FCC-ee Dynamic Aperture @ 175 GeV

Luis MEDINA

UNIVERSIDAD DE GUANAJUATO
División de Ciencias e Ingenierías
Mexico

FCC Week 2015 Rome

Thanks to A. Bogomyagkov, K. Oide, P. Piminov, and F. Zimmermann

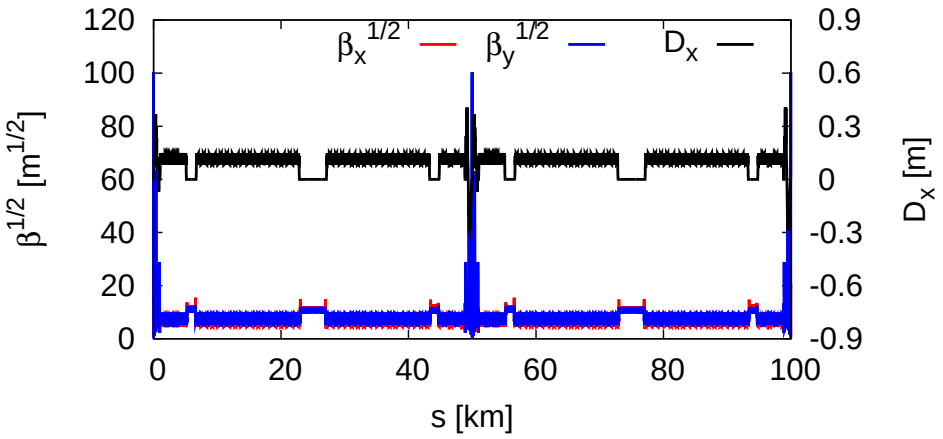
April 14th, 2016

Contents

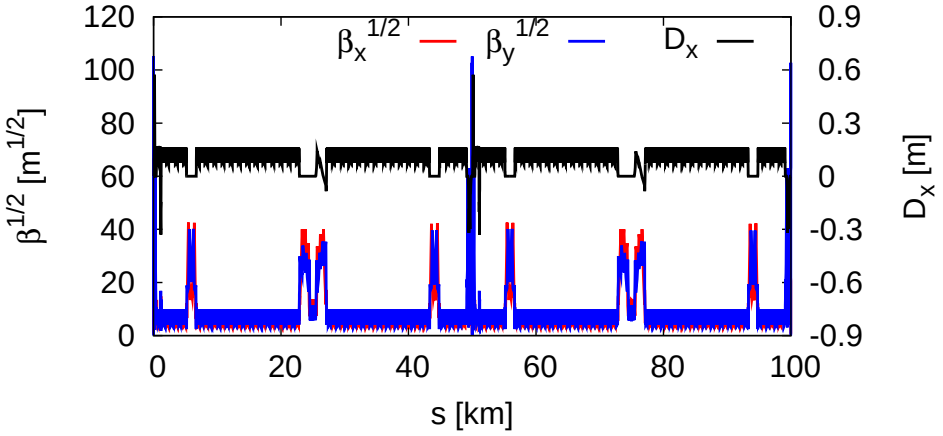
Contents

FCC-ee lattices

- **Review** of DA results.
- Two FCC-ee crab-waist (175 GeV) lattices with asymmetric IRs under study [1].



AB
FCC-ee V9-PS2, 26 mrad, developed by **A. Bogomyagkov** and optimized by **P. Piminov** [4].

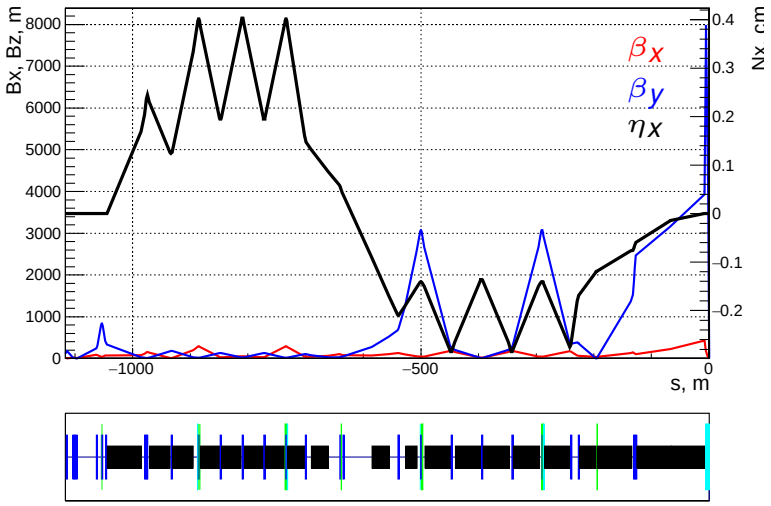


KO
FCC-ee and V74-11, 30 mrad (asymmetric L^*), developed by **K. Oide** [5].

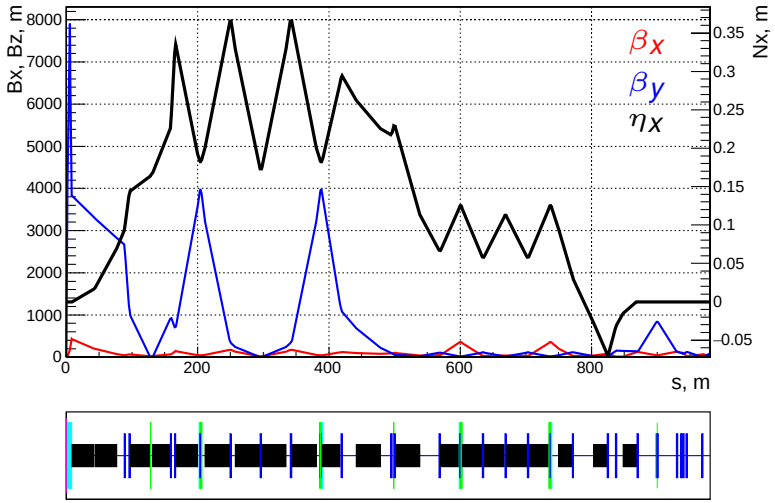
IR optics

AB

Left side

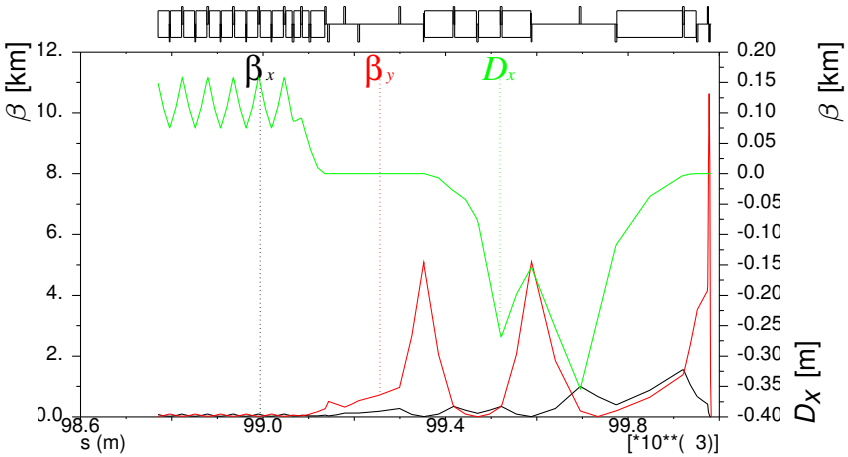


Right side

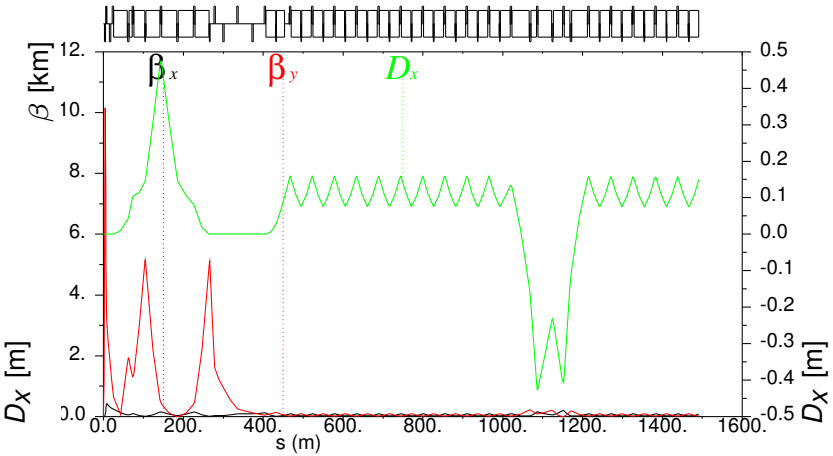


KO

Left side



Right side

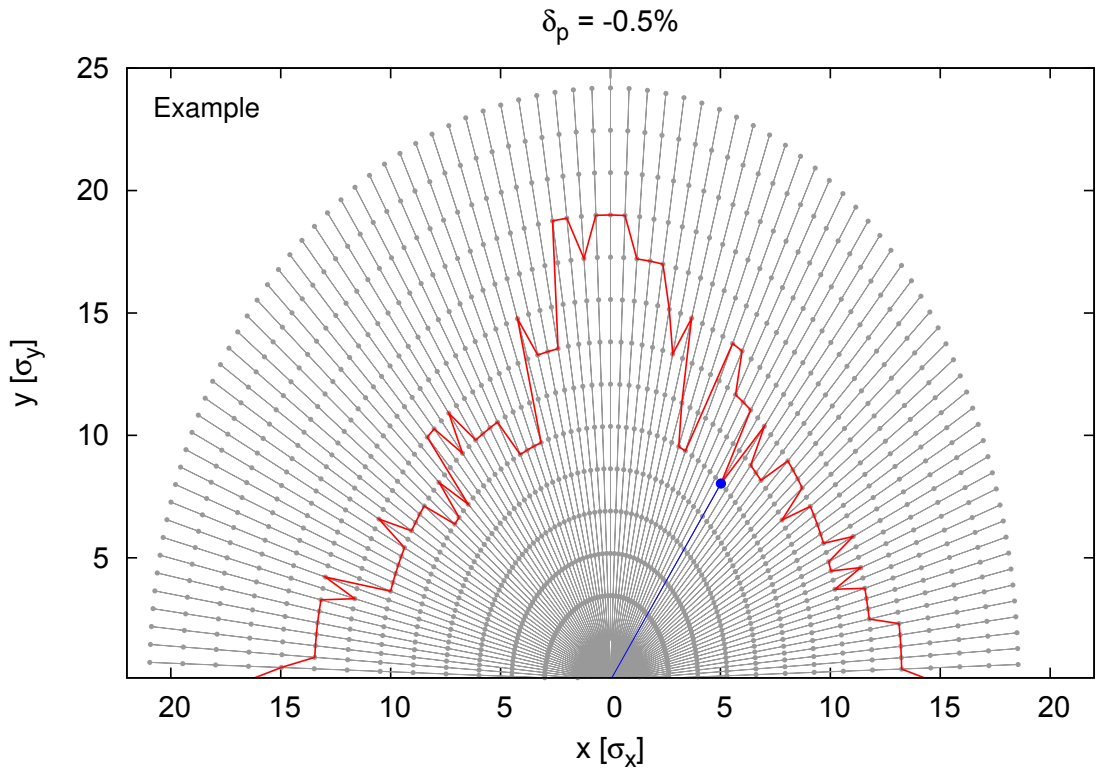


Parameters and Simulations

- Dynamic Aperture (DA): Limit on the **amplitude** of oscillations beyond which motion is unstable. It is usually found by particle tracking.

Studies to be presented:

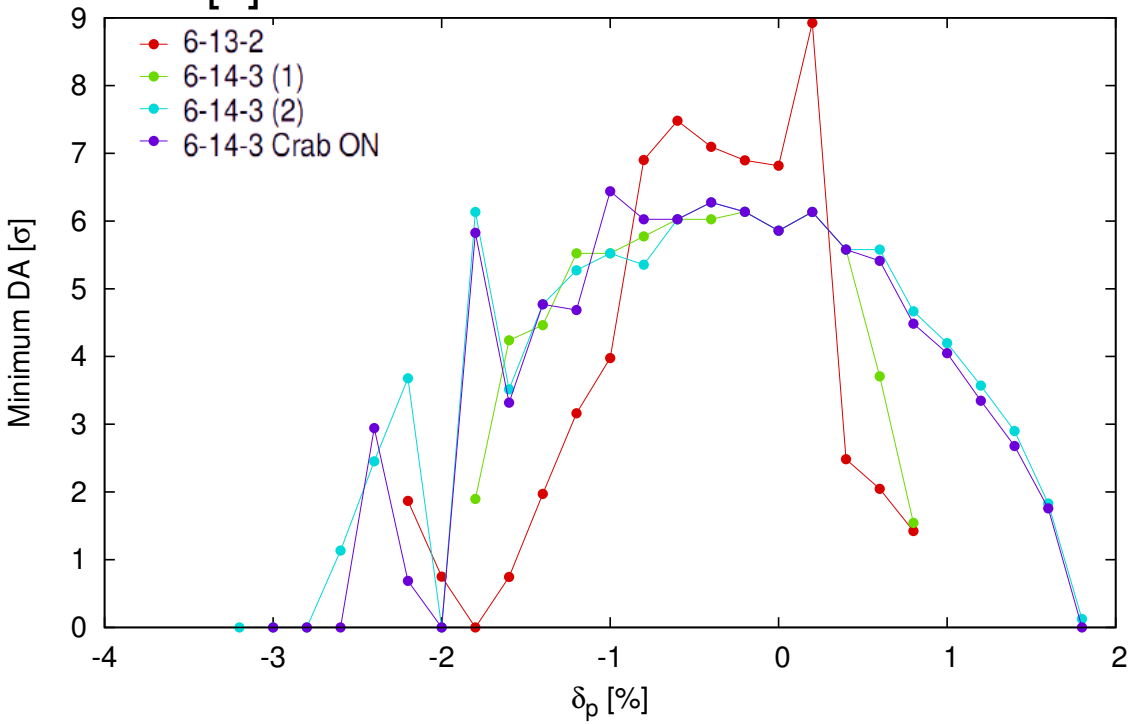
- **4D DA** by tracking with **PTC** on AB V9-PS2-1 and KO V74-11.
- Observation @ IP.
- **6D DA** for the latest lattices, taking into account several **effects**:
  - RF, damping by SR, tapering, crab waist...



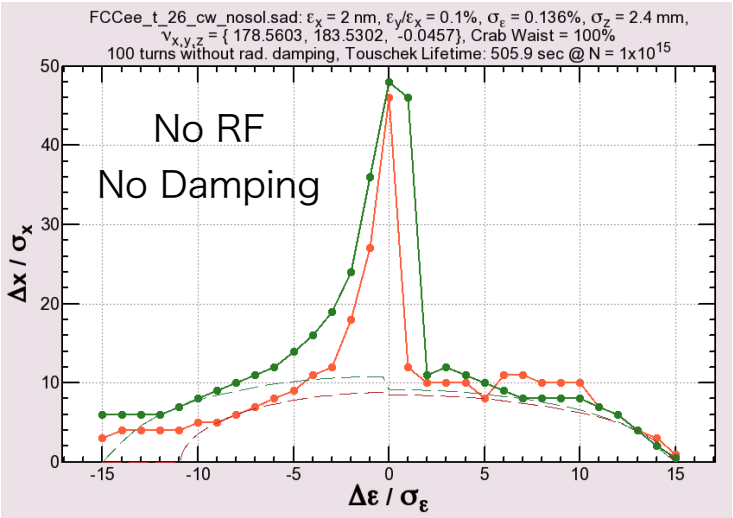
Energy	β_x^*	β_y^*	ϵ_y/ϵ_x
175 GeV	50 cm	1 mm	0.2 %

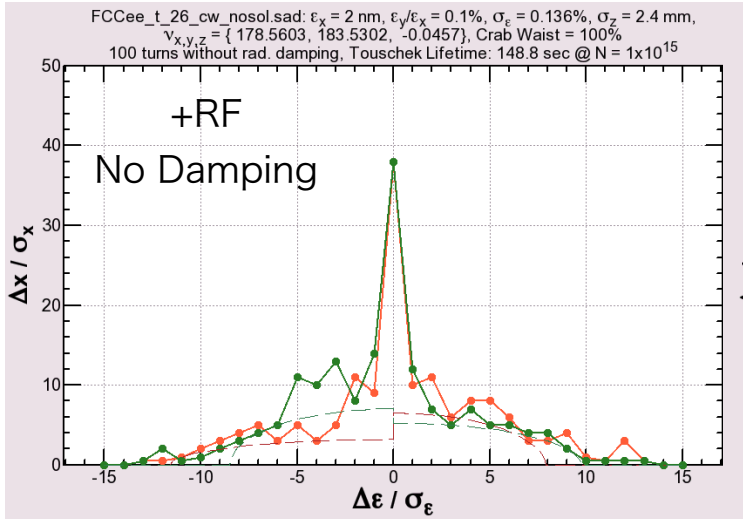
One year ago...

AB [2]



Since then... Adjustments to fulfill geometric constrains, reduction of SR in the IR, optimization of momentum acceptance and DA, etc.





KO [3]

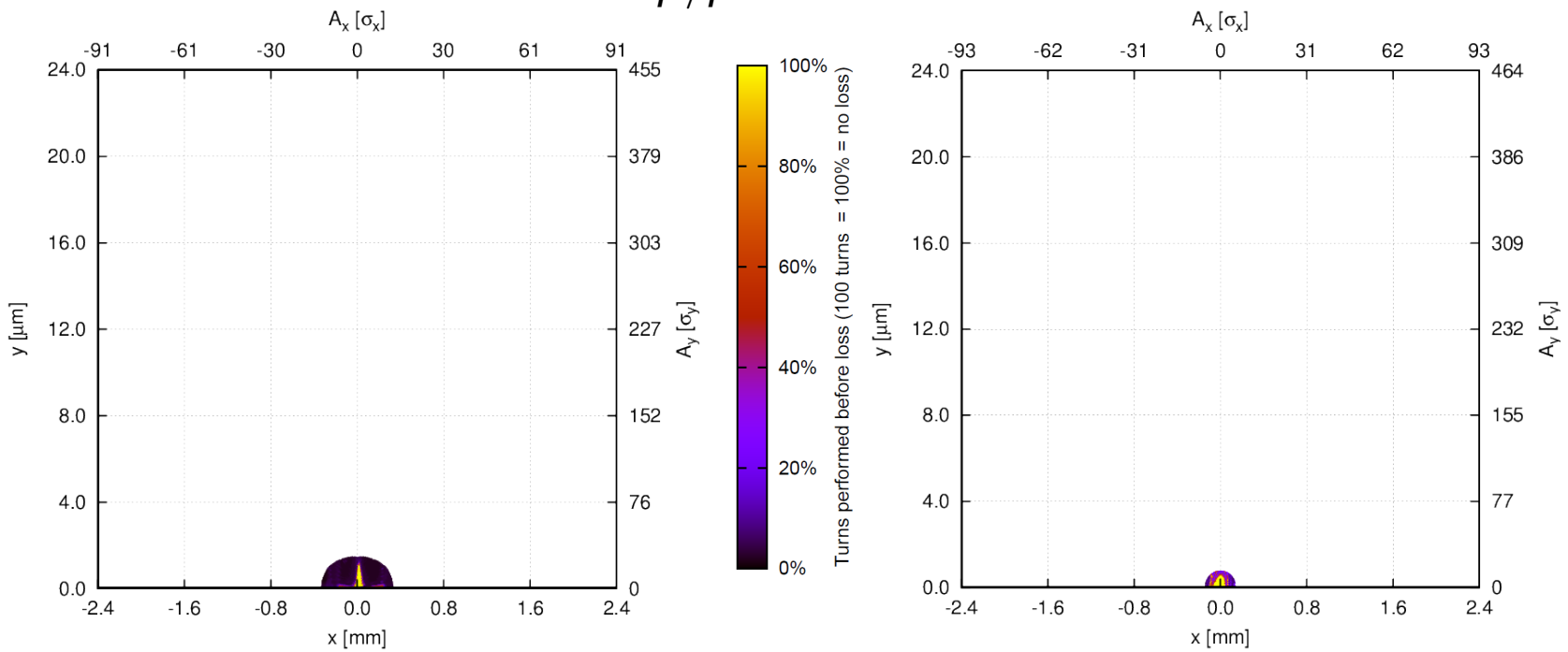
Contents

Contents

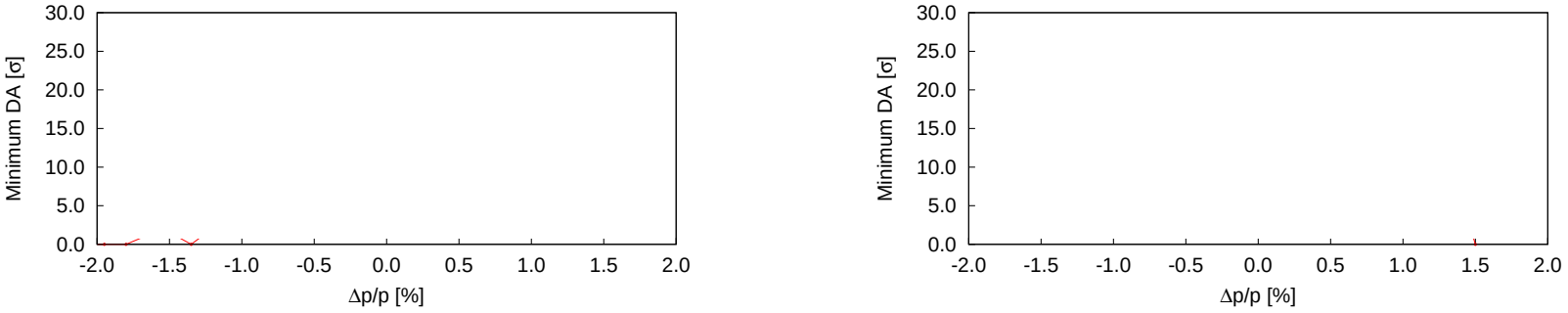
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = -1.8\%$



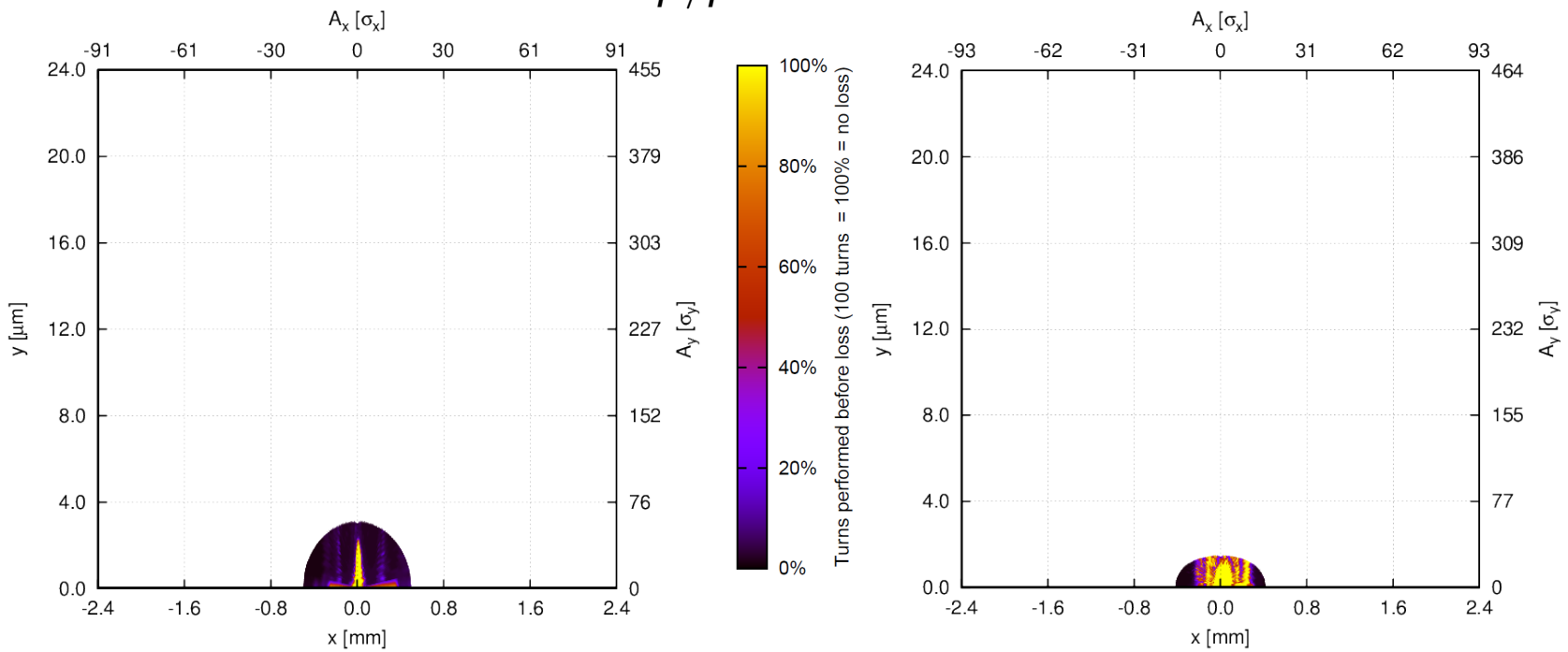
Minimum DA



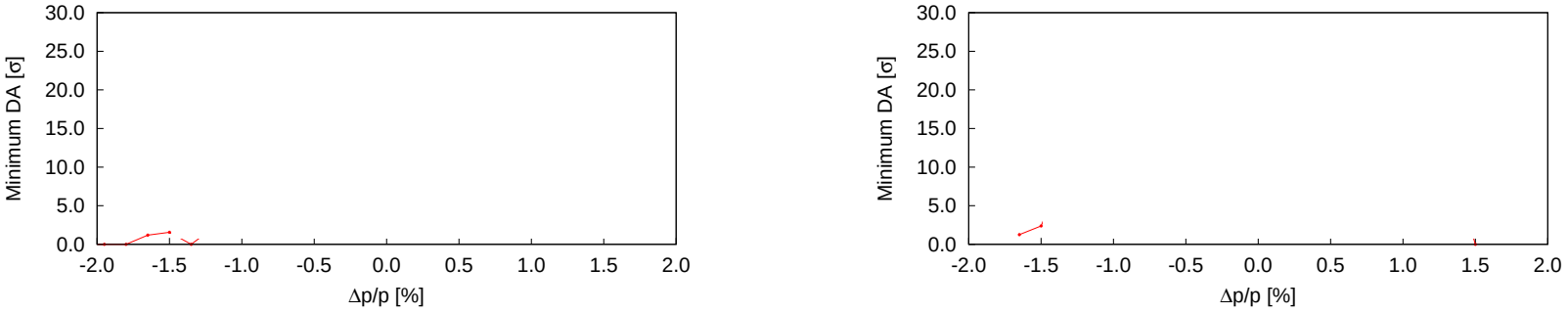
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = -1.5\%$



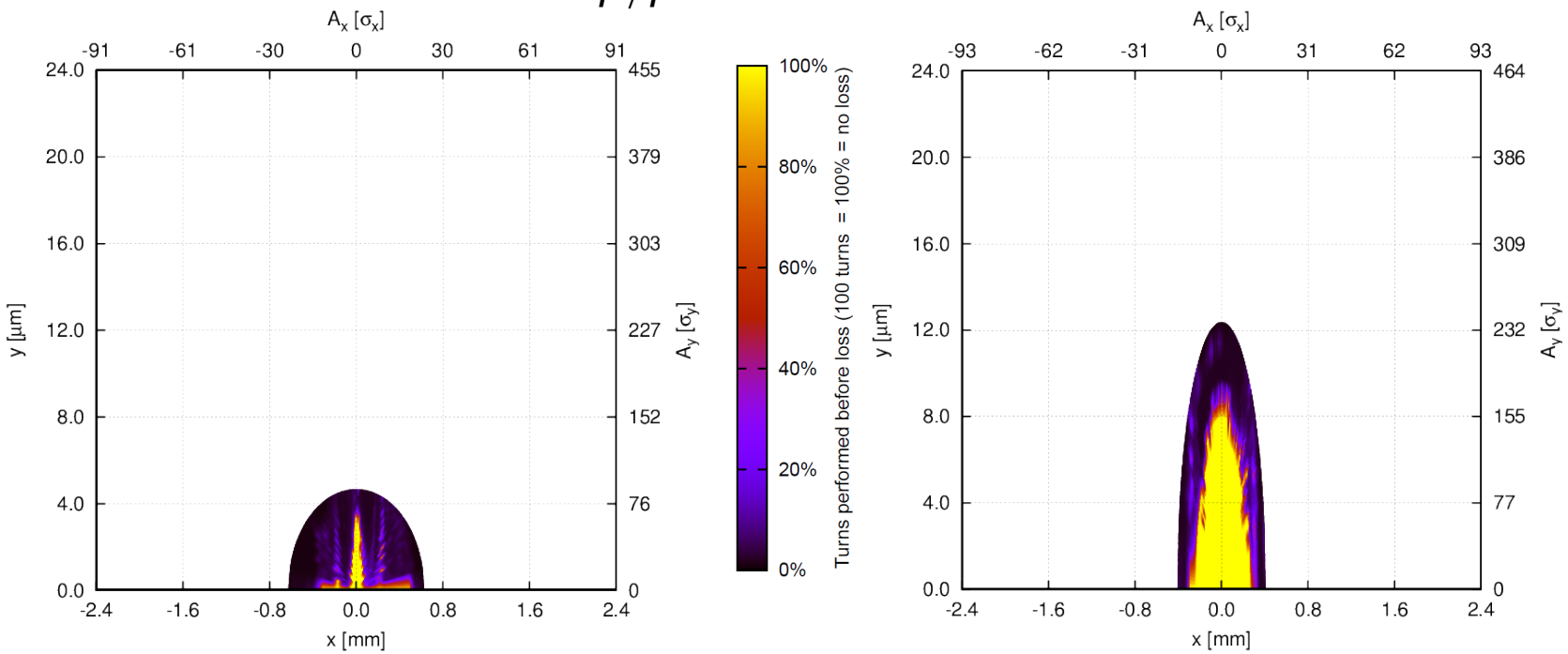
Minimum DA



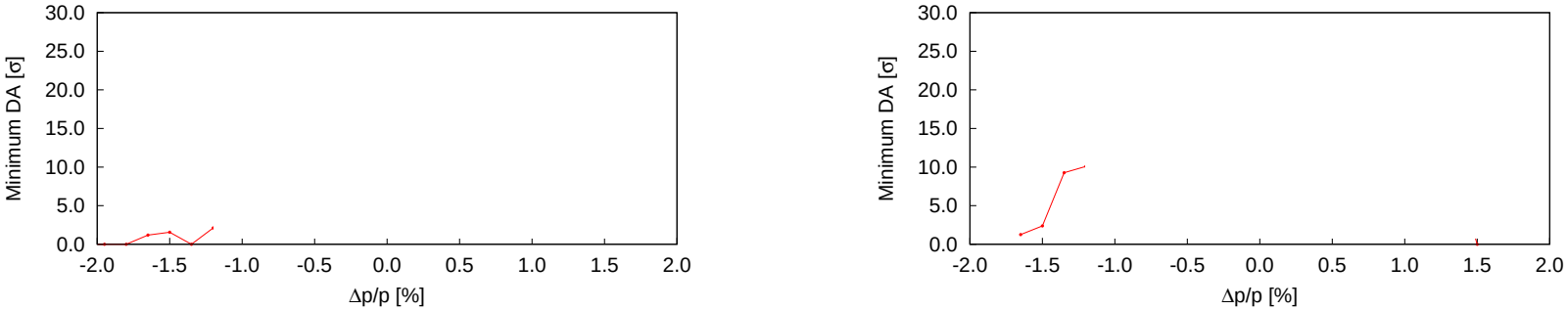
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = -1.2\%$



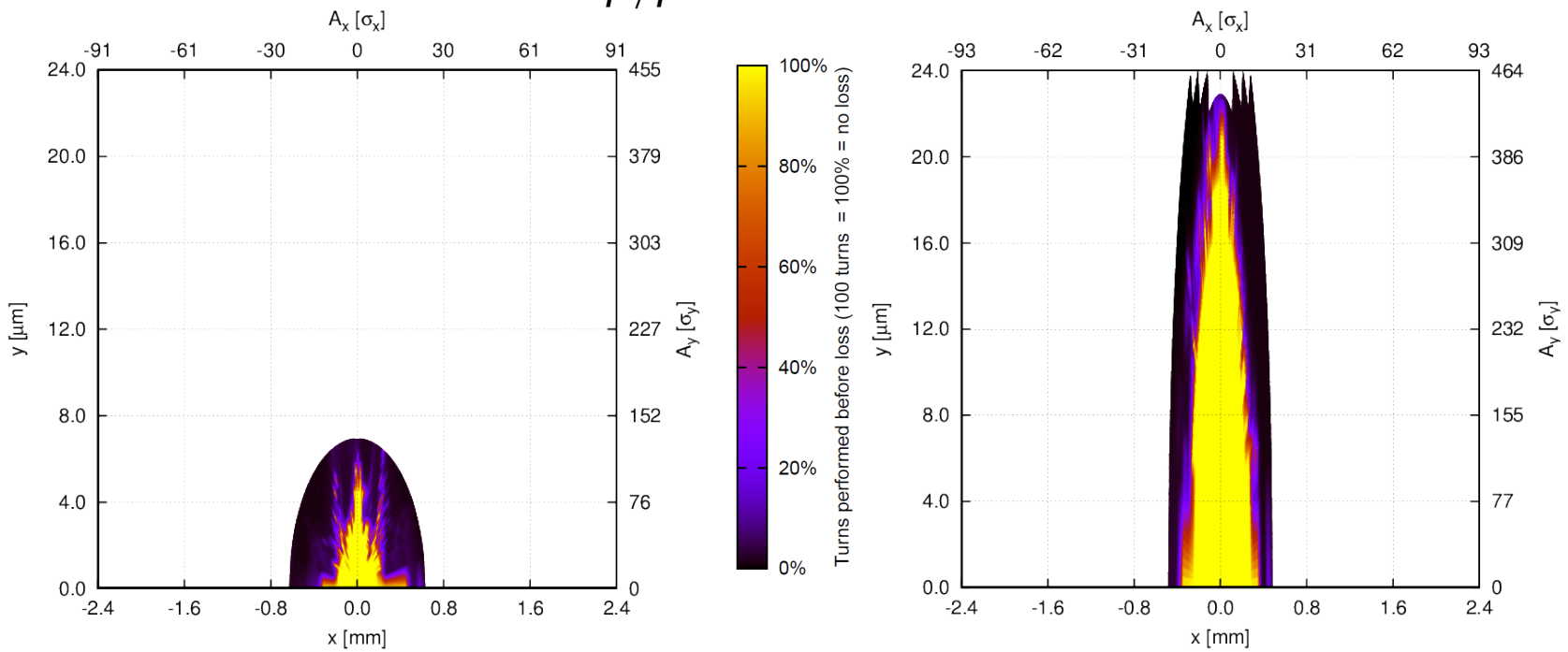
Minimum DA



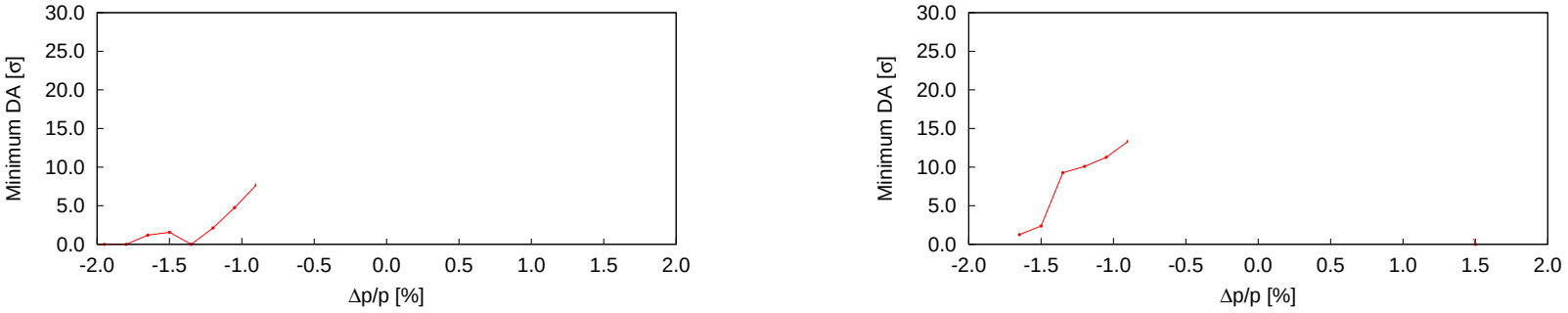
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = -0.9\%$



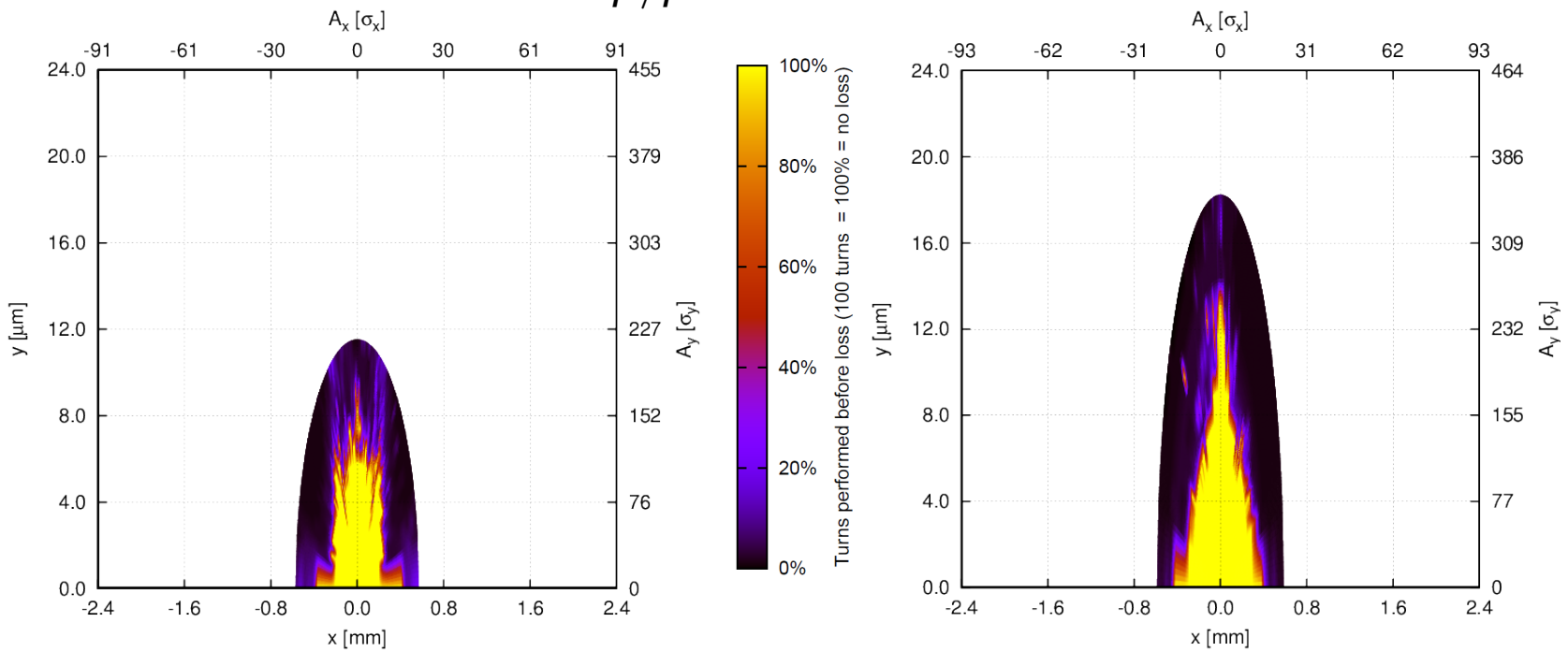
Minimum DA



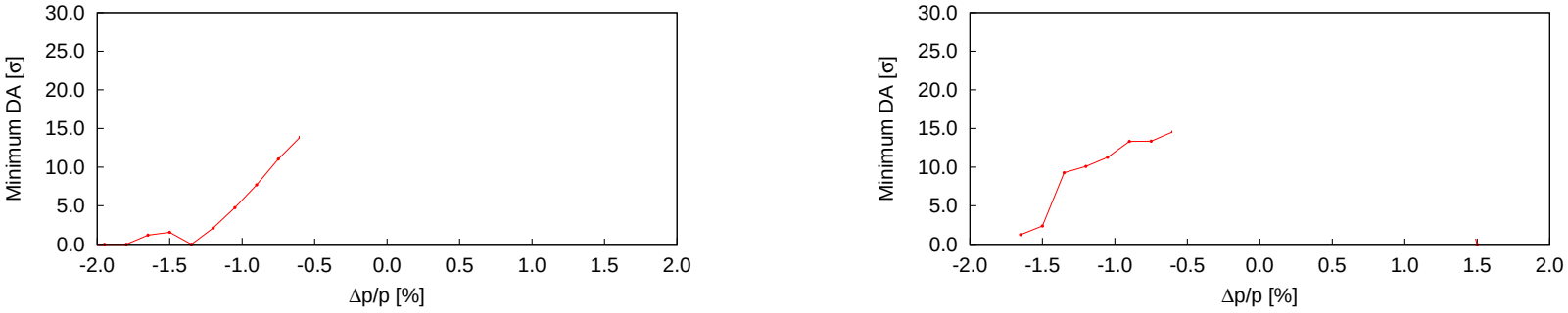
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = -0.6\%$



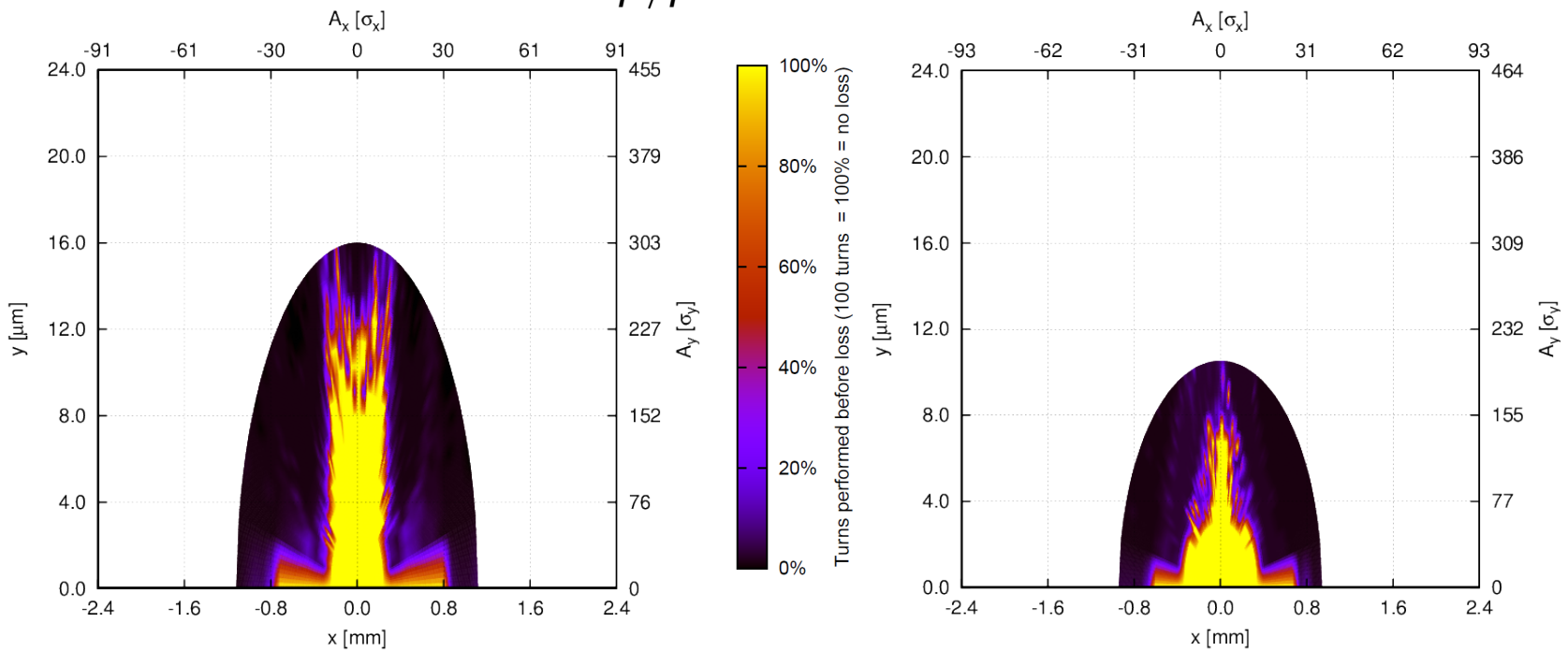
Minimum DA



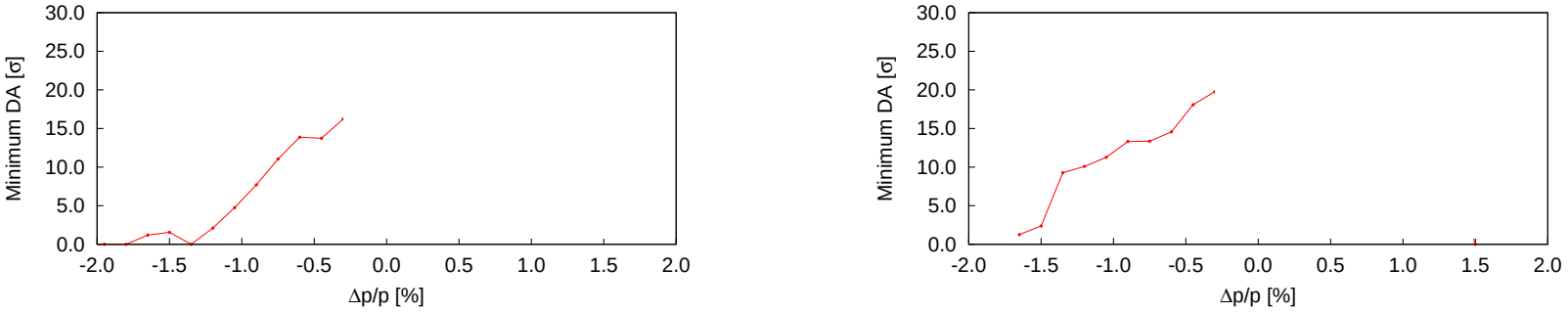
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = -0.3\%$



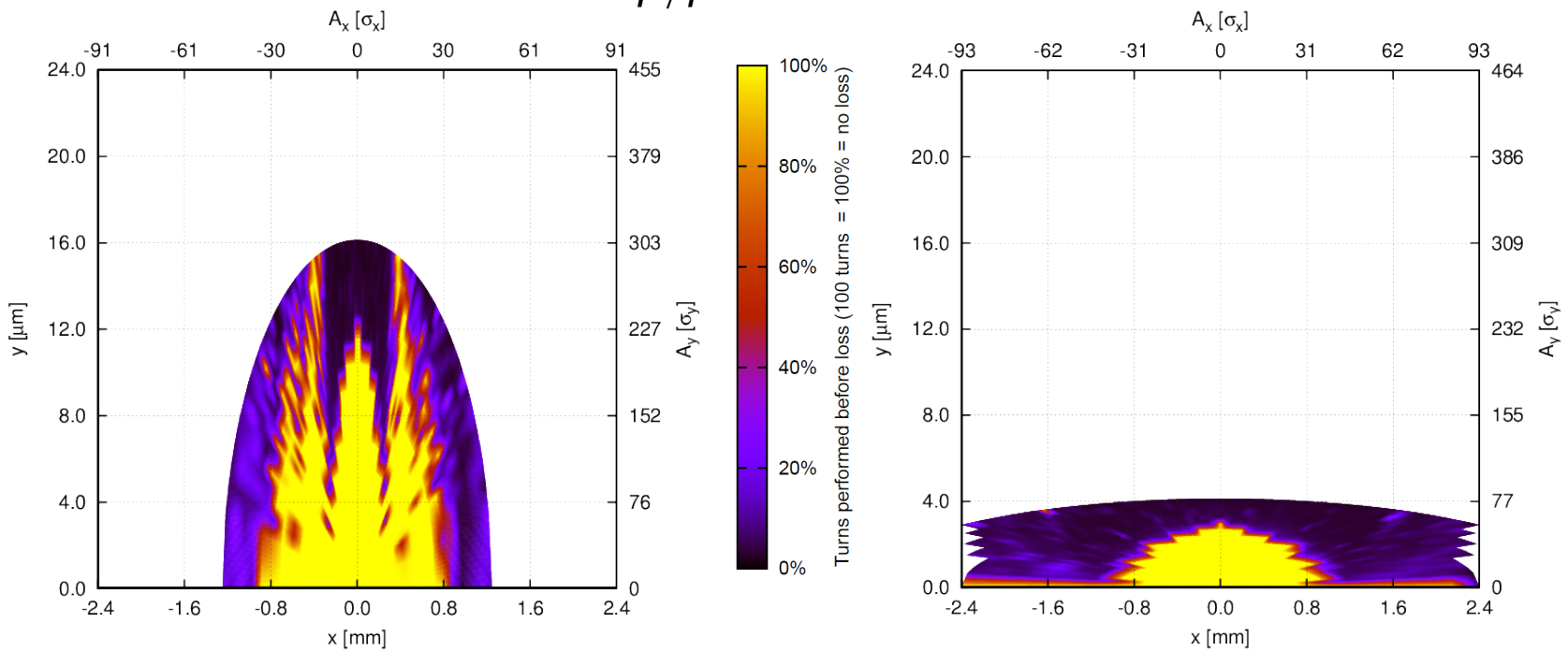
Minimum DA



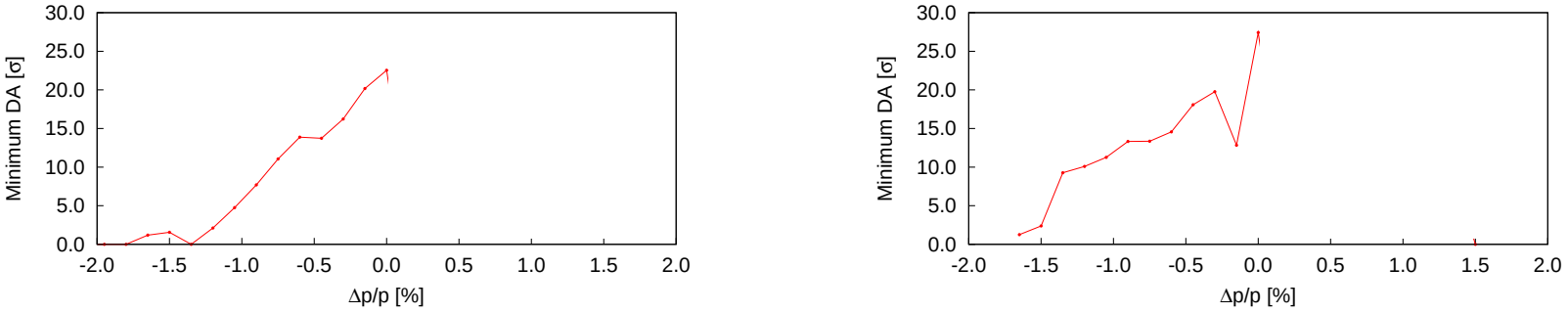
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = 0.0\%$



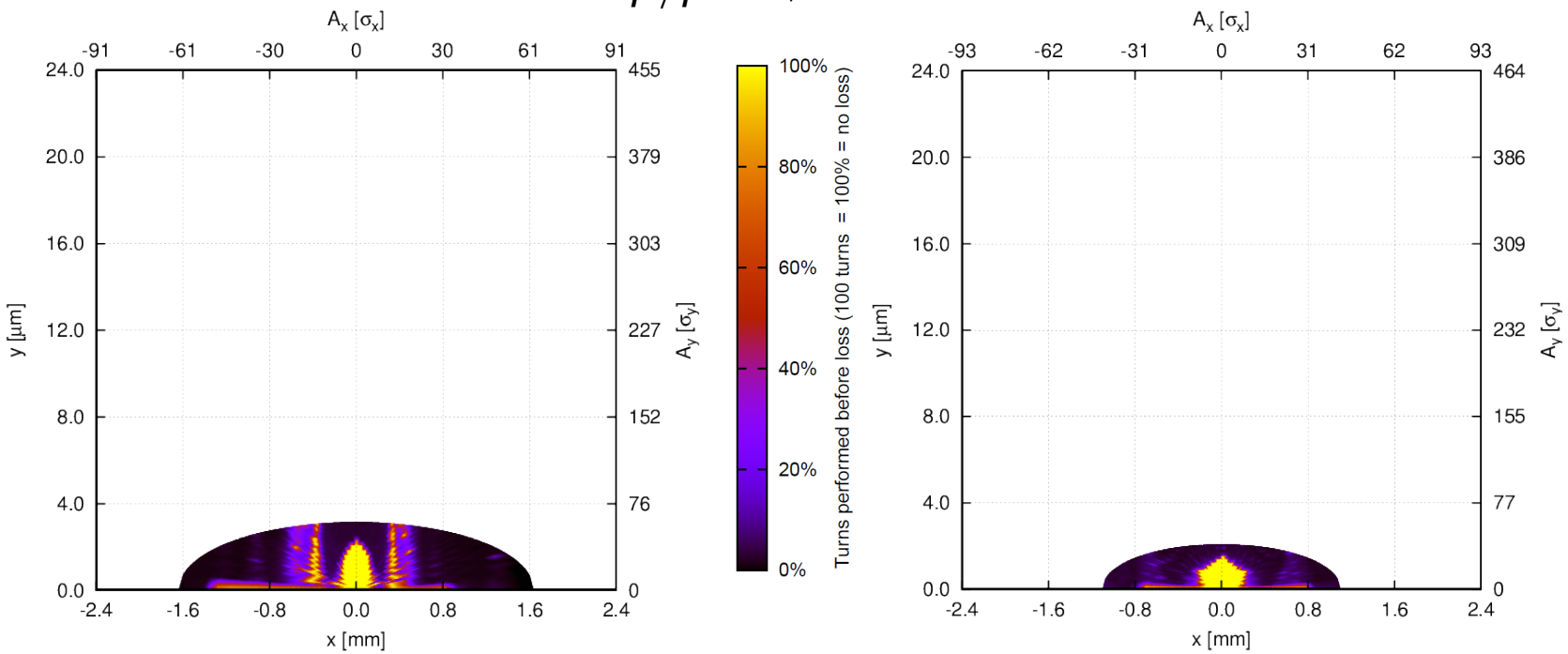
Minimum DA



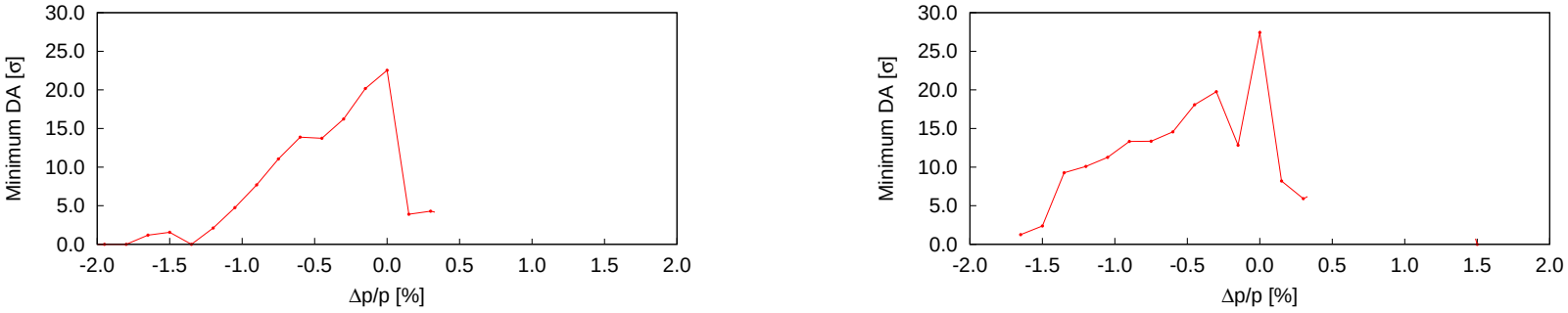
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = +0.3\%$



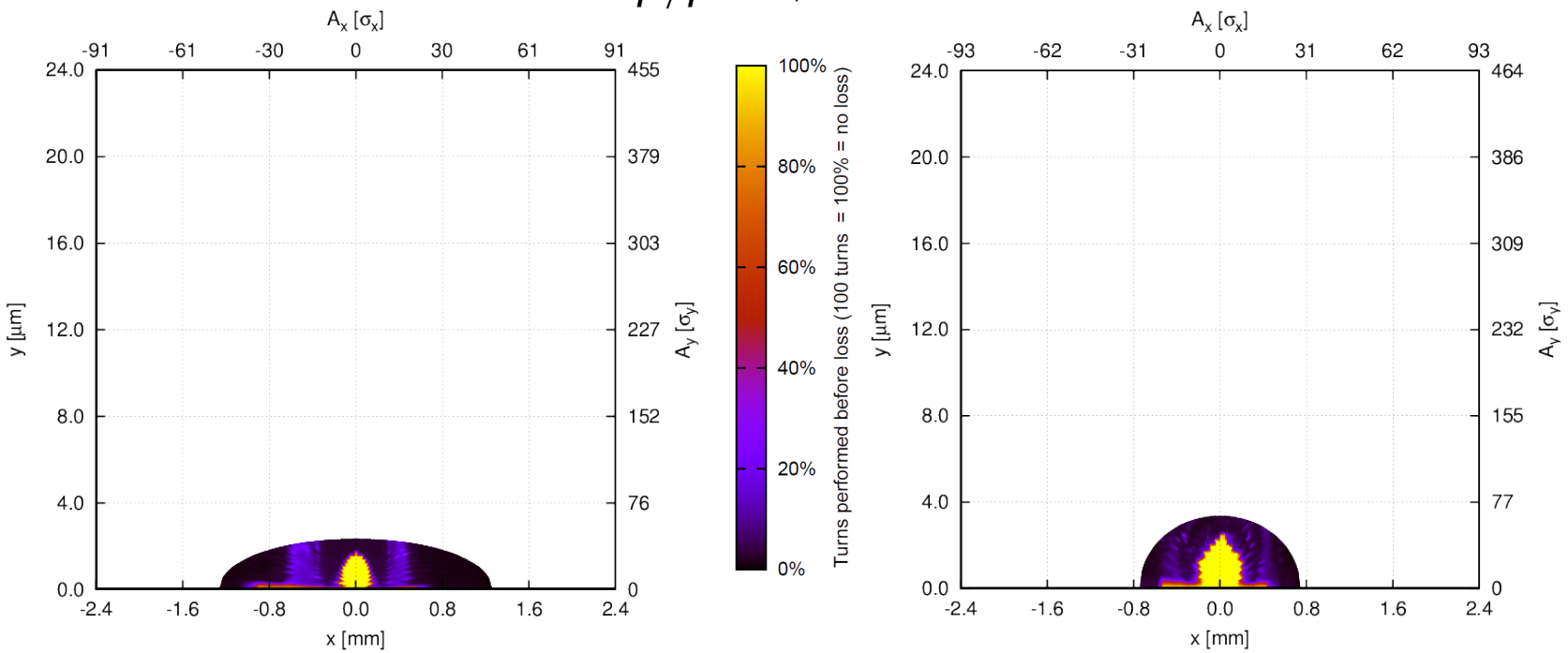
Minimum DA



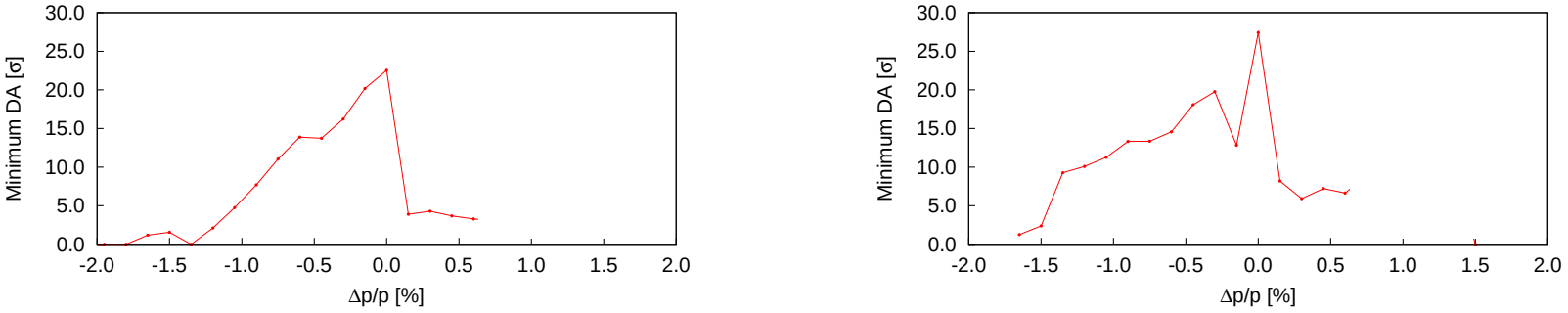
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = +0.6\%$



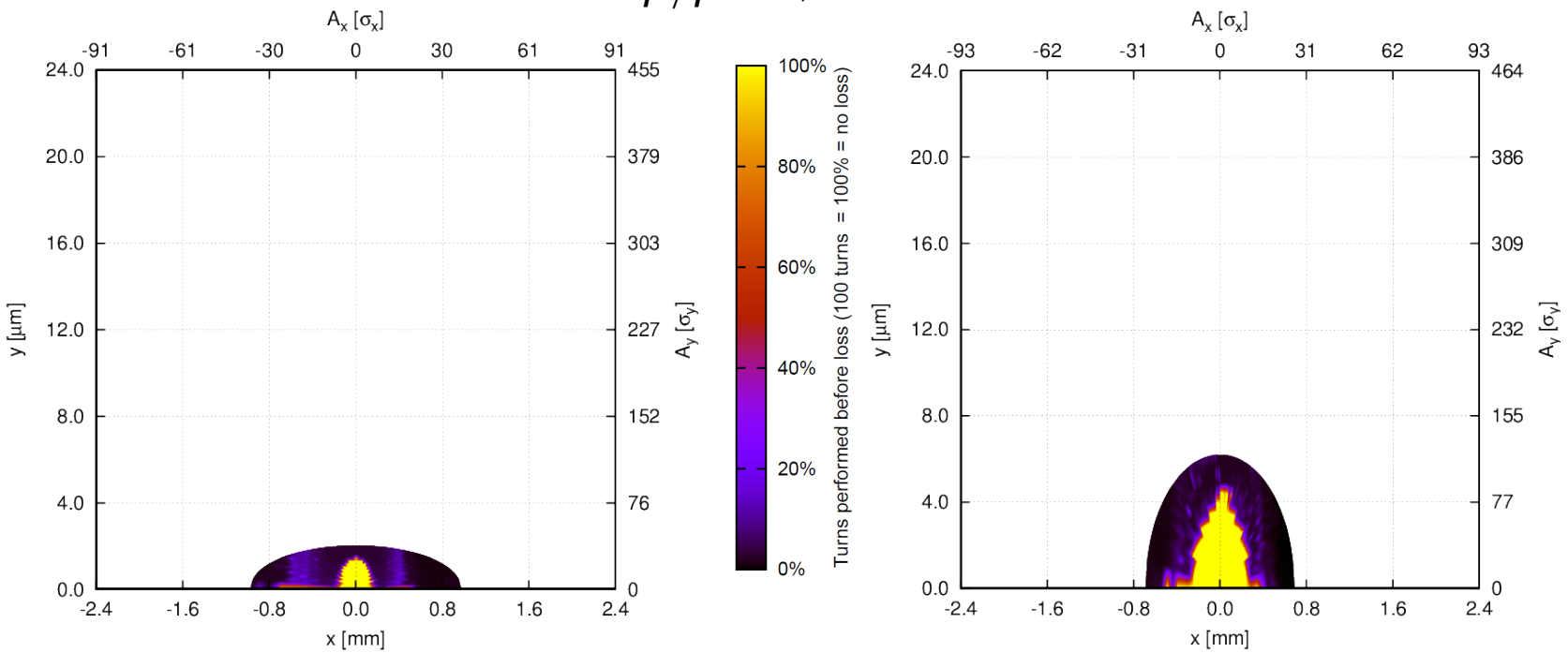
Minimum DA



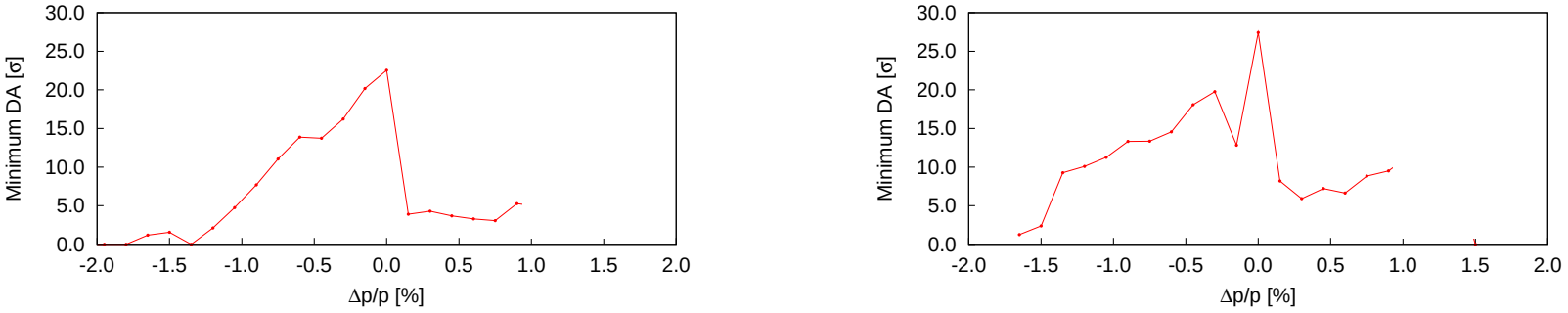
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = +0.9\%$



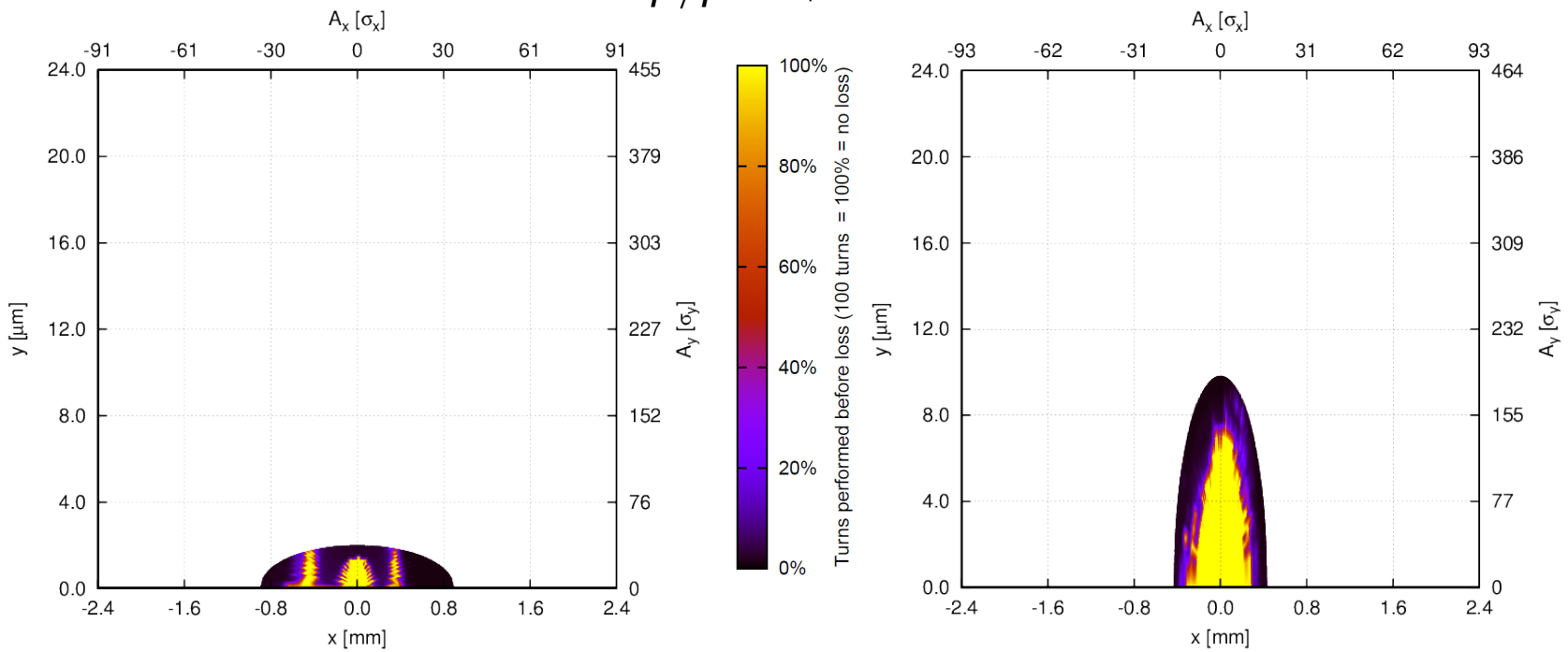
Minimum DA



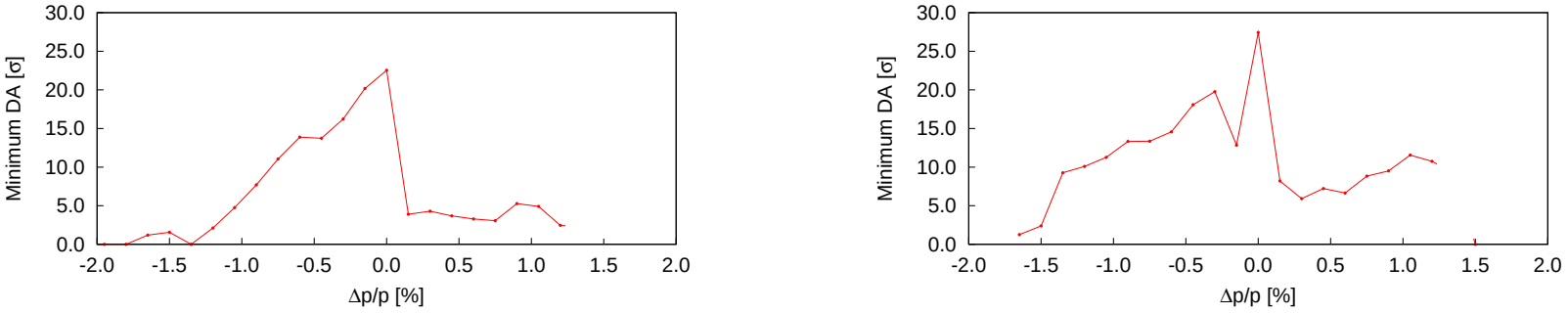
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = +1.2\%$



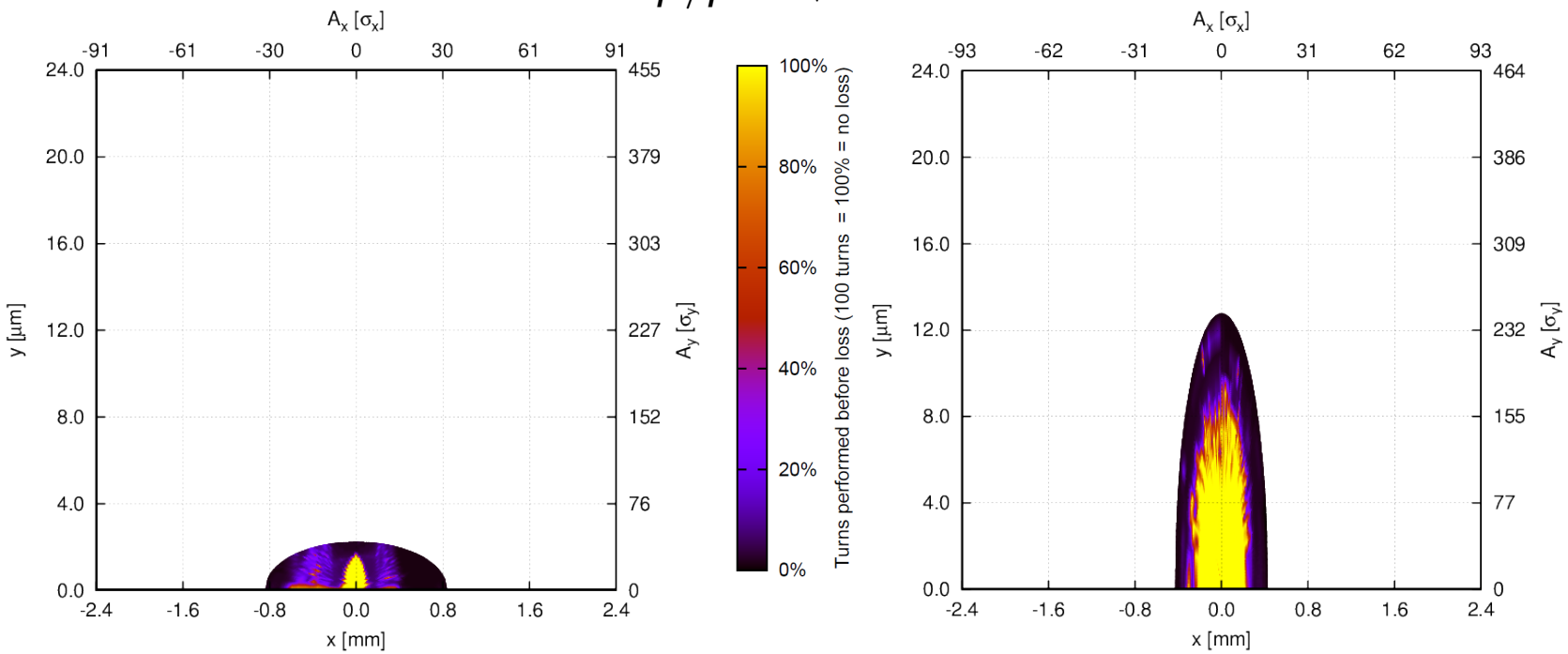
Minimum DA



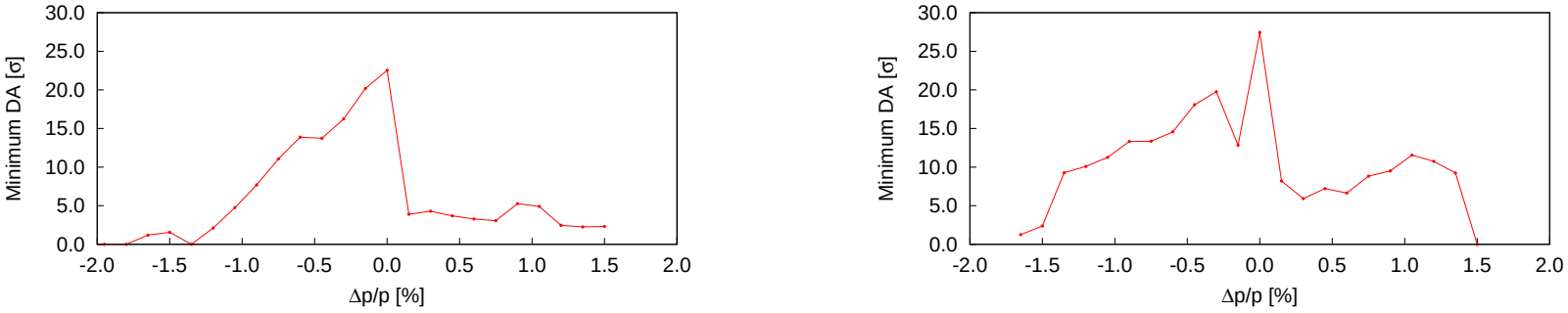
4D DA Comparison

AB FCC-ee V9-PS2-1 **KO** FCC-ee V74-11

$\Delta p/p = +1.5\%$

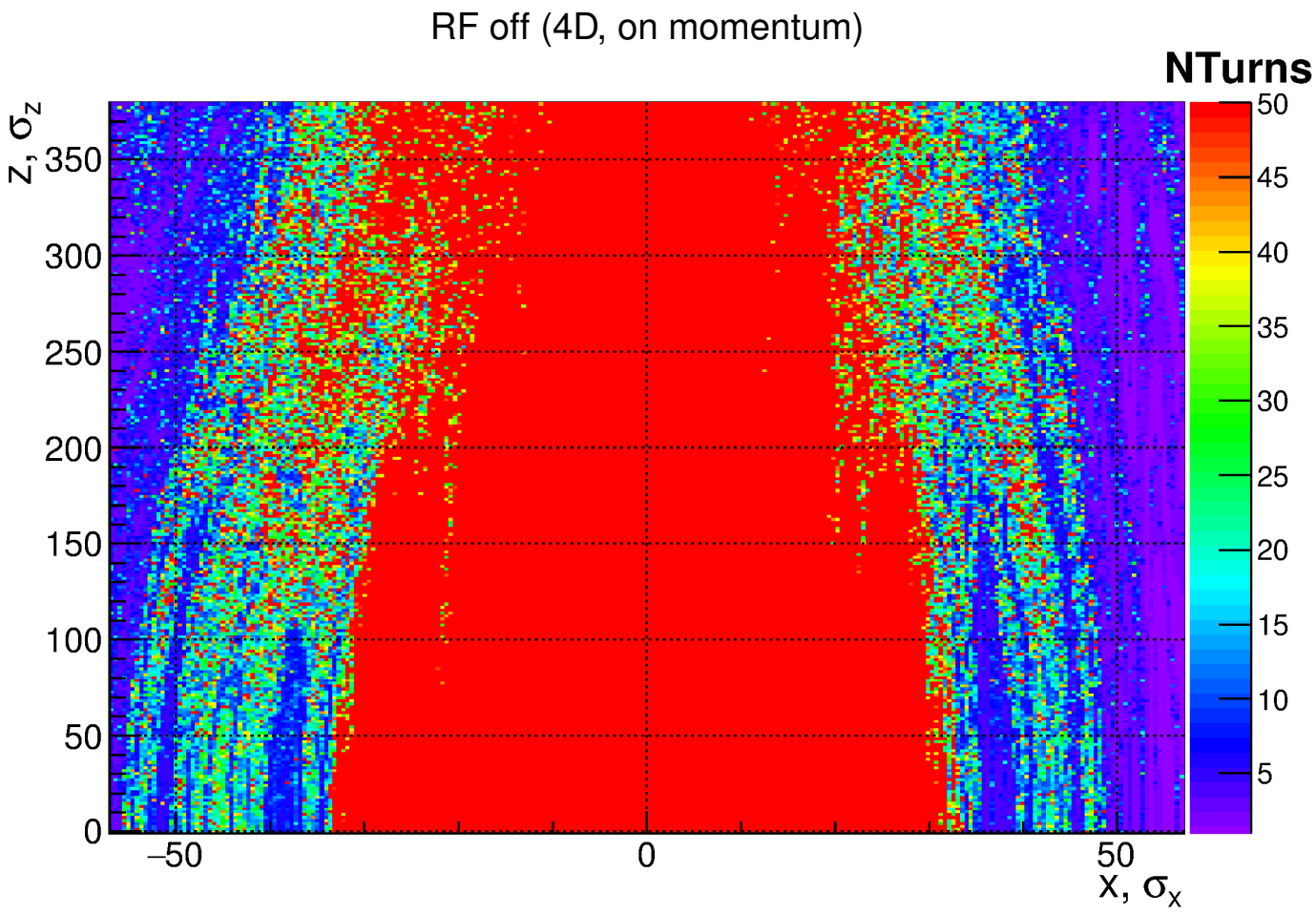


Minimum DA



Contents

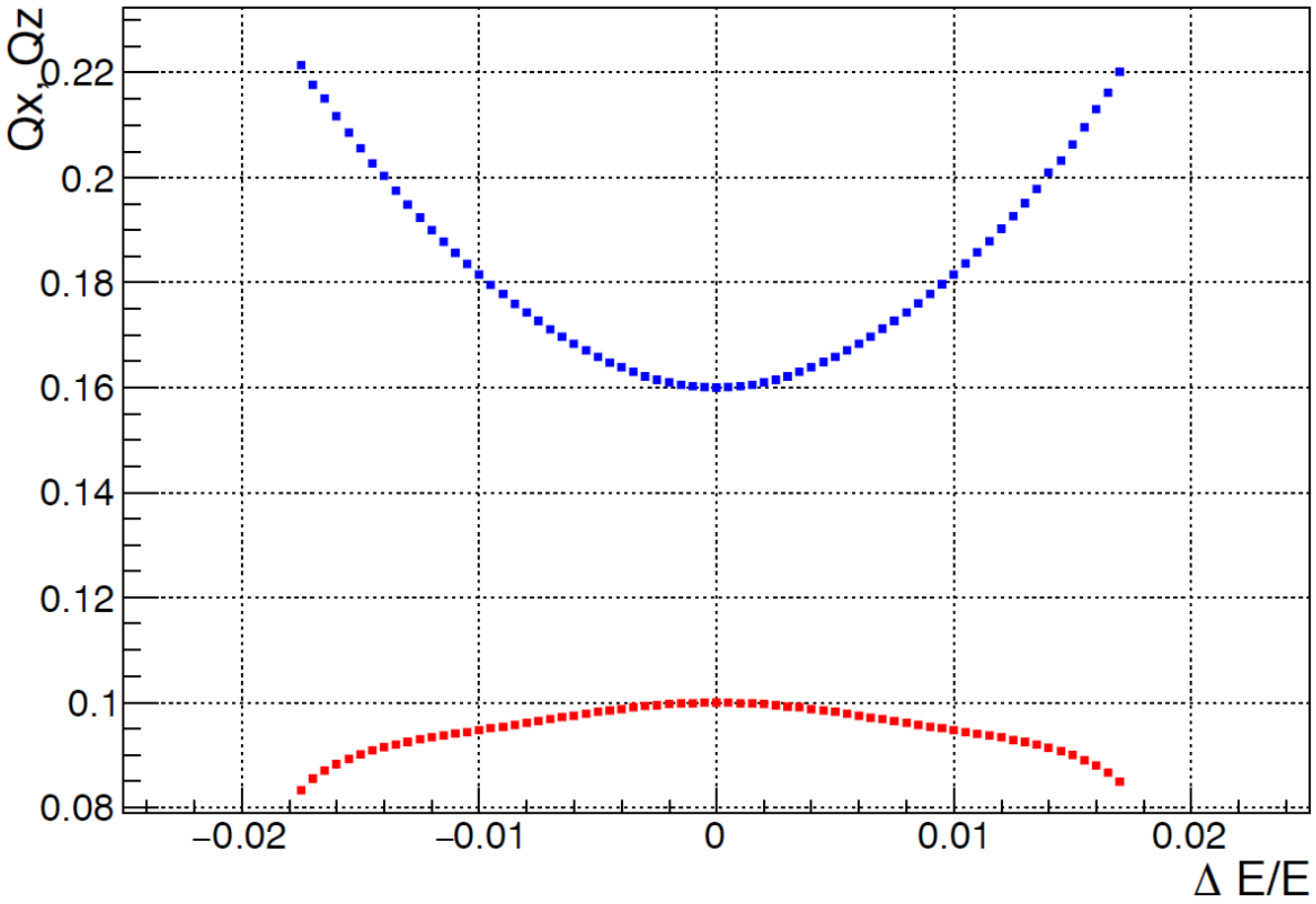
AB: 4D DA revisited



Crab off, 50 turns, $\epsilon_x = 1.4\,\text{nm}\cdot\text{rad}$,
$\nu_{x,y,s} = 395.10, 297.16, 0.0807$, $\tau_x = 44$ turns,
$U_0 = 7.97\,\text{GeV}$, $U_{rf} = 11\,\text{GV}$.

P. Piminov

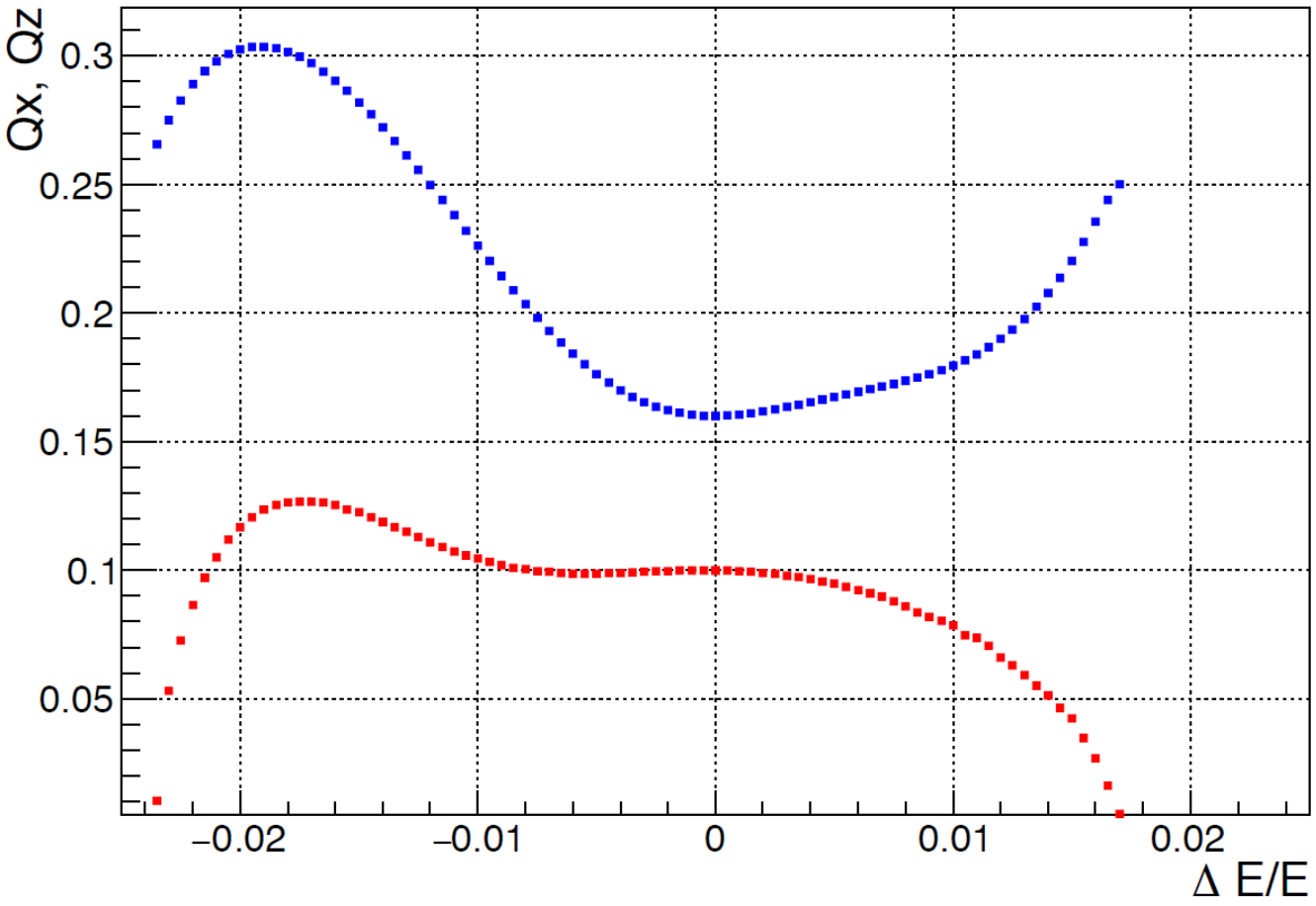
AB: Tunes and Nonlinear Chromaticities



Nonlinear chromaticity from tracking with 1024 turns. Small betatron amplitudes. Initial transverse coordinates are changed according to product of energy deviation and nonlinear dispersion. RF is off.

P. Piminov

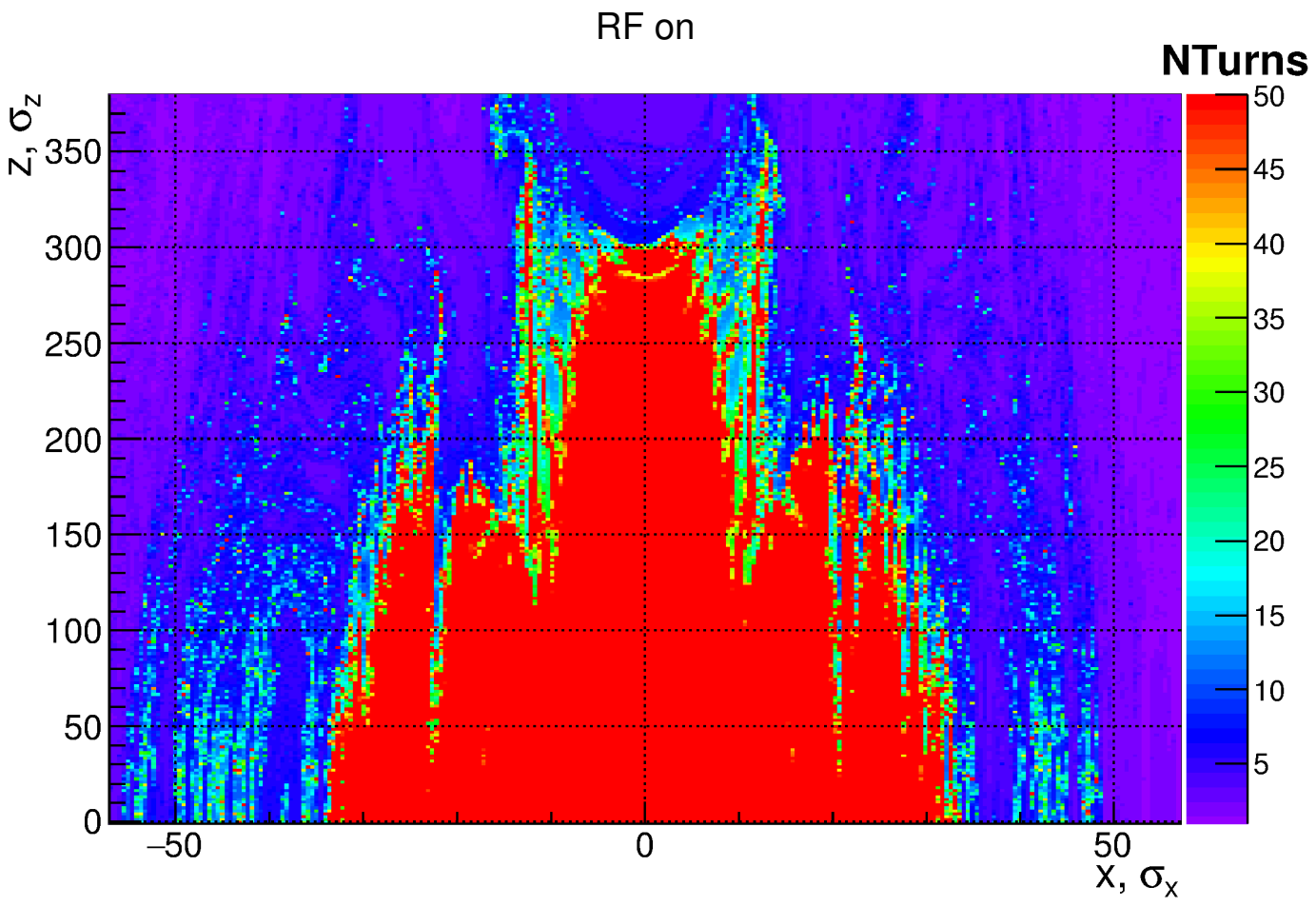
AB: Tunes and Nonlinear Chromaticities



Betatron tunes dependence on energy deviation obtained from tracking with 1024 turns. Initial transverse coordinates are zero, but betatron amplitudes depend on growing energy deviation. RF is on.

P. Piminov

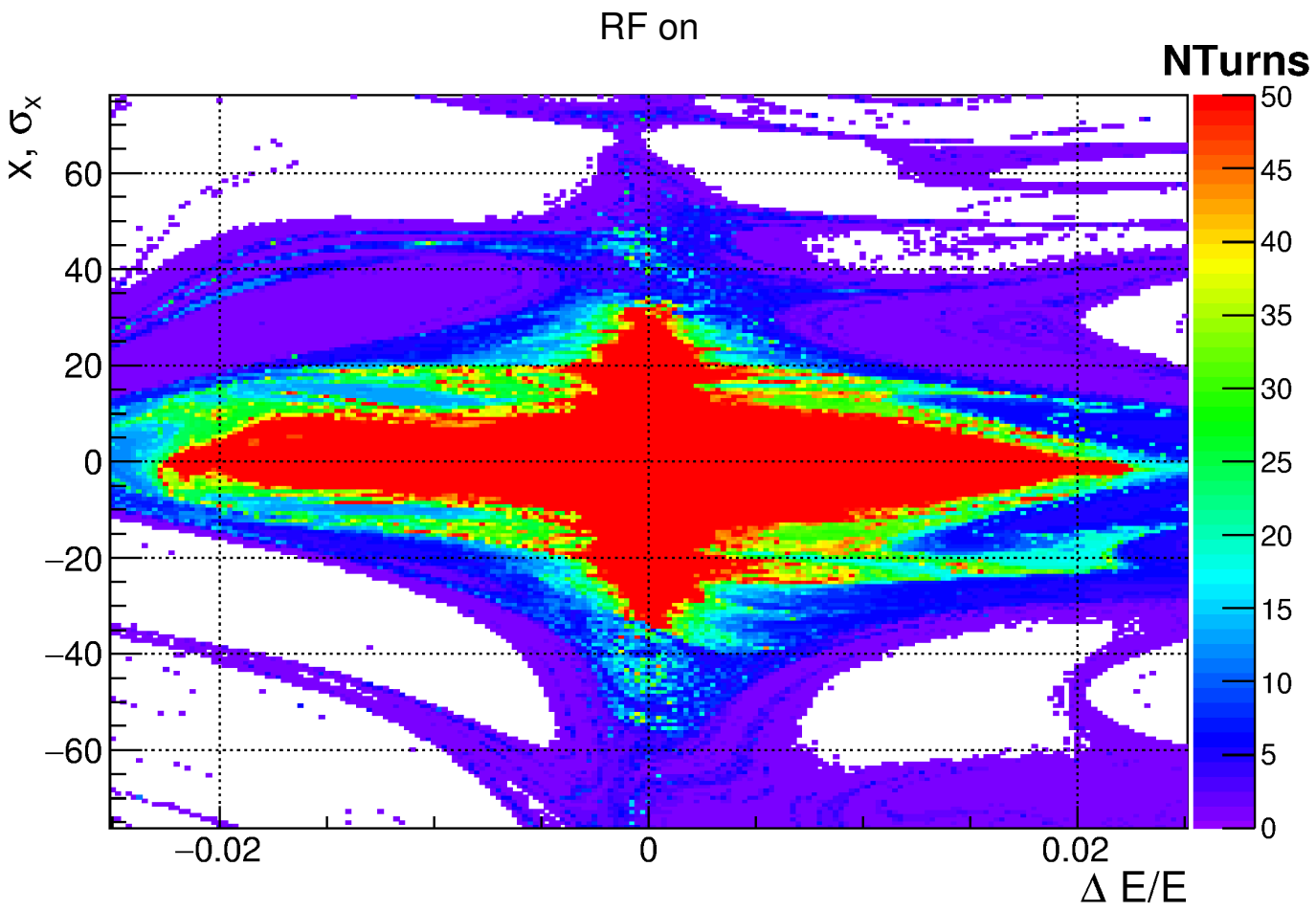
AB: No damping nor tapering



Crab off, 50 turns, $\epsilon_x = 1.4\,\mathrm{nm}\cdot\mathrm{rad}$,
$\nu_{x,y,s} = 395.10, 297.16, 0.0807$, $\tau_x = 44$ turns,
$U_0 = 7.97\,\mathrm{GeV}$, $U_{rf} = 11\,\mathrm{GV}$.

P. Piminov

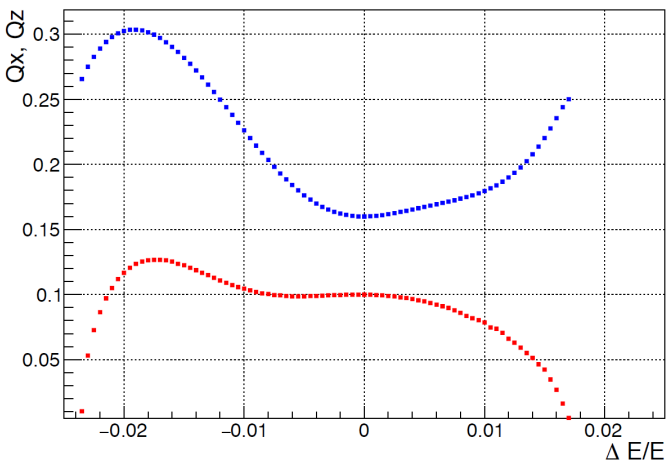
AB: No damping nor tapering

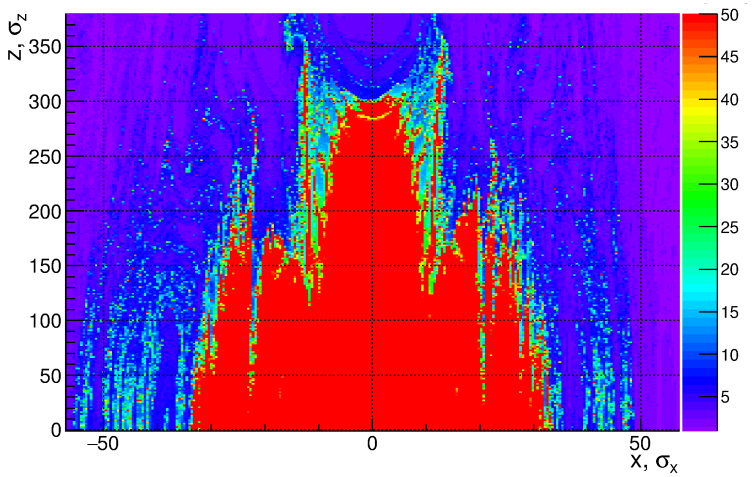


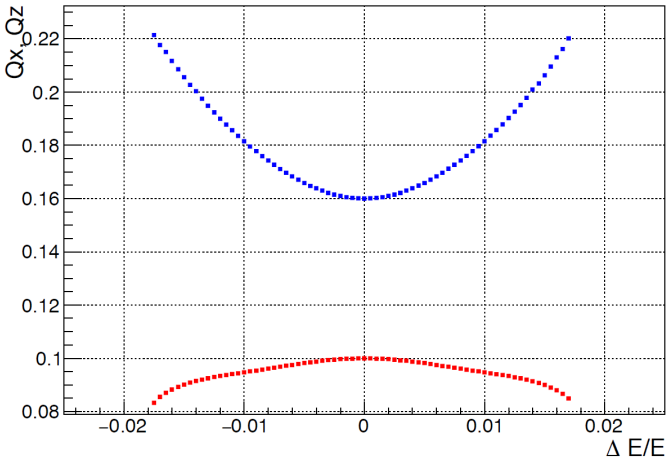
Crab off, 50 turns, $\epsilon_x = 1.4\,\text{nm}\cdot\text{rad}$,
$\nu_{x,y,s} = 395.10, 297.16, 0.0807$, $\tau_x = 44$ turns,
$U_0 = 7.97\,\text{GeV}$, $U_{rf} = 11\,\text{GV}$.

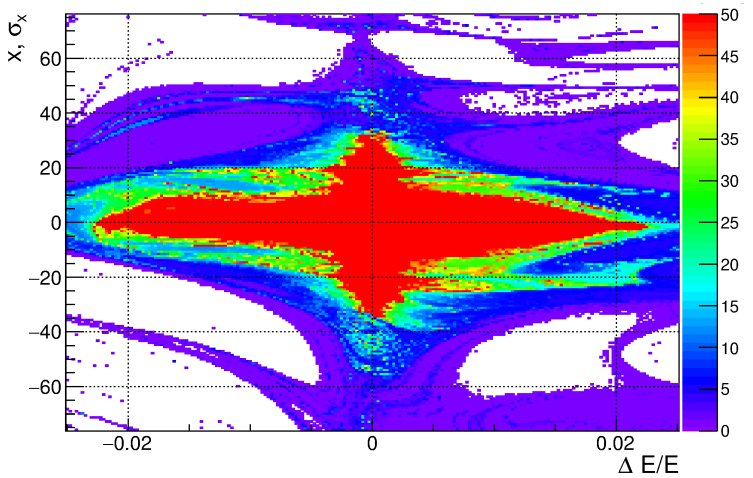
P. Piminov

Summary: **AB** FCC-ee V9-PS2









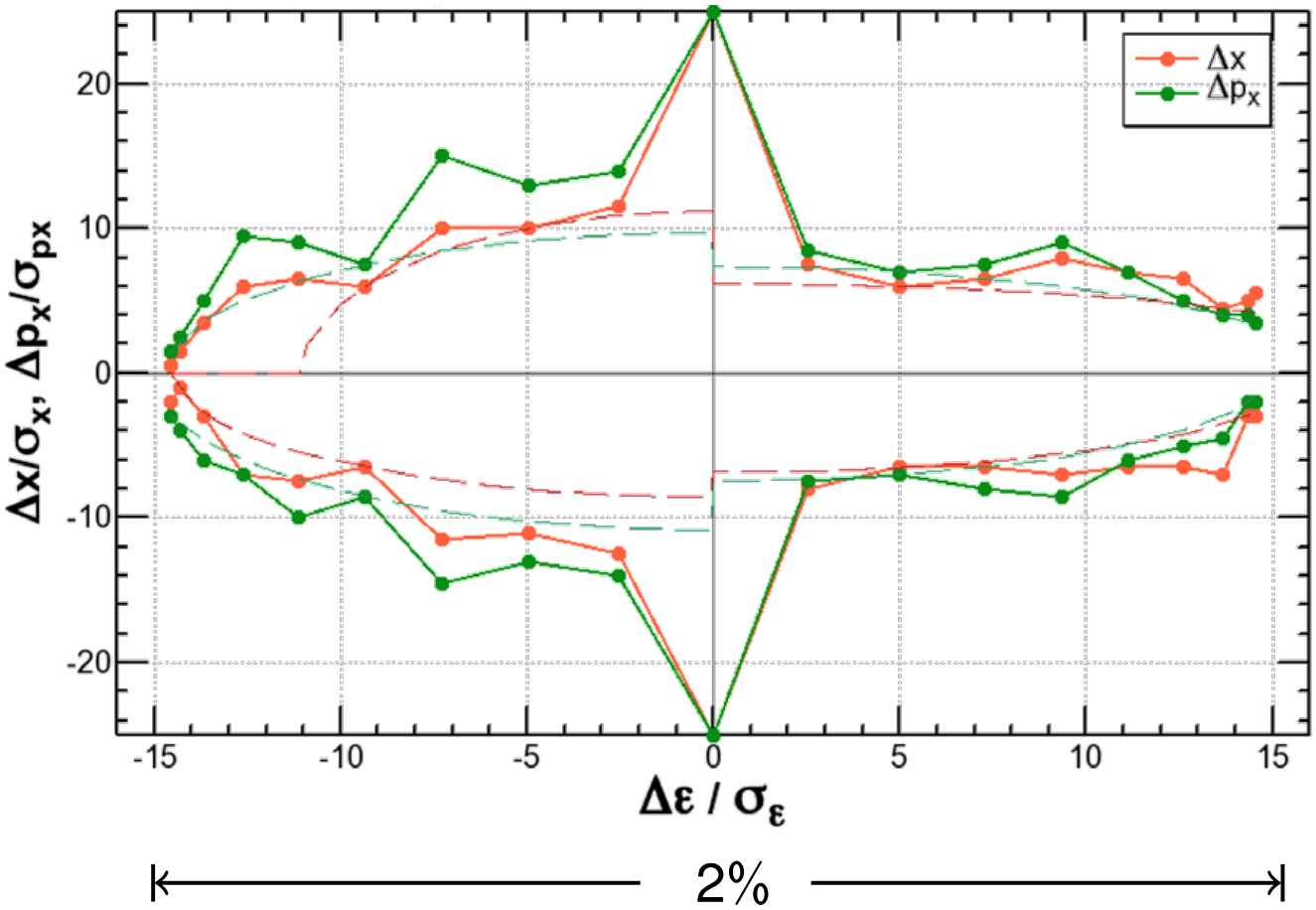
Crab off, 50 turns, $\epsilon_x = 1.4\,\text{nm} \cdot \text{rad}$, RF on, $\nu_{x,y,s} = 395.10, 297.16, 0.0807$, $\tau_x = 44$ turns, $U_0 = 7.97\,\text{GeV}$, $U_{rf} = 11\,\text{GV}$.

P. Piminov

Contents

KO: Effect of RF and radiation

RF off, radiation off

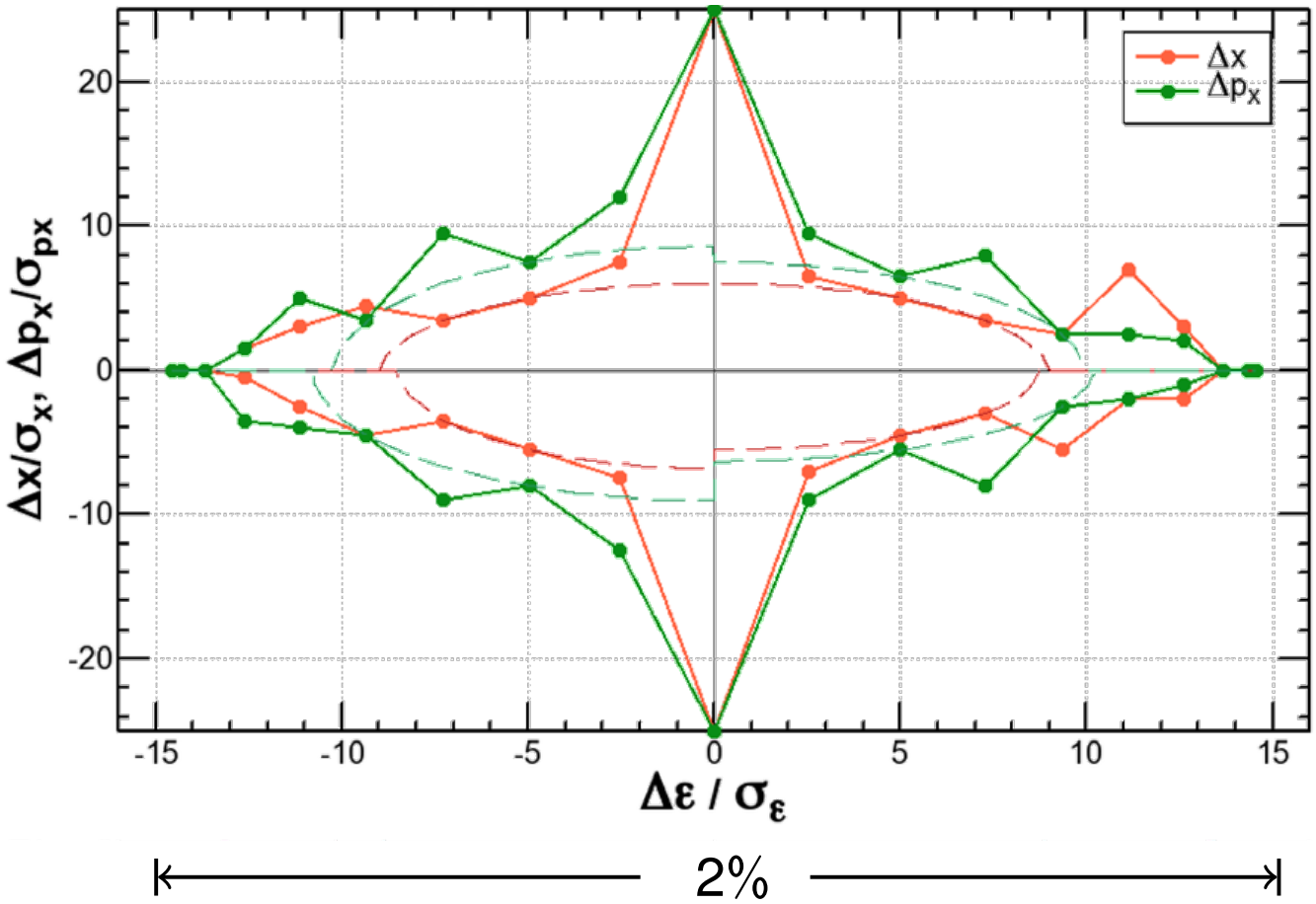


Crab on, 50 turns, $\epsilon_x = 1.34\,\text{nm}\cdot\text{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\text{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\text{GeV}$.

K. Oide

KO: Effect of RF and radiation

RF on, radiation off

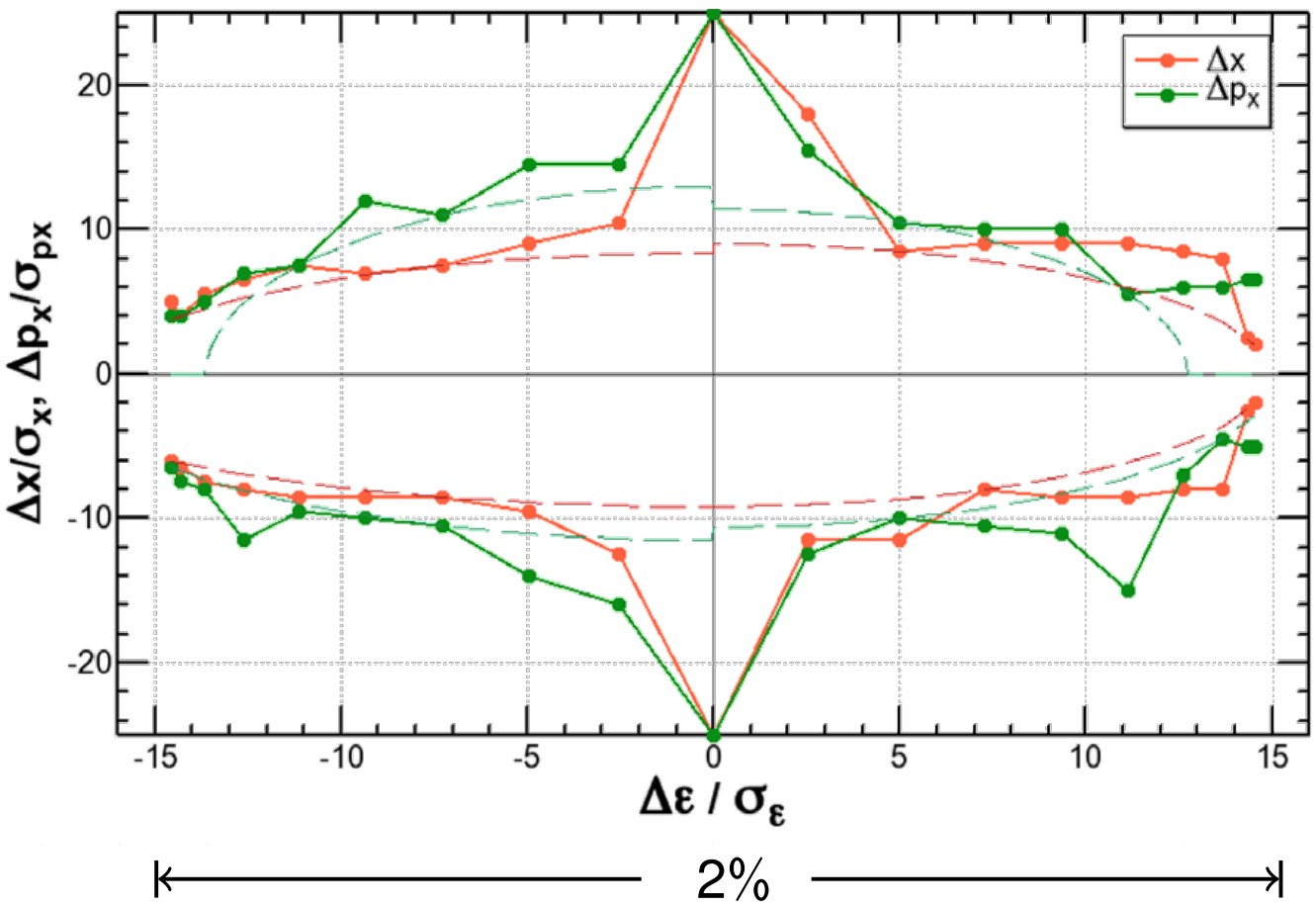


Crab on, 50 turns, $\epsilon_x = 1.34\,\text{nm}\cdot\text{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\text{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\text{GeV}$.

K. Oide

KO: Effect of RF and radiation

RF on, radiation on (damping each turn)

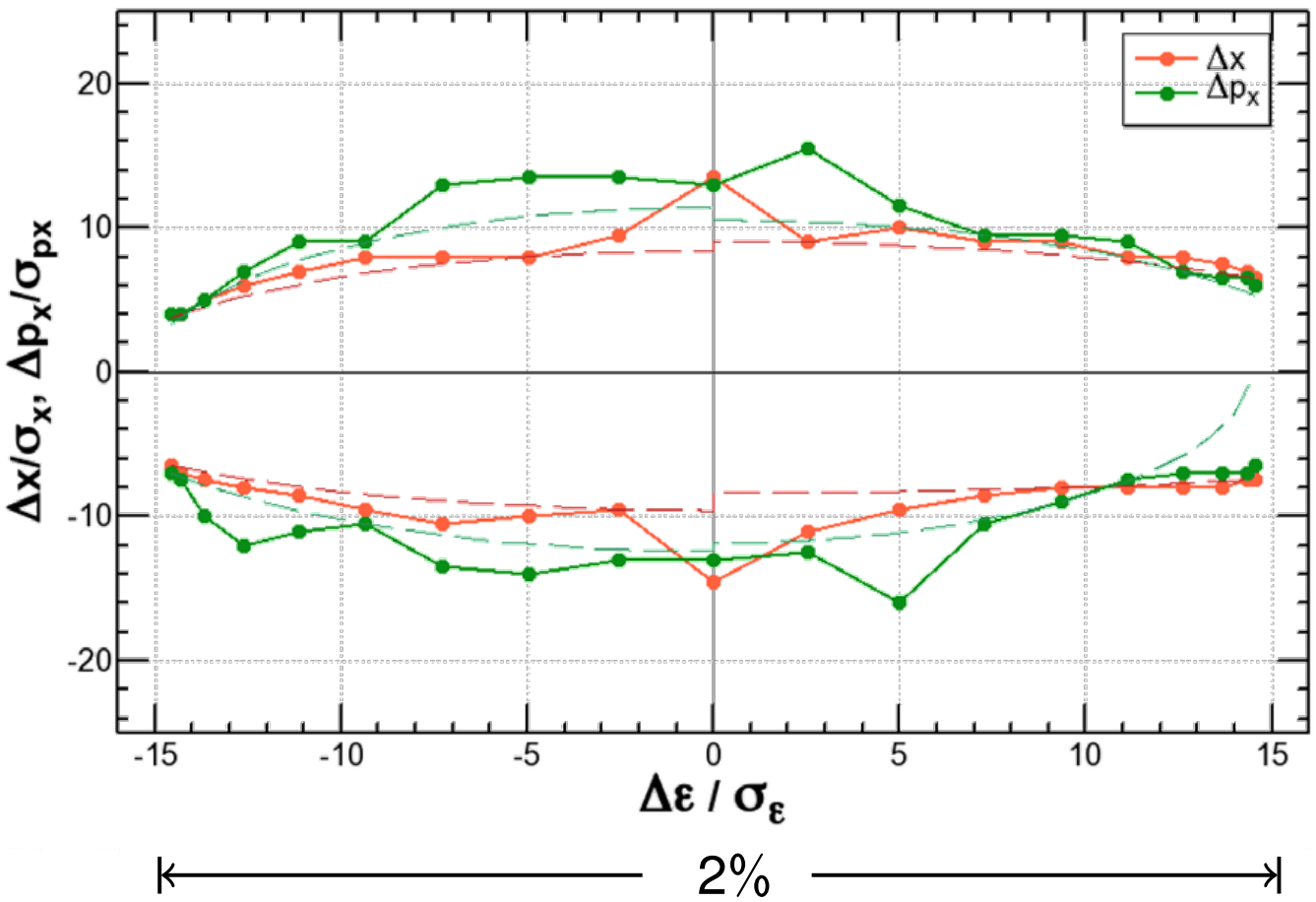


Crab on, 50 turns, $\epsilon_x = 1.34\,\text{nm}\cdot\text{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\text{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\text{GeV}$.

K. Oide

KO: Effect of RF and radiation

RF on, radiation on (each element)



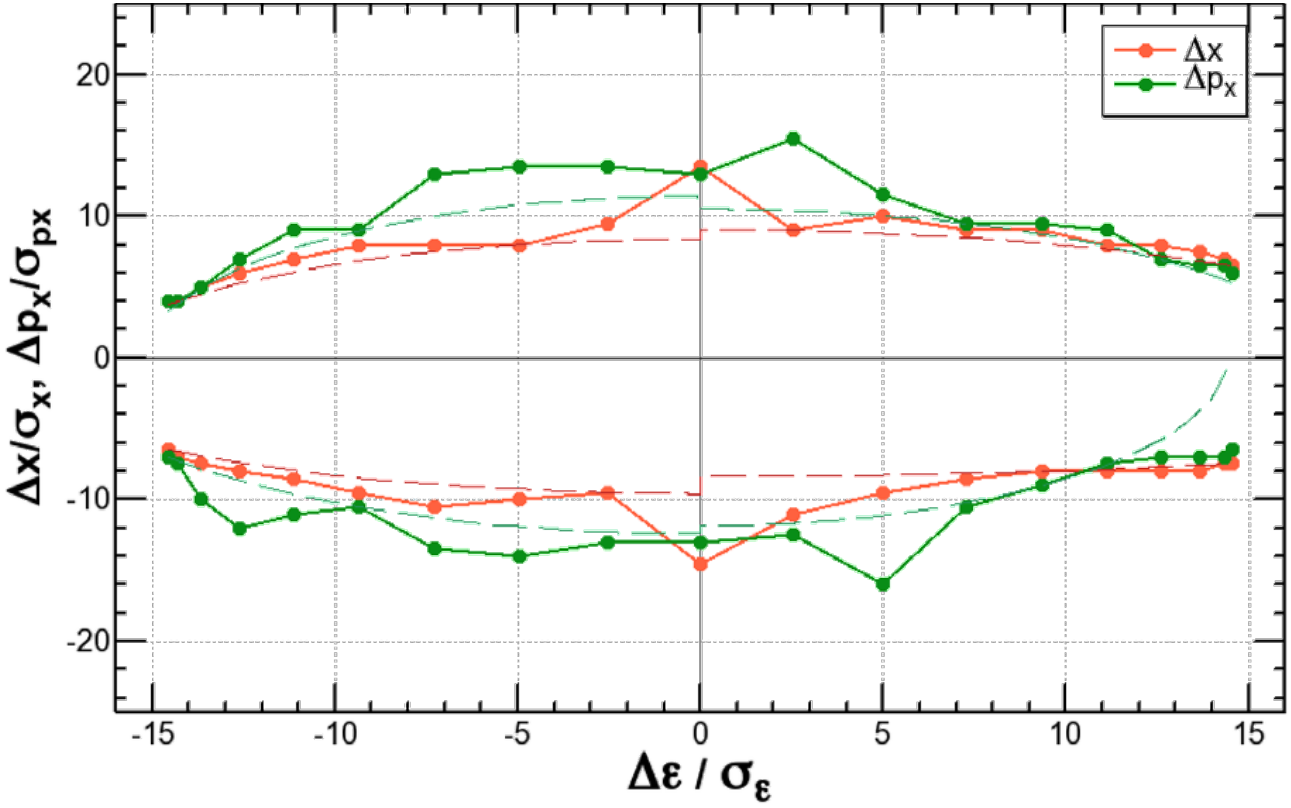
Crab on, 50 turns, $\epsilon_x = 1.34\,\text{nm}\cdot\text{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\text{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\text{GeV}$.

K. Oide

KO: Effect of larger $\beta^*_{x,y}$

$\beta^*_{x,y} = 0.5\,\mathrm{m}, 1\,\mathrm{mm}$

Horizontal plane:



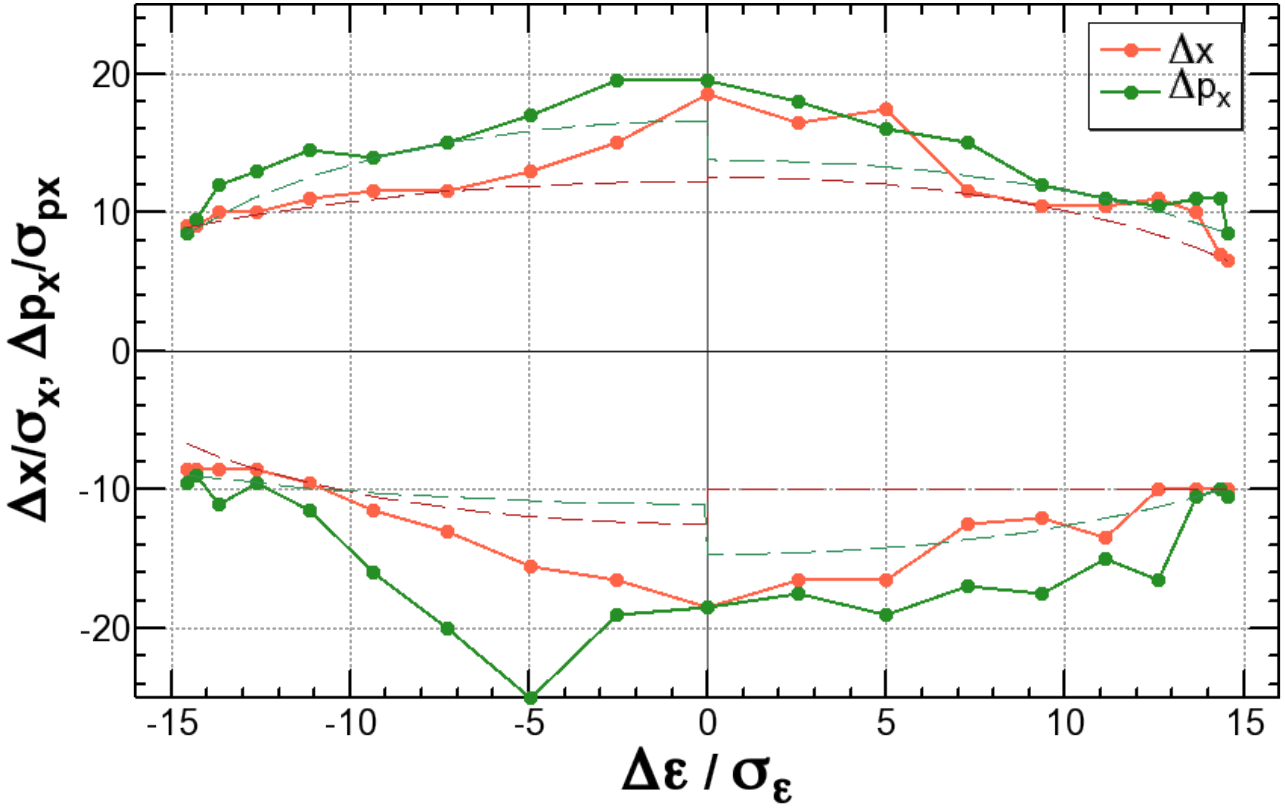
Crab on, 50 turns, $\epsilon_x = 1.34\,\mathrm{nm}\cdot\mathrm{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\mathrm{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\mathrm{GeV}$.

K. Oide

KO: Effect of larger $\beta^*_{x,y}$

$\beta^*_{x,y} = 1.0\,\mathrm{m}, 2\,\mathrm{mm}$

Horizontal plane:



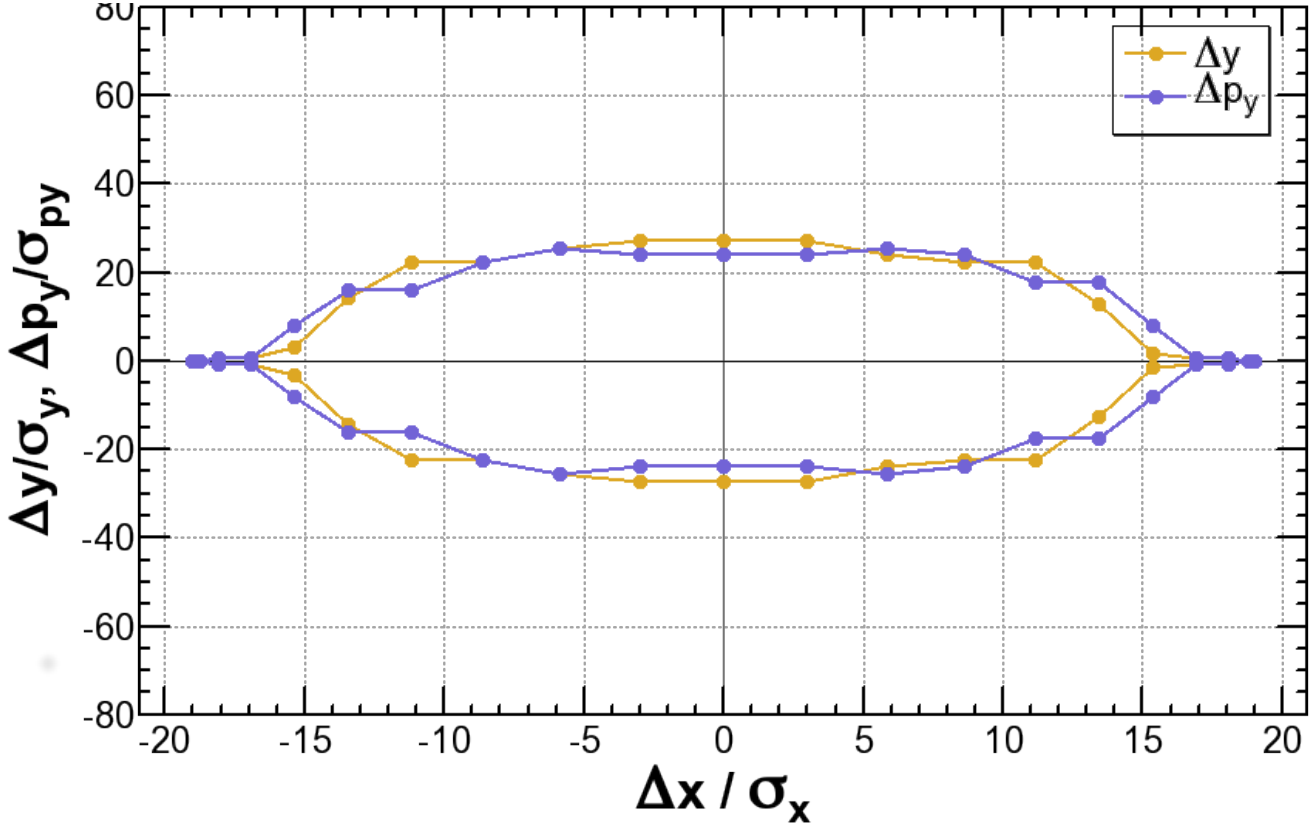
Crab on, 50 turns, $\epsilon_x = 1.34\,\mathrm{nm}\cdot\mathrm{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\mathrm{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\mathrm{GeV}$.

K. Oide

KO: Effect of larger $\beta^*_{x,y}$

$\beta^*_{x,y} = 0.5\,\text{m}, 1\,\text{mm}$

Vertical plane:



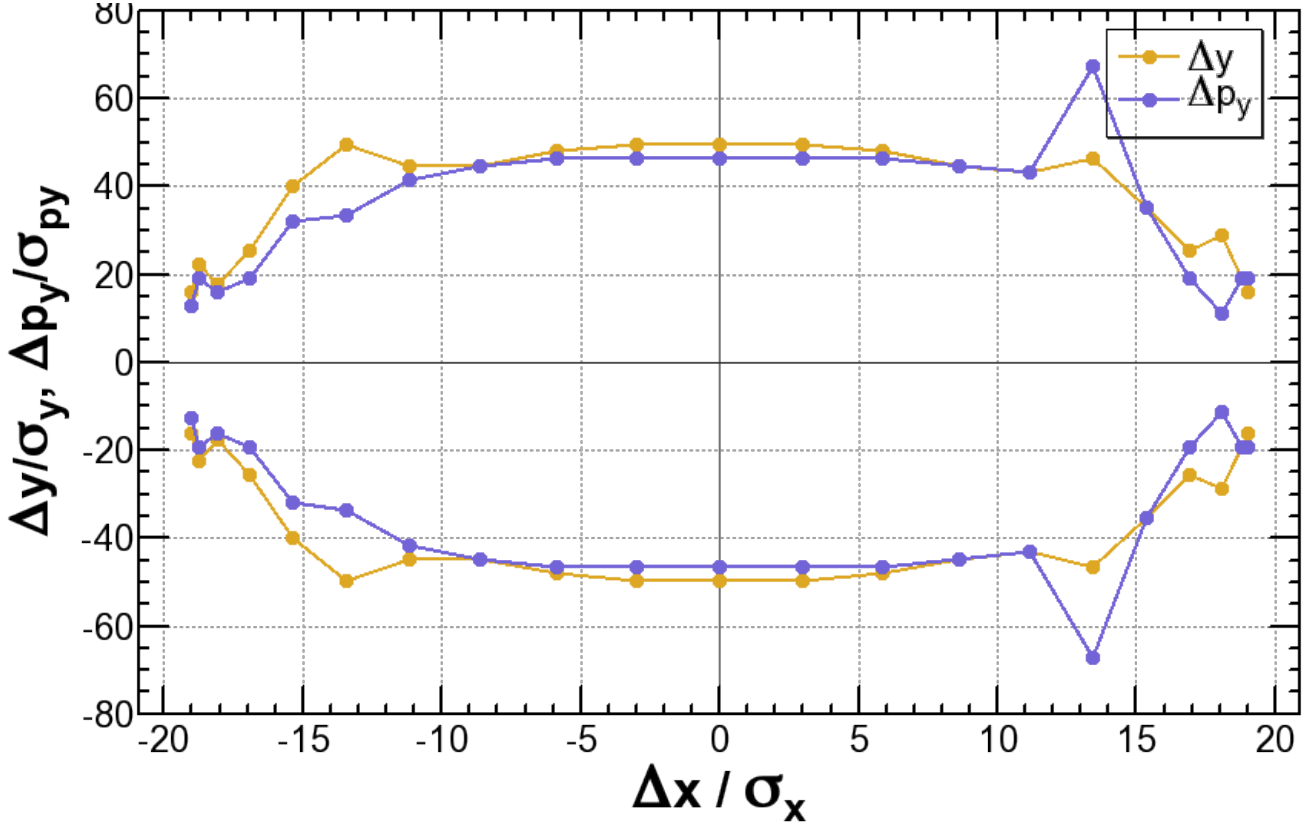
Crab on, 50 turns, $\epsilon_x = 1.34\,\text{nm}\cdot\text{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\text{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\text{GeV}$.

K. Oide

KO: Effect of larger $\beta^*_{x,y}$

$\beta^*_{x,y} = 1.0\,\mathrm{m}, 2\,\mathrm{mm}$

Vertical plane:



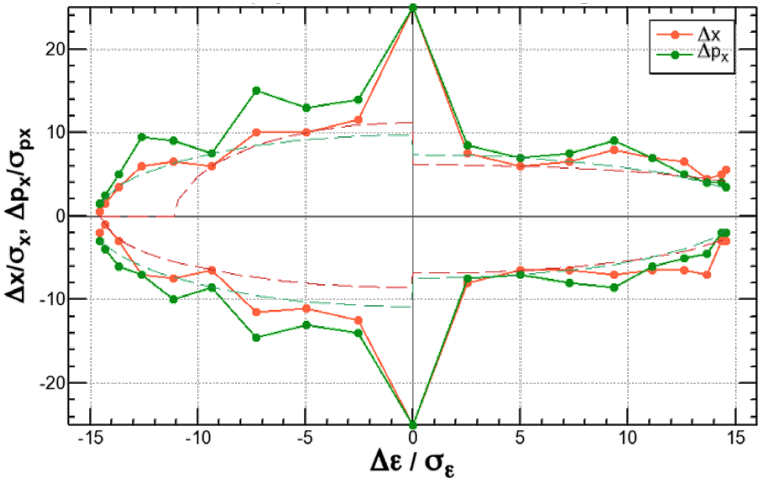
Crab on, 50 turns, $\epsilon_x = 1.34\,\mathrm{nm}\cdot\mathrm{rad}$, $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\mathrm{mm}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $U_0 = 7.74\,\mathrm{GeV}$.

K. Oide

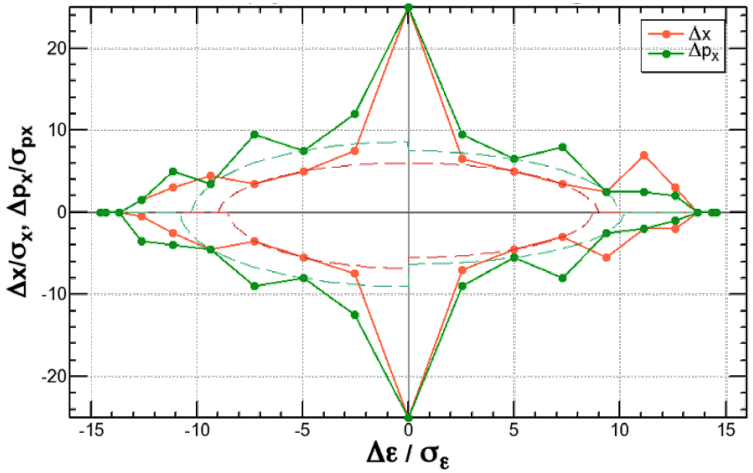
Summary: **KO** FCCee-V74-11

Effect of RF and radiation

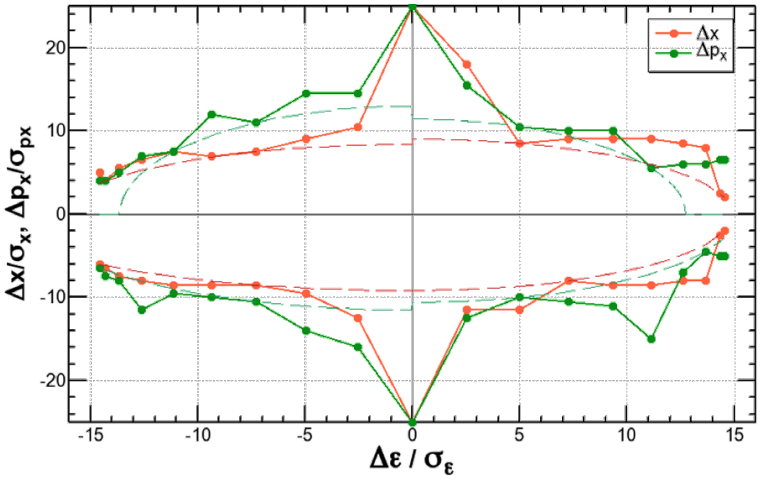
RF off, radiation off



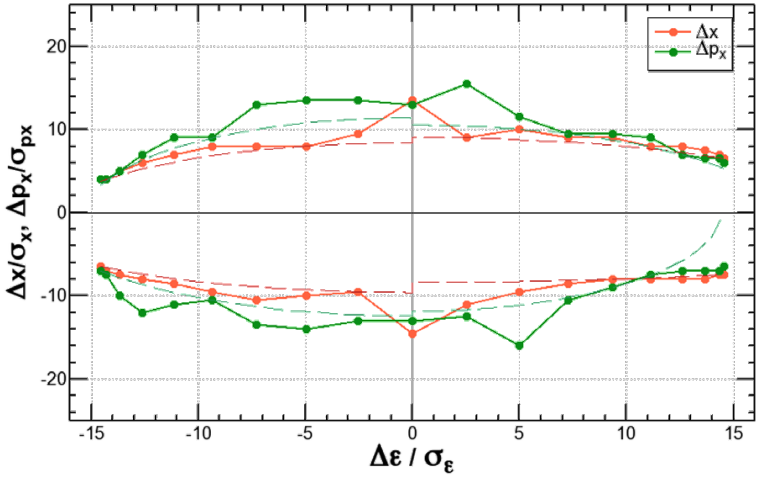
RF on, radiation off



RF on, radiation on (damping each turn)



RF on, radiation on (each element)



K. Oide

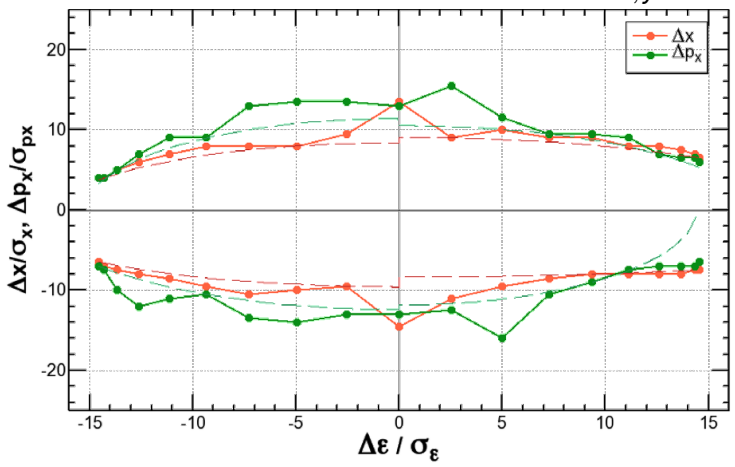
Crab on, 50 turns, $\epsilon_x = 1.34\,\text{nm}\cdot\text{rad}$,
$\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$.
$\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\text{mm}$, $U_0 = 7.74\,\text{GeV}$.

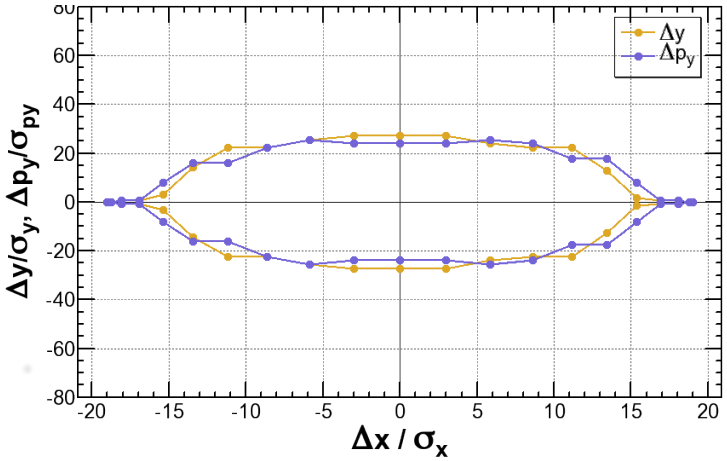
$\longleftarrow$ 2% $\longrightarrow$

Summary: **KO** FCCee-V74-11

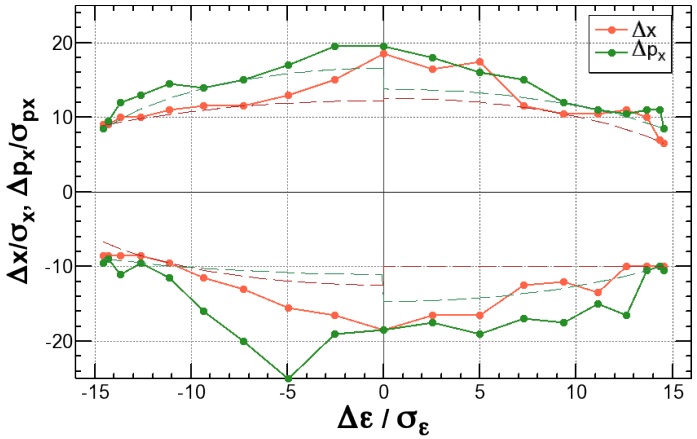
Effect of larger $\beta^*_{x,y}$

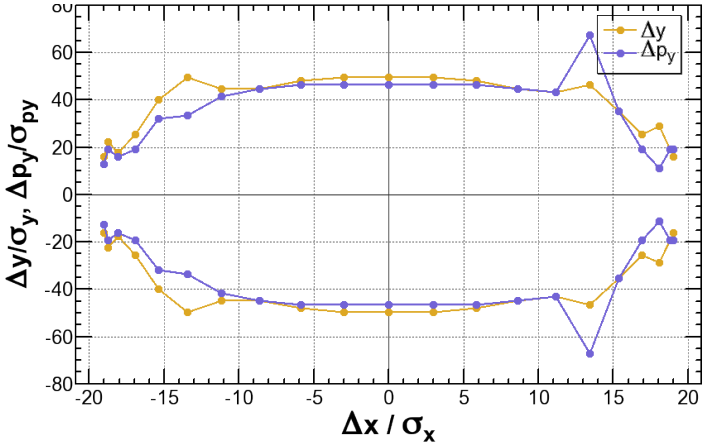
$\beta^*_{x,y} = 0.5\,\text{m}, 1\,\text{mm}$





$\beta^*_{x,y} = 1.0\,\text{m}, 2\,\text{mm}$





K. Oide

Crab on, 50 turns, $\epsilon_x = 1.34\,\text{nm}\cdot\text{rad}$, $\nu_{x,y,z} = 387.0800, 387.1400, -0.0686$. $\sigma_E = 0.144\,\%$, $\sigma_z = 2.4\,\text{mm}$, $U_0 = 7.74\,\text{GeV}$.

The reduction of the vertical aperture for $\beta^*_y = 1\,\text{mm}$ is due to synchrotron radiation in the final quadrupoles.

Effects included in KO studies

Effects	Included?	Significance for DA
Synchrotron motion	✓	**Essential**
Radiation damping (turn-by-turn)	✓	**Essential**, increases DA
Radiation damping (each element)*	✓	**Essential**, decreases DA
Tapering	✓	**Essential**
Crab-waist	✓	**Essential**, decreases DA,
Solenoids	✓	Minimal, if locally compensated
Maxwellian fringe fields	✓	Small
Kinetic terms	✓	Small
Errors / misalignments	✗	**Essential**, correction schemes must be developed

* No fluctuations yet.

K. Oide

Contents

Conclusions

- Significant **progress** has been done in both AB and KO optics.
- Lattice optimizations have lead to increased DAs.
- Several **effects** have been simulated, and their impact on the 6D DA has been observed.
- Minimum DA (on-momentum): 20σ for AB, and 28σ for KO.
- DA almost **satisfy** the requirement of 15σ / 5σ for on-energy / 2% off-energy. [6].

Outlook

- Continue with **optimization**...
- **Statistical** approach for DA with **radiation**.
- Estimation of DA with **errors** and **misalignments**.

References

[1] A. Bogomyagkov *et al.*, "Interaction region optics solutions" Presentation at the FCC Week 2016, available at https://indico.cern.ch/event/438866/

[2] L. Medina, R. Martin, R. Tomas, and F. Zimmermann "Dynamic Aperture Studies for the FCC-ee", in *Proc. of the Int. Particle Accelerator Conf. 2015 (IPAC'15)*, MOPWA059, VA, USA, May 2015.

[3] L. Medina, R. Tomas "Follow up of DA estimation". Presentation at the 5th FCC-ee Optics Design Meeting, July 10, 2015. Available at https://indico.cern.ch/event/407142/

[4] P. Piminov, S. Sinyatkin, and A. Bogomyagkov, "Dynamic aperture optimization for FCC-ee version 9.PS2". Presentation at the 27th FCC-ee Optics Design Meeting, April 1st, 2016. Available at https://indico.cern.ch/event/512802/

[5] K. Oide, "Asymmetric L^* optics, etc." *Ibíd.*

[6] M. Aiba, and Á. Sáa Hernández "Top-up injection schemes" Presentation at the FCC Week 2016, available at https://indico.cern.ch/event/438866/