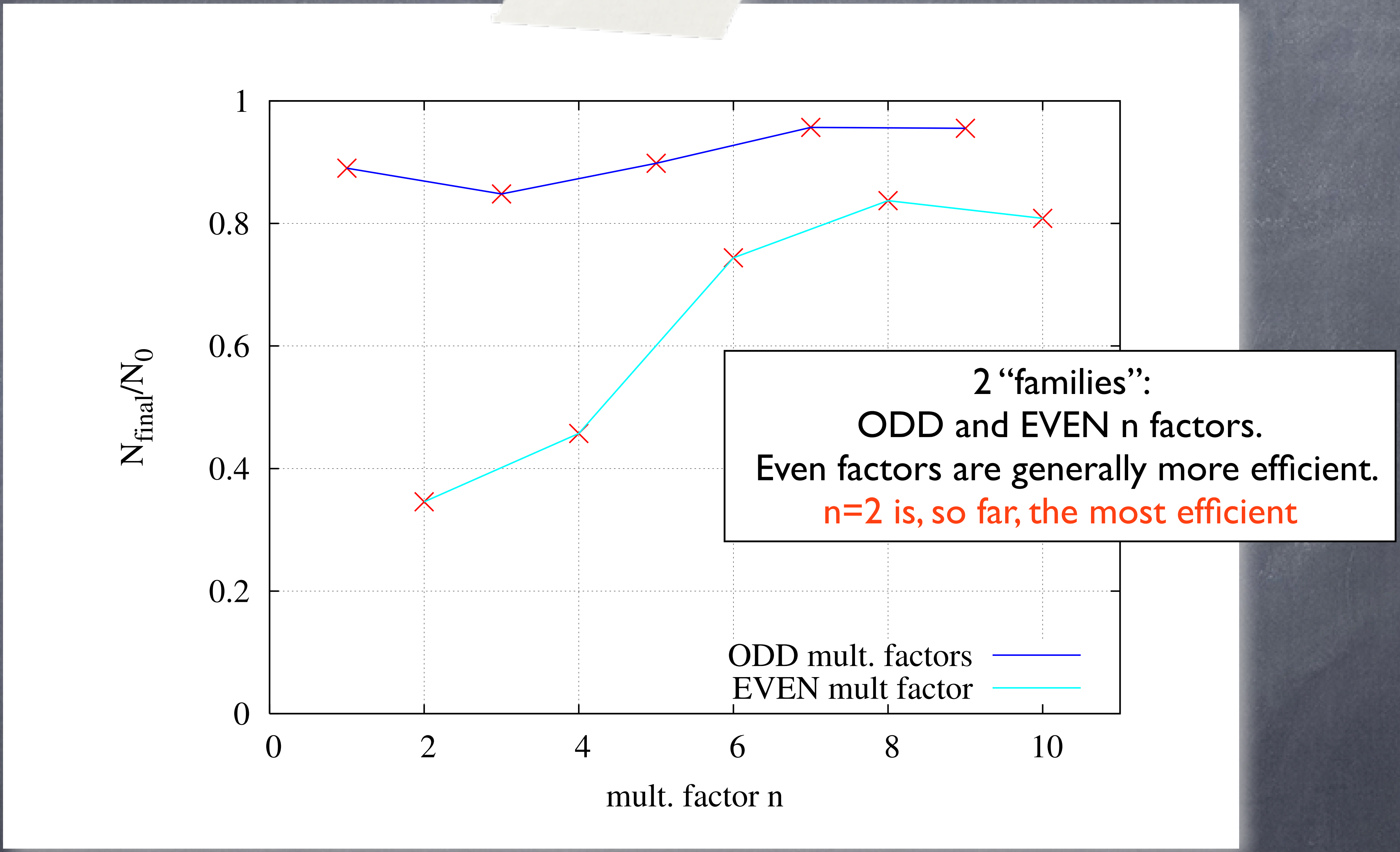
  - for this case $\omega_e = 2\omega + \epsilon$

n=2

Resonance frequency is double of the system "natural" oscillation frequency

- attempt to solve analytically the "hollow" e-lens case not straightforward

finding the resonance frequency by "brute force"



I simulated the scraping effect of an el-lens driven by different multiples of the natural frequency $n\omega_0$, with the multiplying factor n in the range {1, 2 ... 10}

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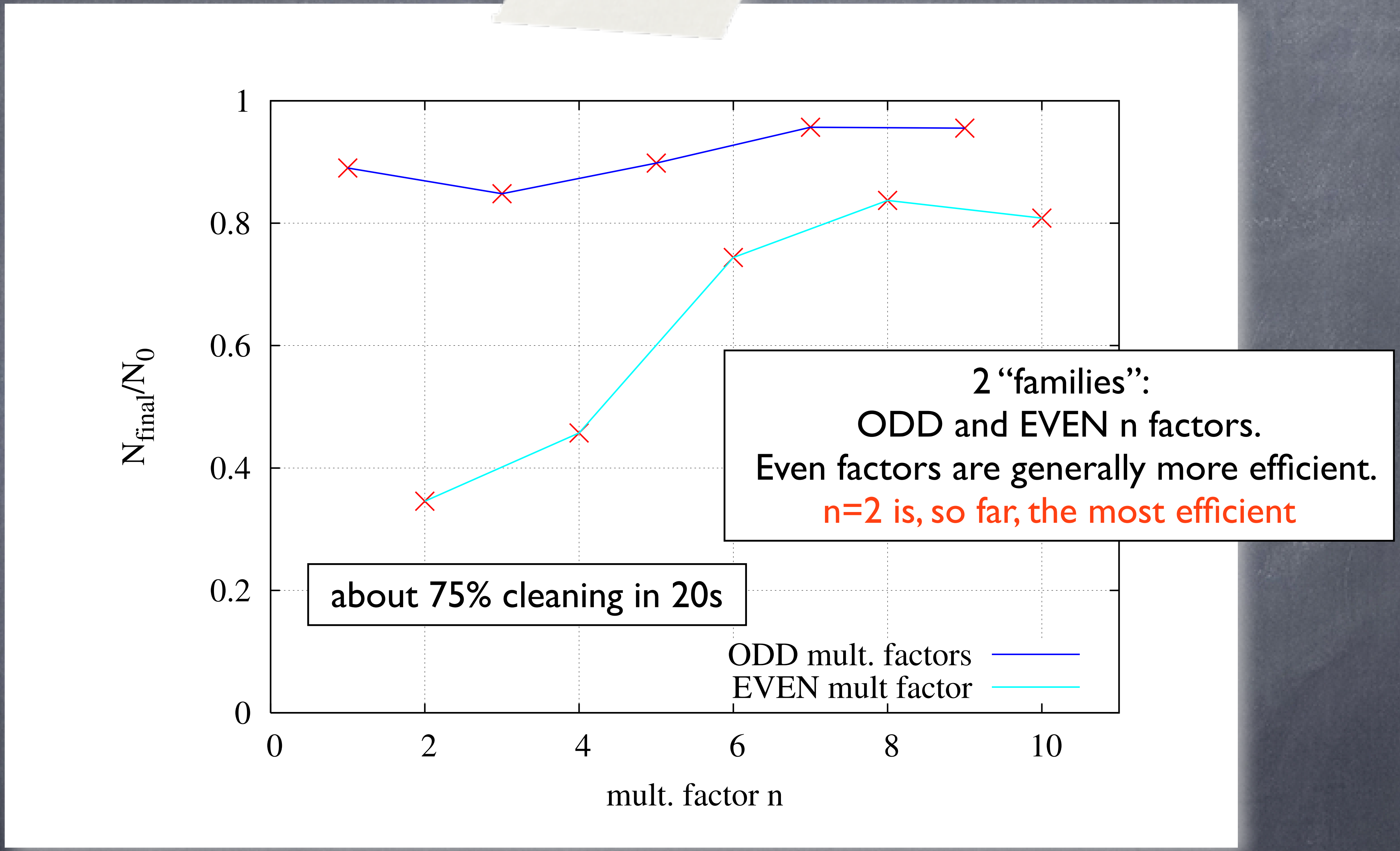

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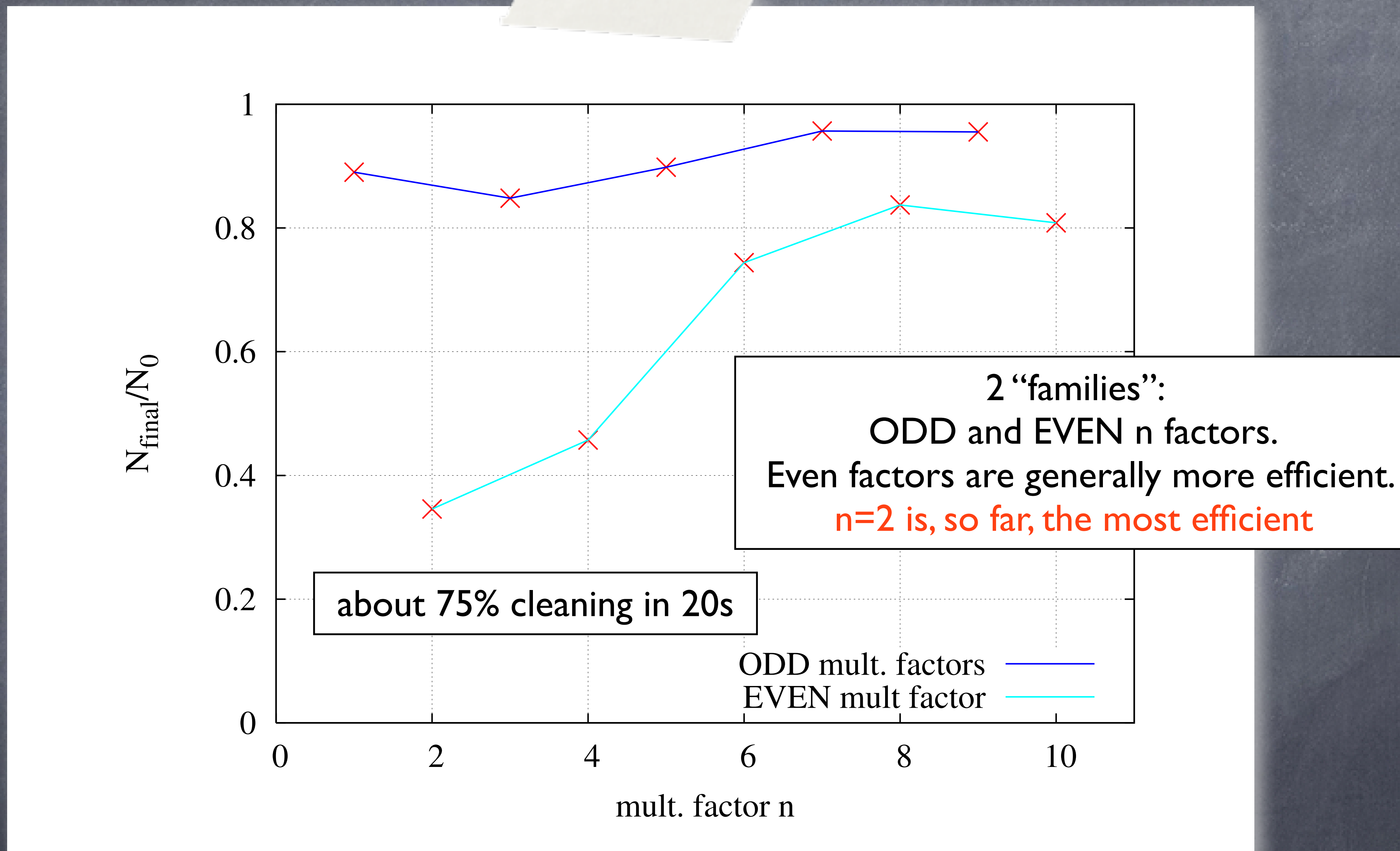

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what is ω_0???

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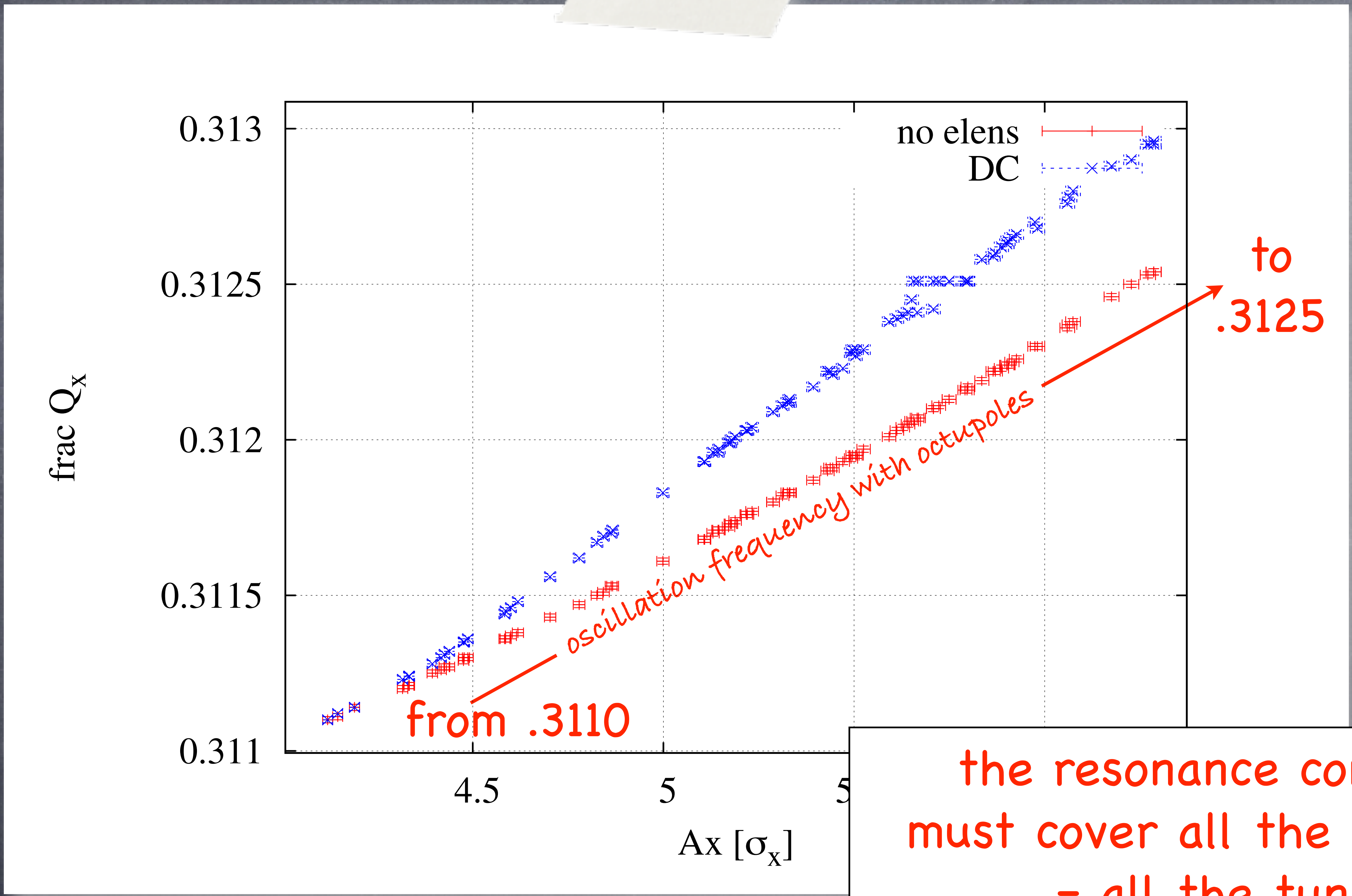
We have seen from the study of the tune that there is no a single "natural frequency" of the system



the resonance condition must cover all the particles = all the tunes

repeat cycles over all the tunes (optimization in progress)

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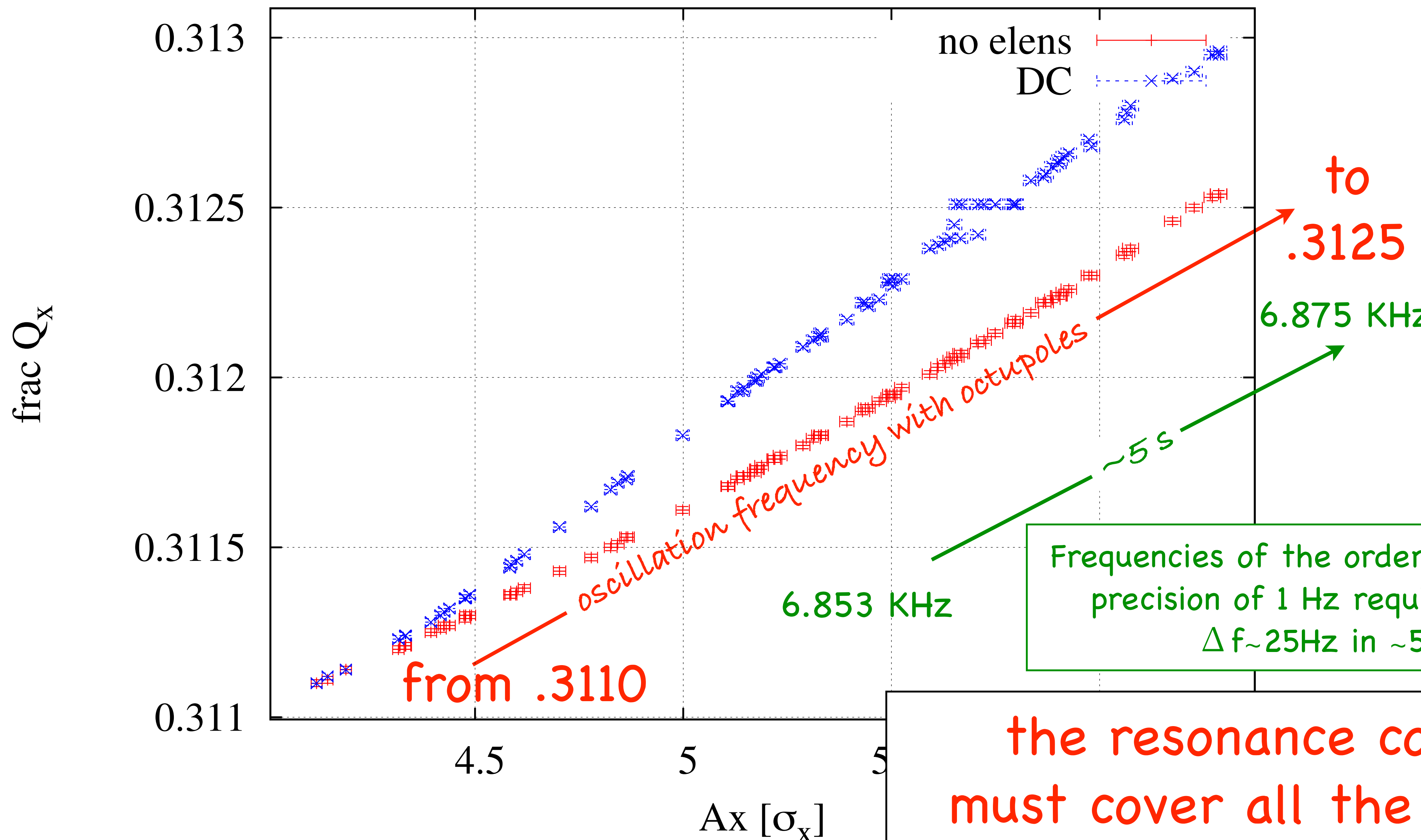
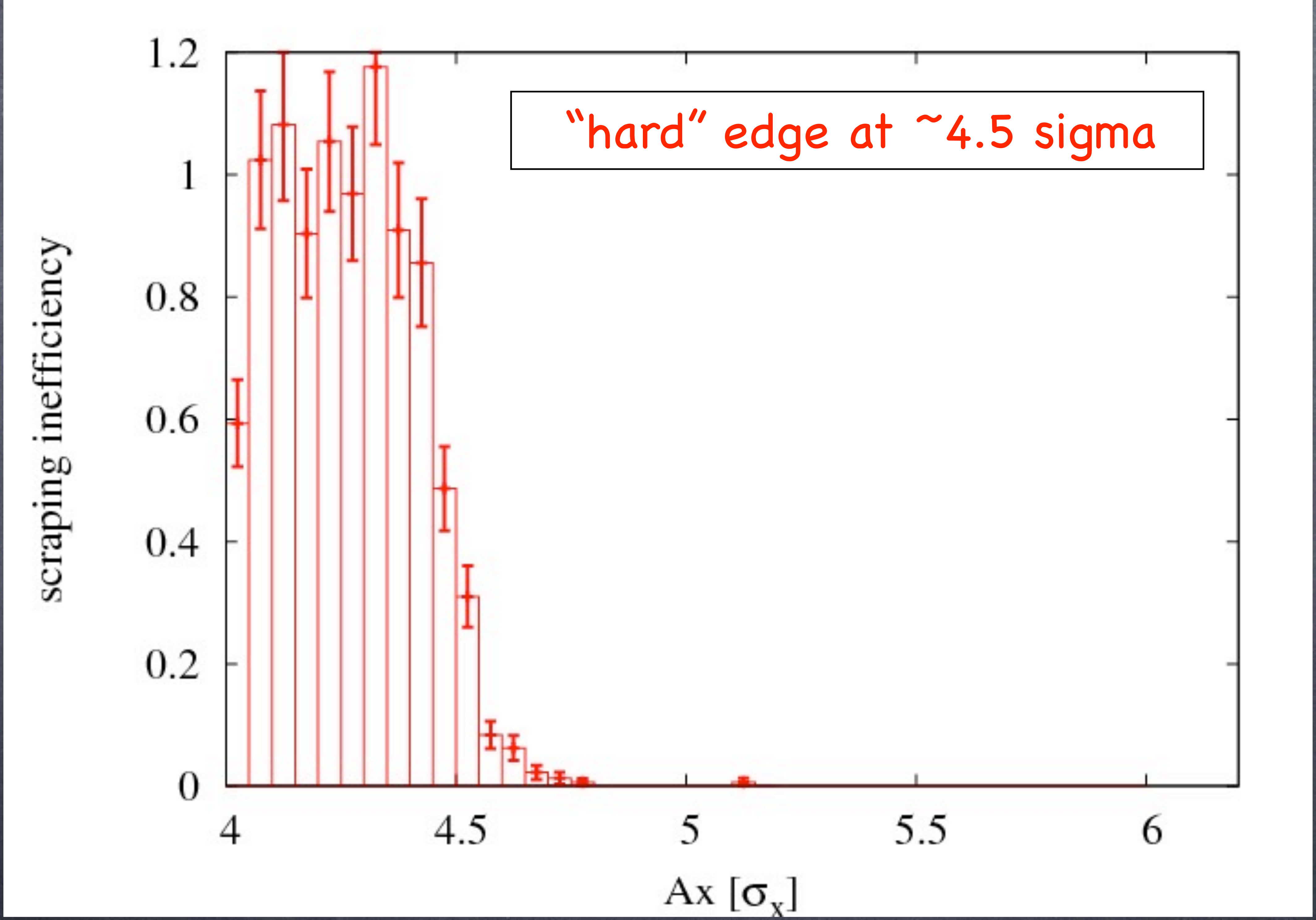


Frequencies of the order of 6.8 KHz, precision of 1 Hz required, total Δf~25Hz in ~5 s.

the resonance condition must cover all the particles = all the tunes

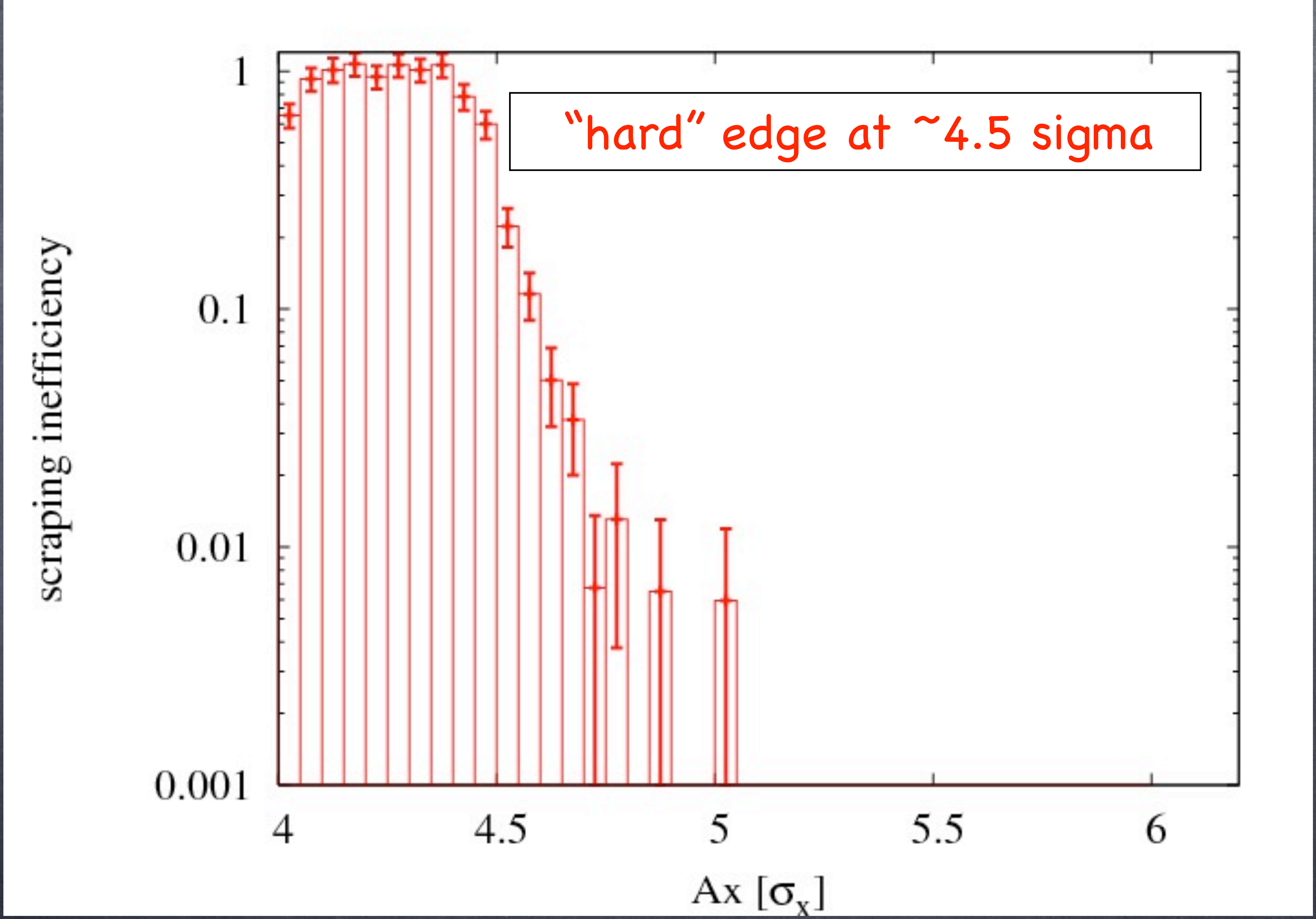
repeat cycles over all the tunes (optimization in progress) is 75% enough?

effect on the halo while we cycle the resonant frequency over tune range (1 full cycle about 5 s, total of 4 cycles)



https://dl.dropbox.com/u/7248203/AC_movie.gif is 75% enough?

effect on the halo while we cycle the resonant frequency over tune range (1 full cycle about 5 s, total of 4 cycles)

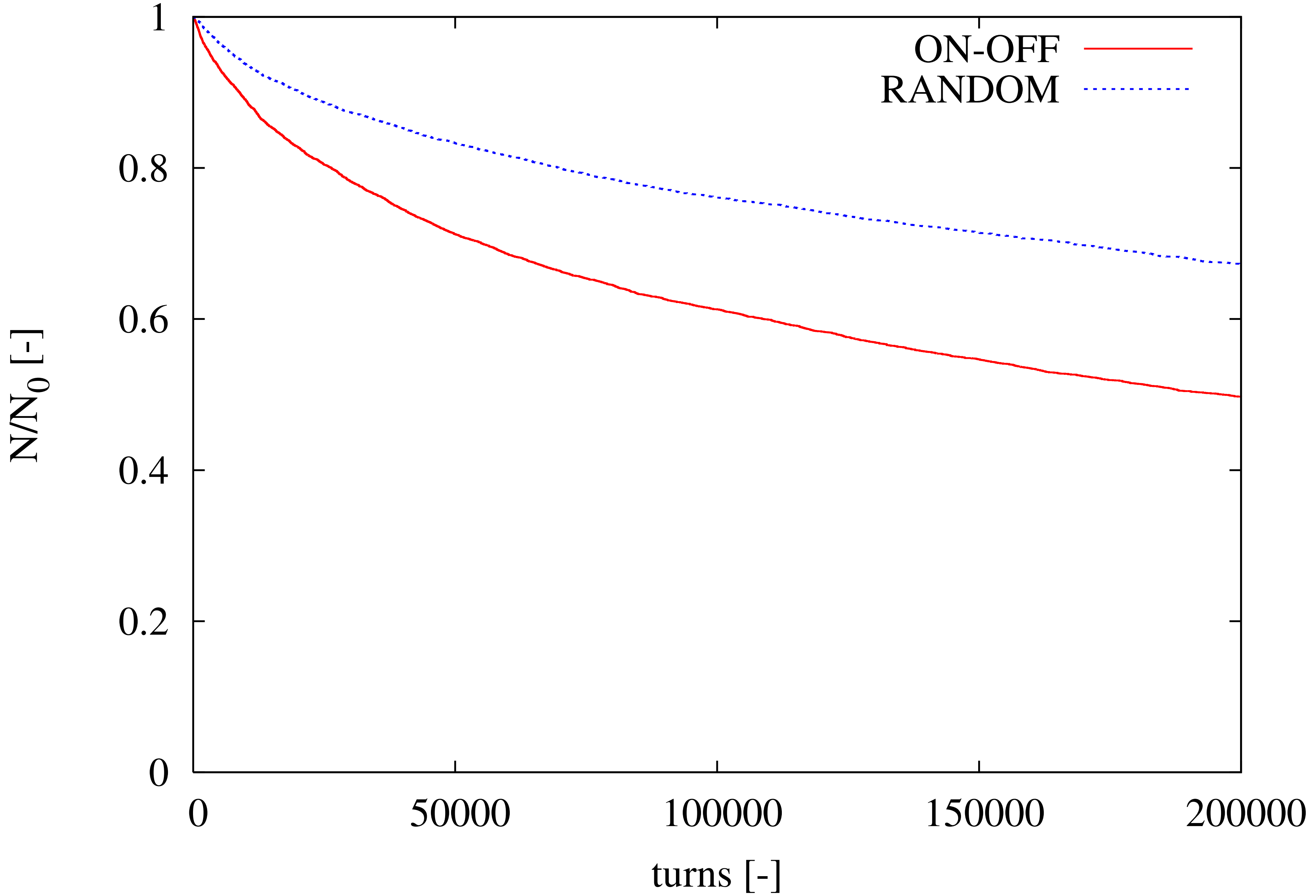


https://dl.dropbox.com/u/7248203/AC_movie.gif

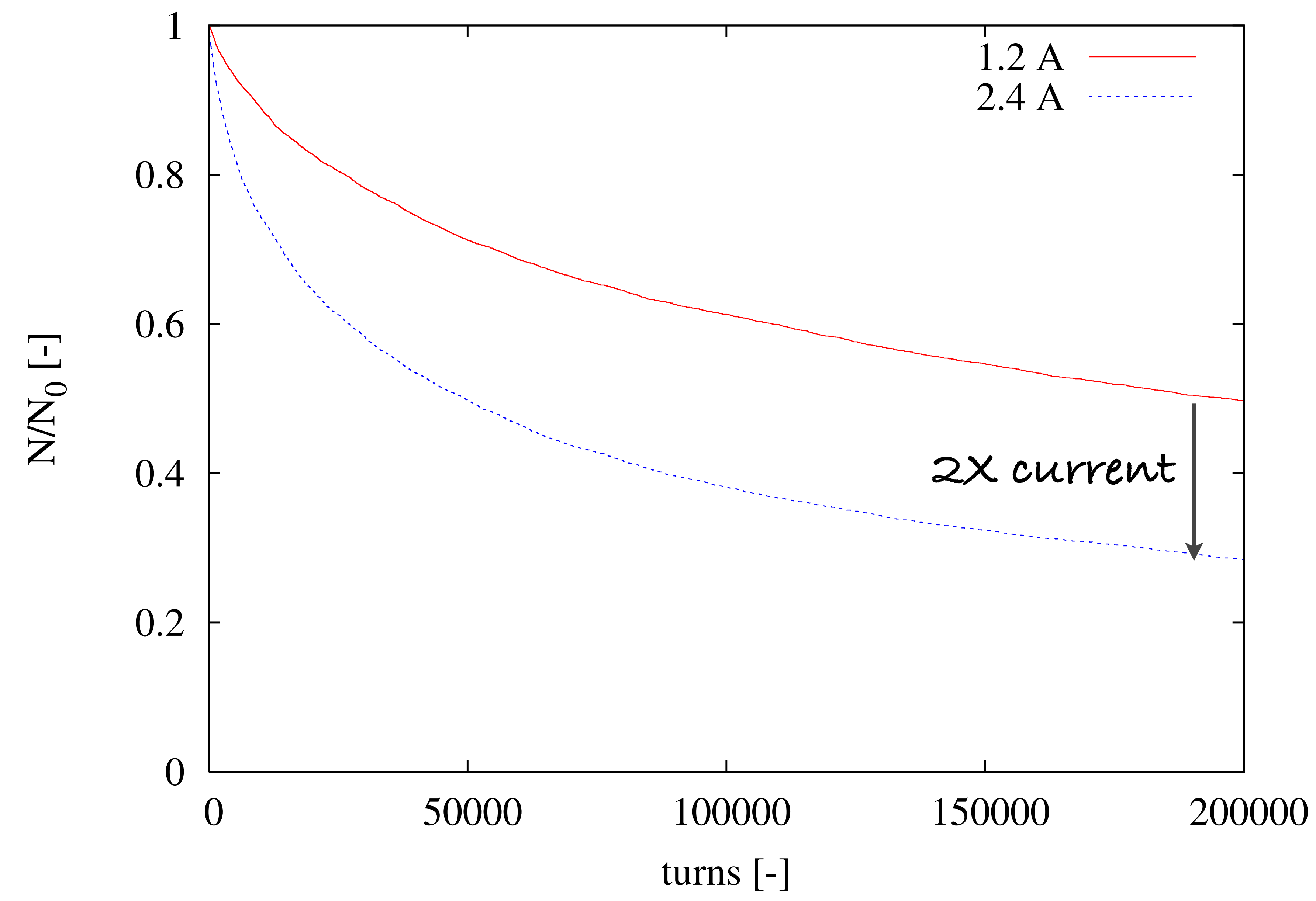
Diffusive mode

- 2 different random mode tested:
  - ON-OFF mode: then electron beam was either reduced to zero (OFF) or at its full power (ON) randomly on a turn-by-turn basis.
  - Random mode: the electron beam current was modulated on turn by turn basis by a random multiplier in the range [0,1];
- Smoother-slow scraping
- PROS
  - completely uncorrelated with the particle state (both amplitude and tune)
  - works simultaneously for Vertical and Horizontal plane
  - the scraping efficiency can be easily increased by in- creasing the beam current.
- CONS:
  - not "hard-edge" as AC mode

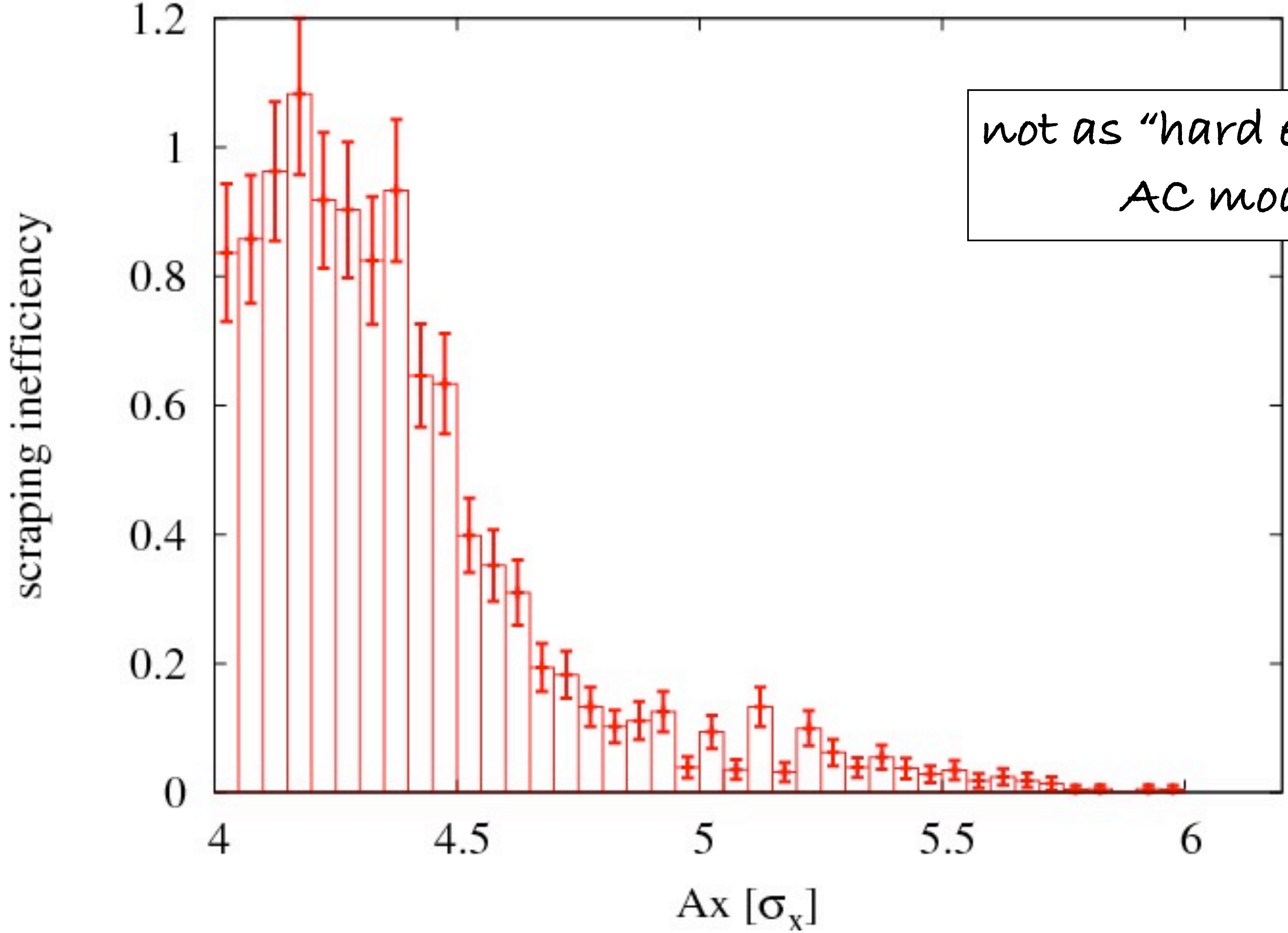
Random vs ON-OFF



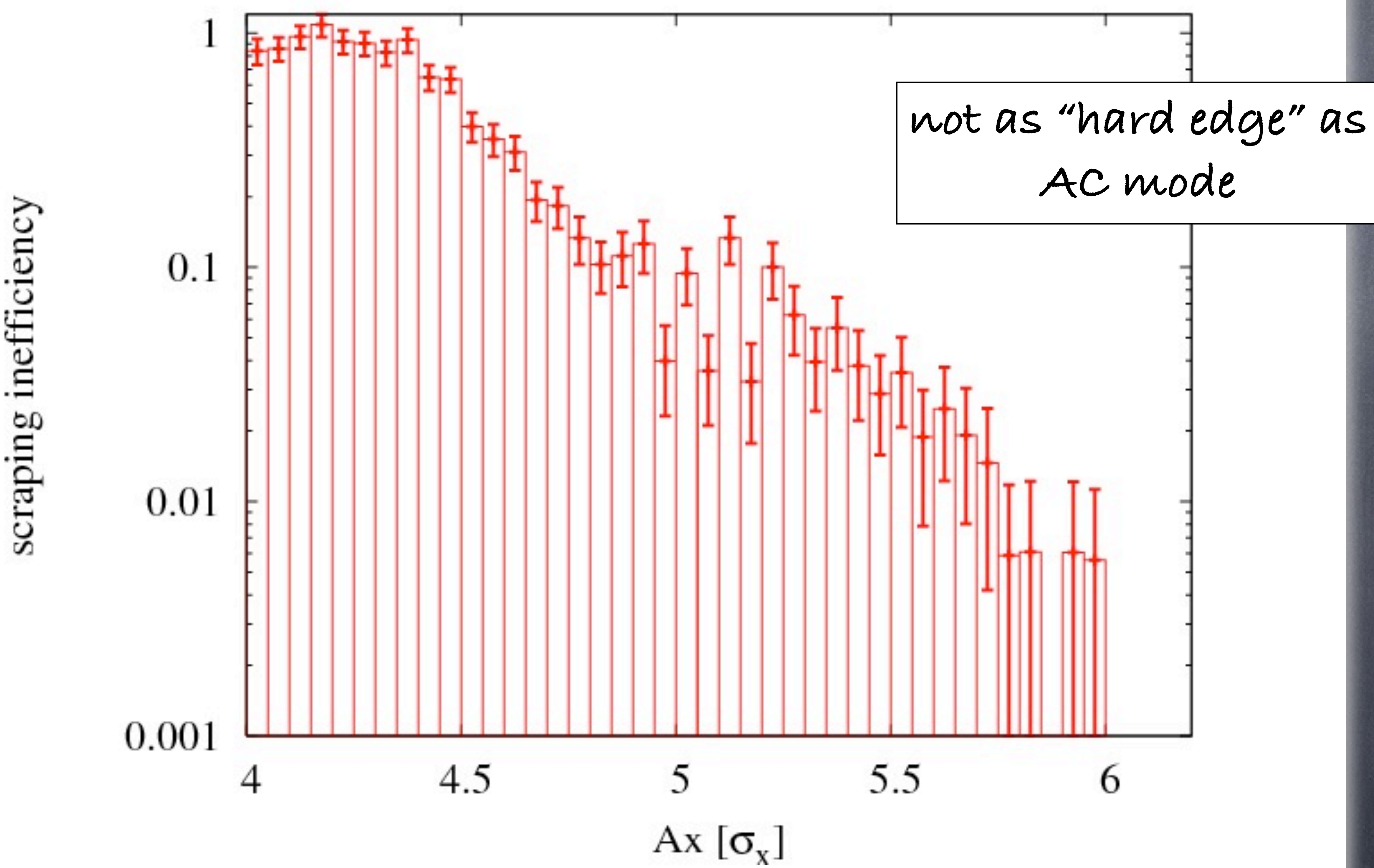
scaling with the current



almost reaching the performances of AC mode



not as “hard edge” as AC mode



1
0.1
0.01
0.001
scraping inefficiency
4
4.5
5
5.5
6
Ax [σ_x]
not as "hard edge" as AC mode

Conclusions

- preliminary results with 6track are encouraging (N/N0 < 25% in 20 s)
- identified diff op modes which allow us to go from smooth to fast cleaning
- Diffusive mode seems to be preferable for:
  - easy operation mode
  - flexibility
  - independent of particle tune
- characterized performances of new e-gun designed for the LHC (4A, 10 KV)
- simulation of details of e-beam with WARP, studies of impact of e-lens on beam core
- working of conceptual design for LHC in collaboration with LHC collimation working group

Thanks :)

Reserve Slides

The "e-lens for LHC" project so far

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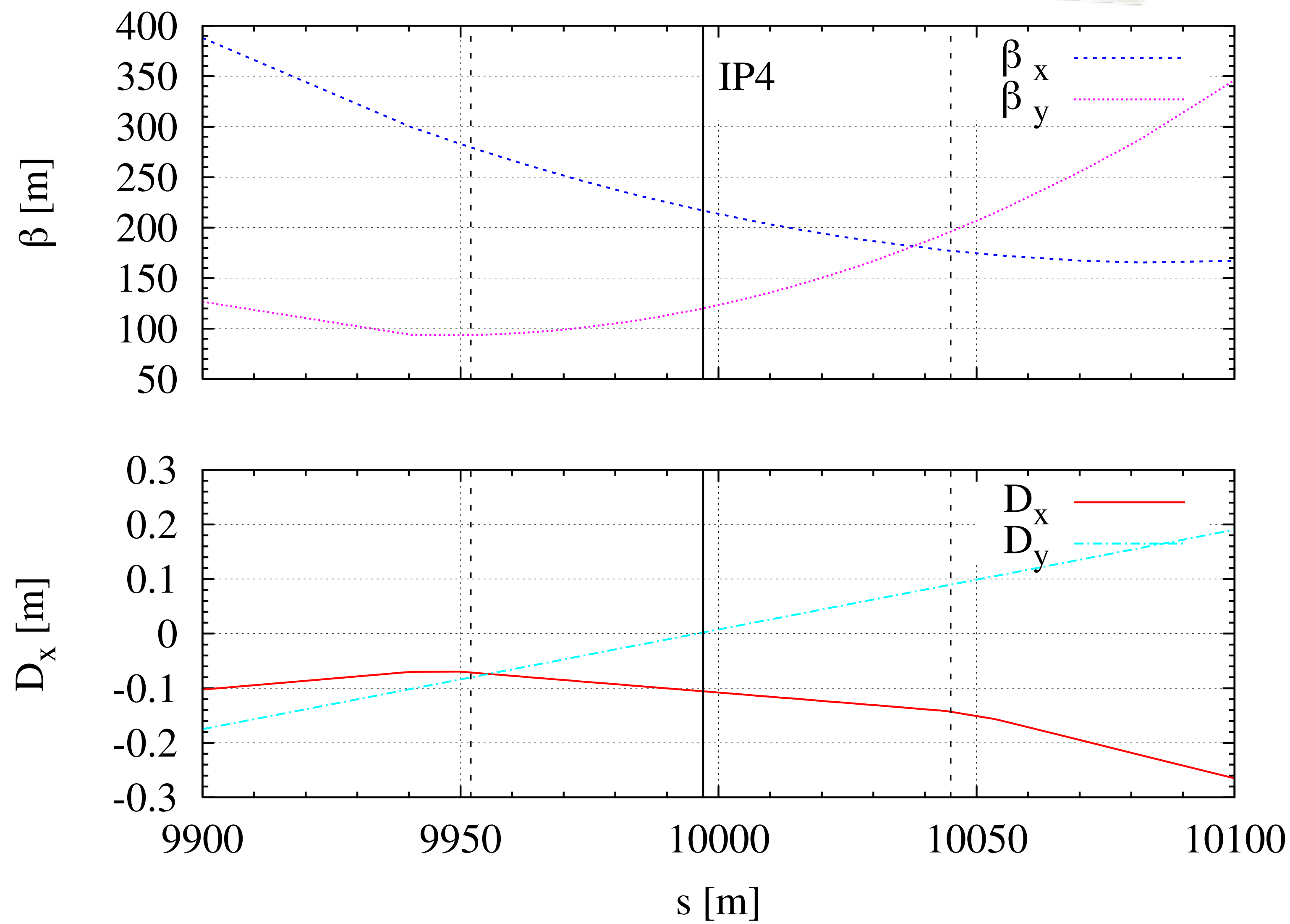
  - identified possible installation locations



identified an optimal location downstream IP4.

Space is available (for the moment).

First integration studies are promising (Adriana, Belen)

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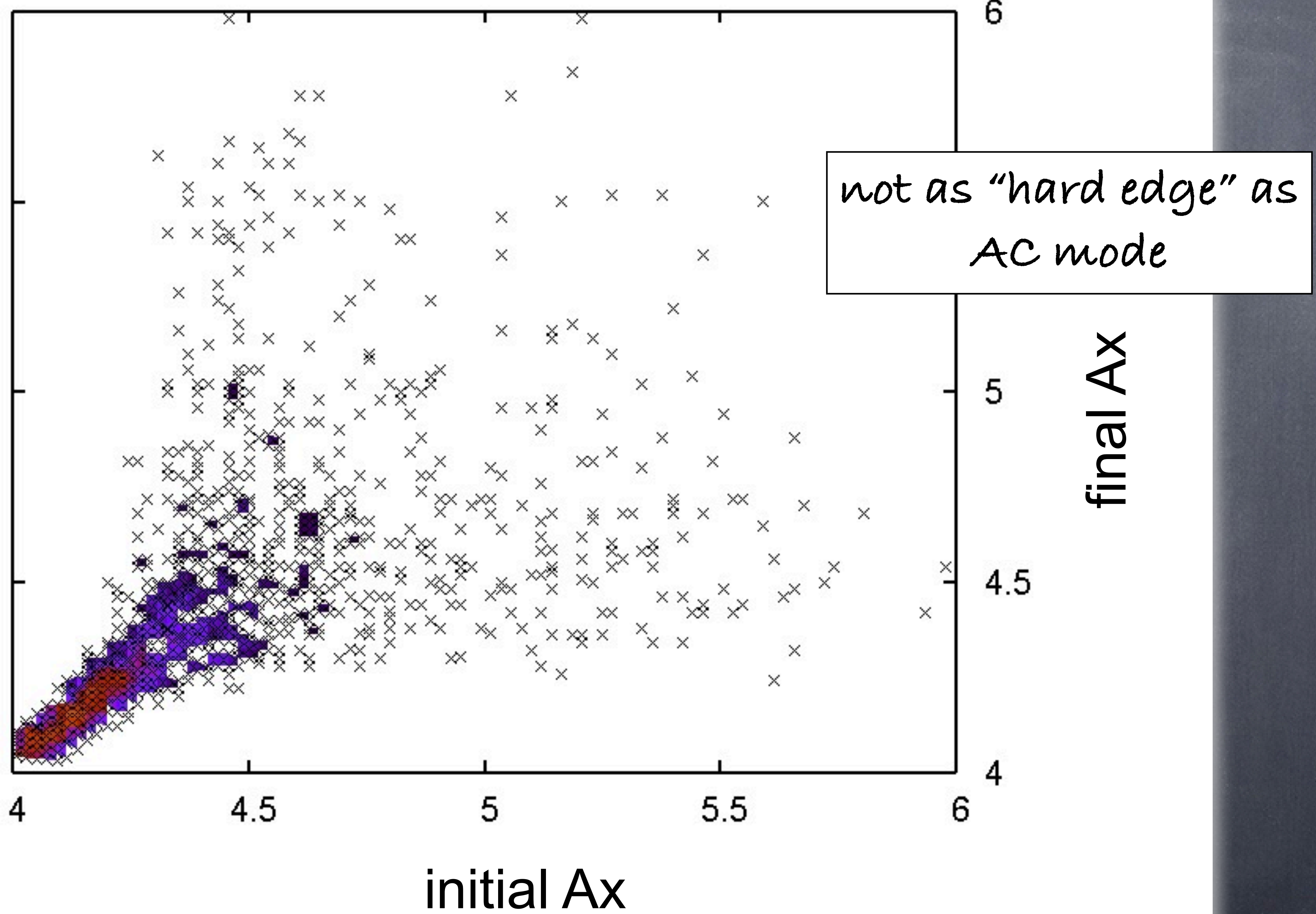
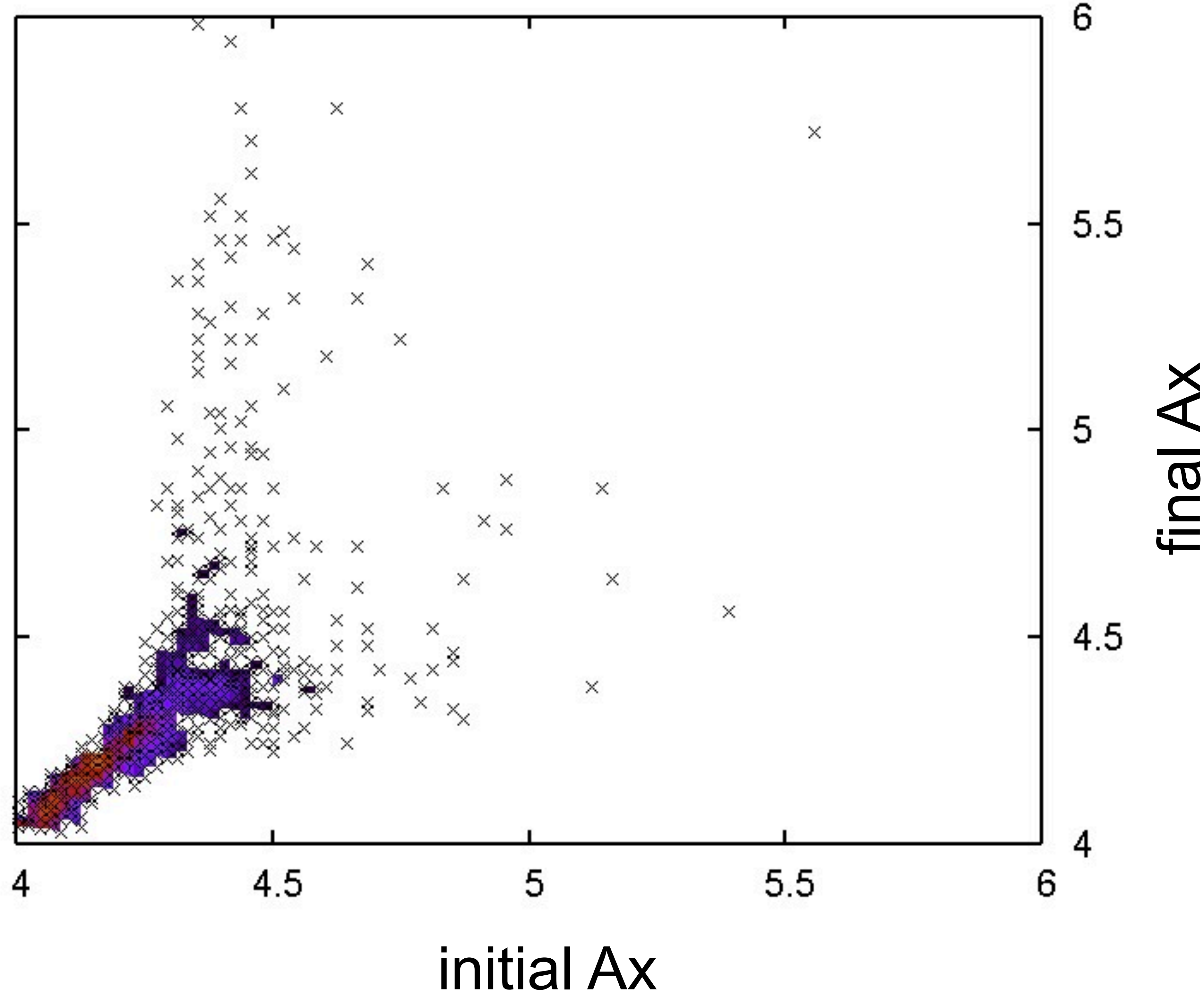


not as "hard edge" as AC mode
6
5
4.5
4
4
4.5
5
5.5
6
final Ax
initial Ax



6
5.5
5
4.5
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4.5
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6
final Ax
initial Ax