Nonlinear analysis and dynamic aperture

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Acknowledgements:

M. Benedikt, M. Crouch, L. Deniau, R. De Maria, E. Forest, S. Fartoukh, M. Giovannozzi, M. Hofer, K. Oide, T. Risselada, L. Riesen-Haupt, D. Sagan, D. Schoerling, I. Tecker, R. Tomas, P. Thrane, E. Todesco, D. Tommasini, F. Zimmermann

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Outline

- ➤ **Introduction**
  - HE-LHC optics under design
  - See Y. Nosochkov's talk for HE-LHC optics design efforts
- ➤ **Resonance driving term (RDT) and dynamic aperture (DA) calculation**
  - Only applied to injection optics w/o errors for HE-LHC for this moment
  - Only lattice sextupoles taken as sources of non-linear effects
- ➤ **Summary and outlook**

1. Introduction

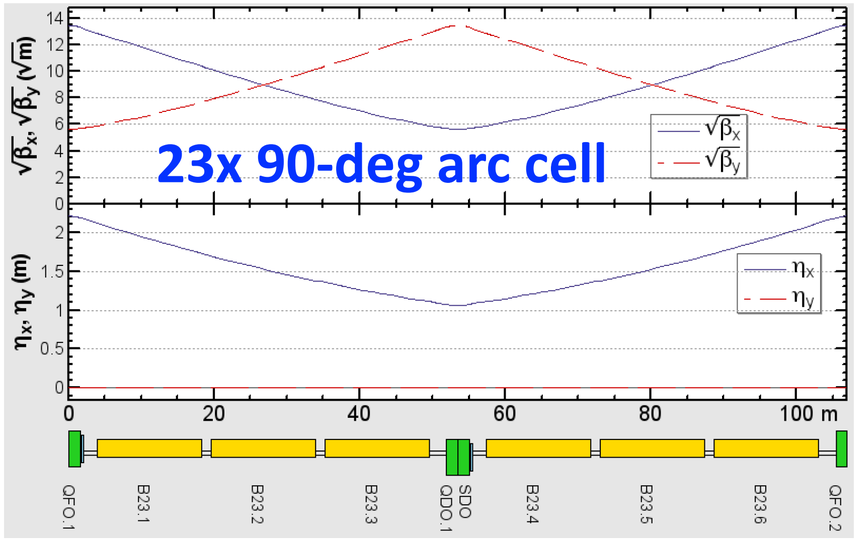
➤ Alternatives for arc cells fitting to the geometry of LHC arcs

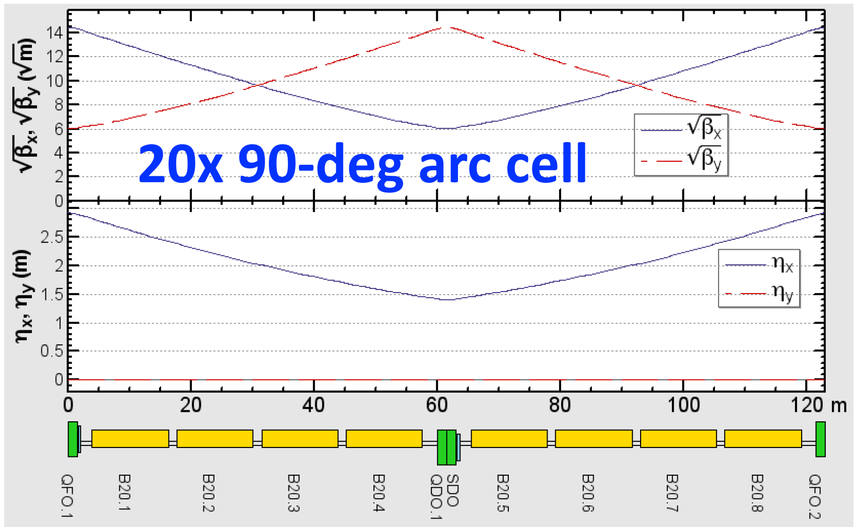
- Motivation: simply scaling (HL-)LHC hits the limits set by FCC technologies
- Rules: Assume the same drifts between magnets as LHC; Fit to the arc length of LHC

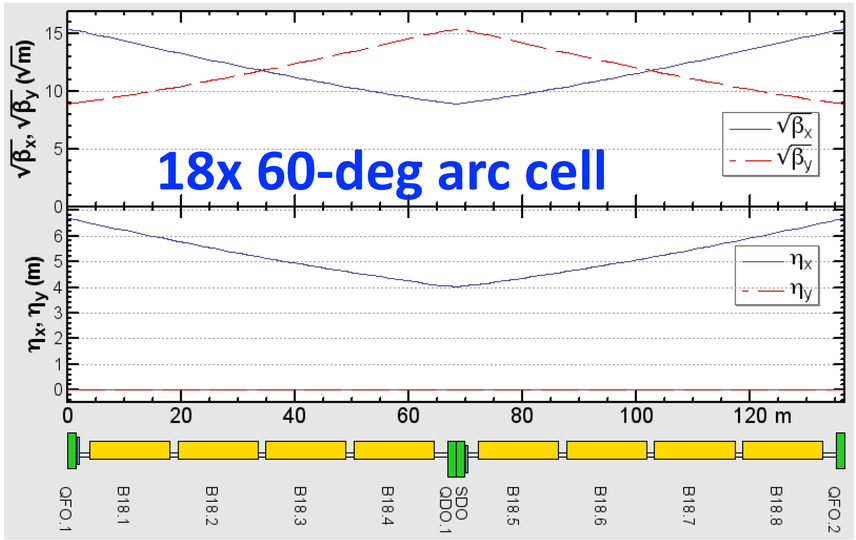
	LHC-like	24x 60^0 HE-LHC	20x 90^0 HE-LHC	18x 60^0 HE-LHC
Arc cell phase advance [deg]	90/90	60/60	90/90	60/60
Arc cell length [m]	106.9584	102.5018	123.00	136.669
K1 [m^{-1}]	0.02697	0.0199	0.0234	0.01485
$\beta_{max/min}$ [m]	181.3/31.54	176.6/59.48	208.68/36.24	235.74/79.22
$\eta_{max/min}$ [m]	2.21/1.07	3.75/2.26	2.92/1.41	6.67/4.02
Dipole length [m]	14.3 [x6]	13.56 [x6]	12.39 [x8]	14.1 [x8]
Dipole field [T]@13.5TeV	16.06	16.23	15.99	15.61
Filling factor	0.802	0.794	0.806	0.825

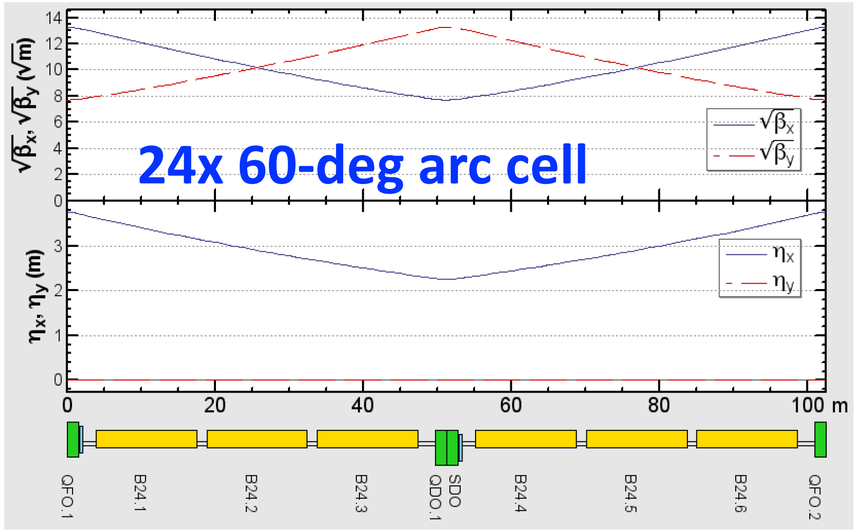
1. Introduction

➤ Alternatives for arc cells





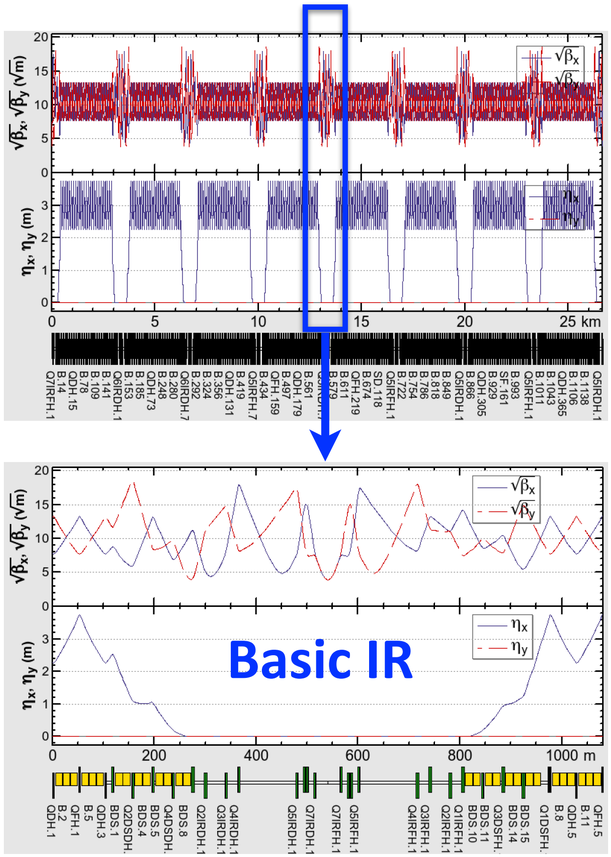




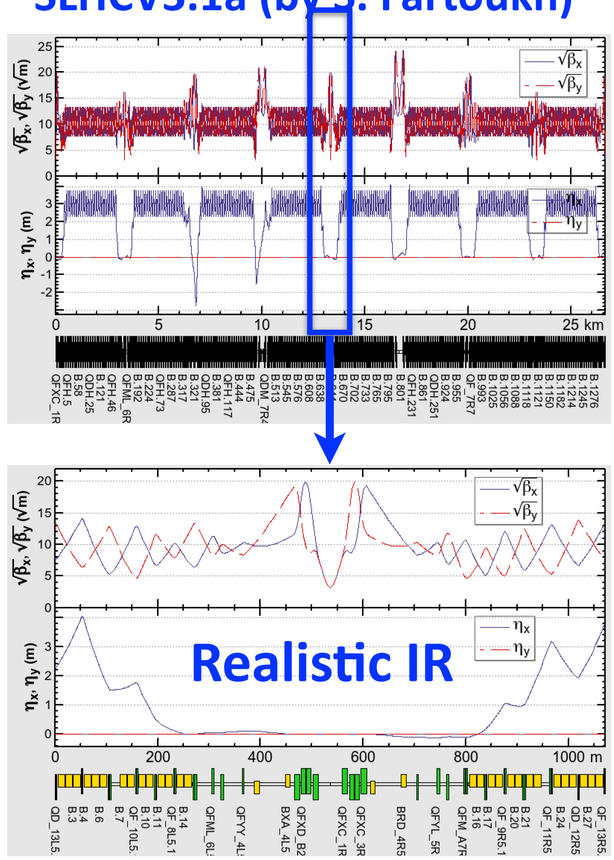
1. Introduction

➤ Integration with IRs (Start from IP1 for plots)

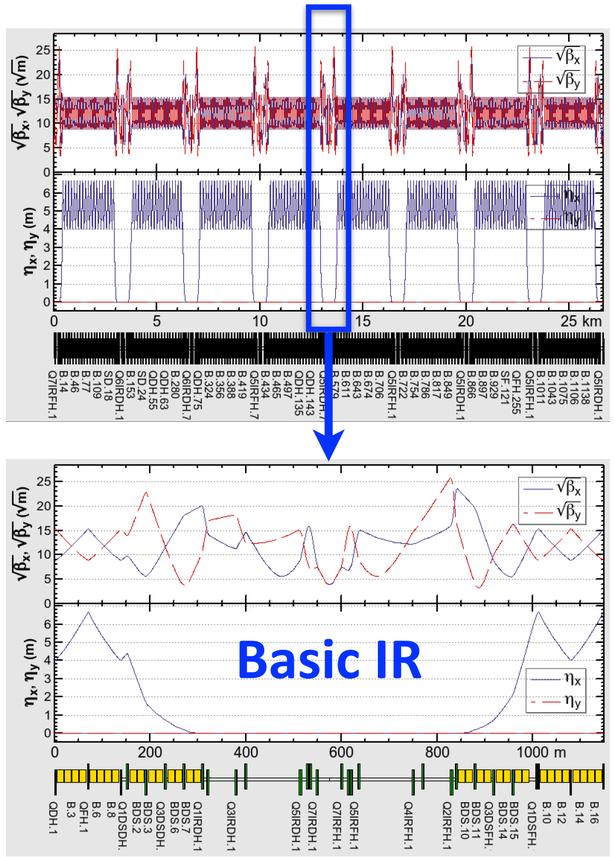
Injection lattice by Y.N.
24x 60-deg arcs



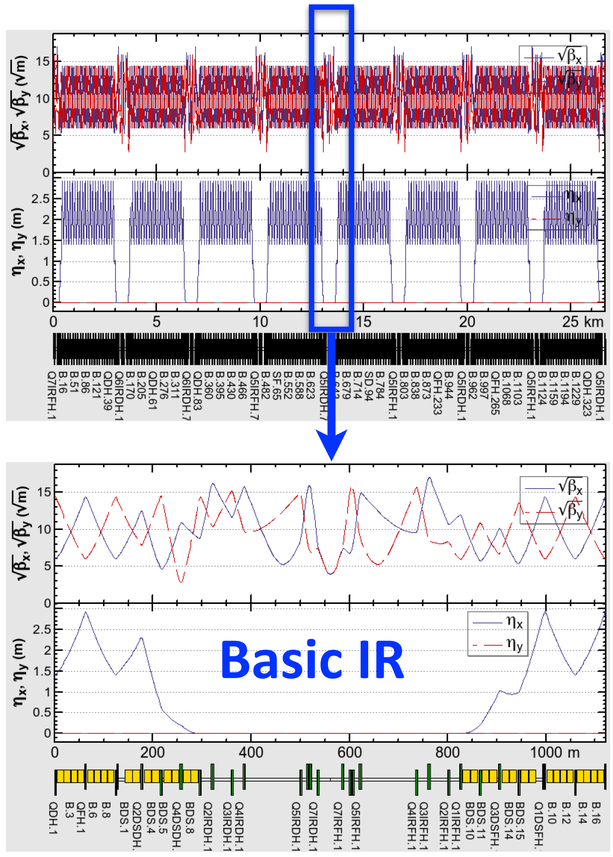
Modified HL-LHC injection lattice by T. Risselada
24x 60-deg arcs + IRs of SLHCV3.1a (by S. Fartoukh)



Injection lattice by Y.N.
18x 60-deg arcs



Injection lattice by Y.N.
20x 90-deg arcs

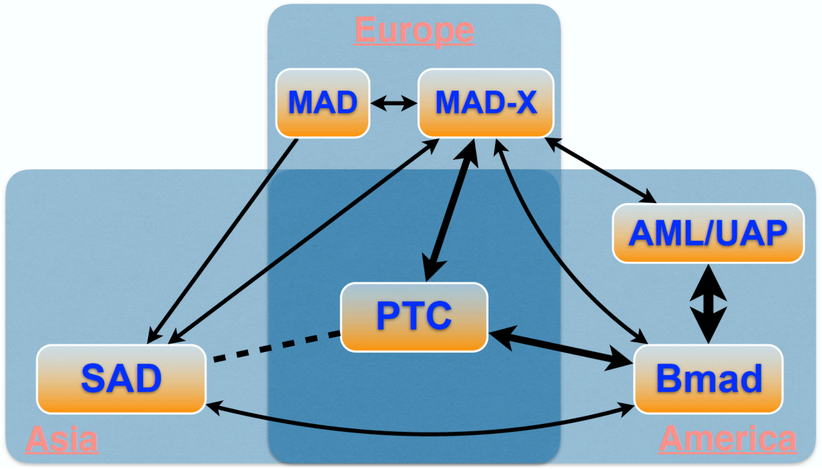


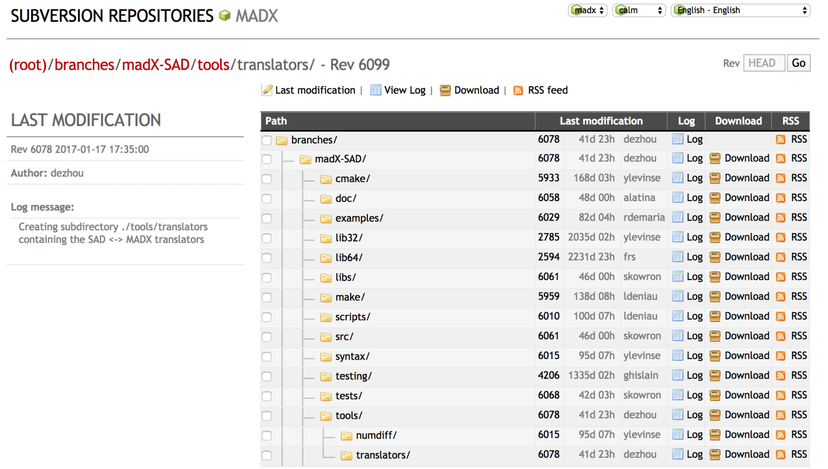
1. Introduction

➤ Simulation tools

- PTC developed by E. Forest at KEK
  * MAD8/MAD-X lattices translated to PTC flat format via Bmad or AML/UAP
- SAD developed by K. Oide et al. at KEK
  * MAD8/MAD-X lattices translated to SAD via Bmad or SAD scripts
- Translators developed (still under development, and collaborations always welcomed!)

with collaborative efforts by M. Biagini, L. Deniau, E. Forest, M. Giovannozzi, H. Koiso, A. Morita, K. Oide, D. Sagan, D. Zhou, et al., and strong support from M. Benedikt and F. Zimmermann.





See webpage: http://svnweb.cern.ch/world/wsvn/madx/branches/madX-SAD/tools/translators/

1. Introduction

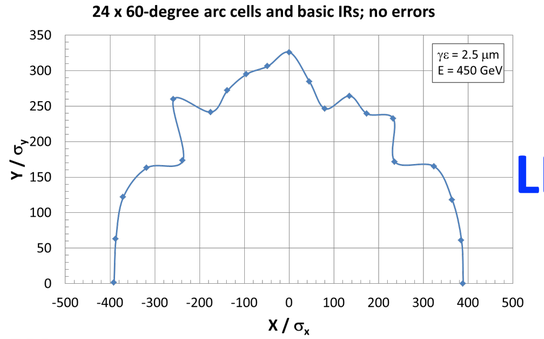
➤ Simulation conditions

- RDT calculation
  - * PTC tracking w/o SR, w/o errors
  - * Integrate RDTs along beam orbit
- DA calculation
  - * SAD tracking w/o SR, w/o errors
  - * Use standard FMA algorithm
  - * Short-term DA by tracking 1024 turns (also see Y.N.'s talk)
- Normalized emittance γε=2.5 μm; Beam energy E=450 GeV
- Linear chromaticity set at (Qx', Qy')=(3, 3) for all lattices under consideration

2. RDT and DA calculation

➤ Injection lattice with 24x 60-deg arcs (by Y.N.)

- Use basic IRs
- Working point (49.28, 47.31)



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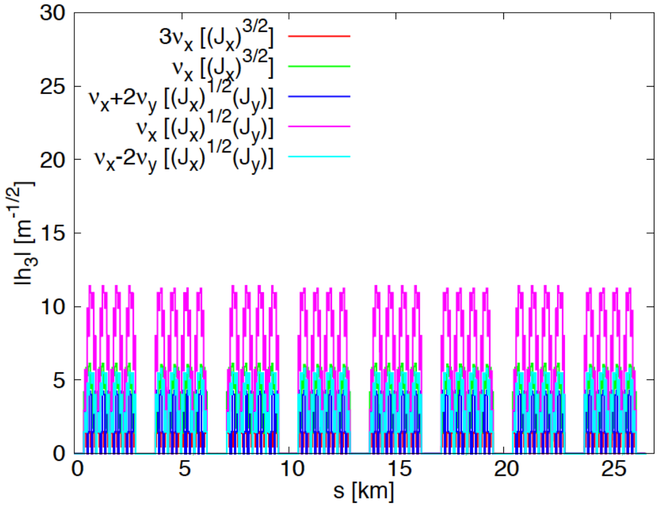
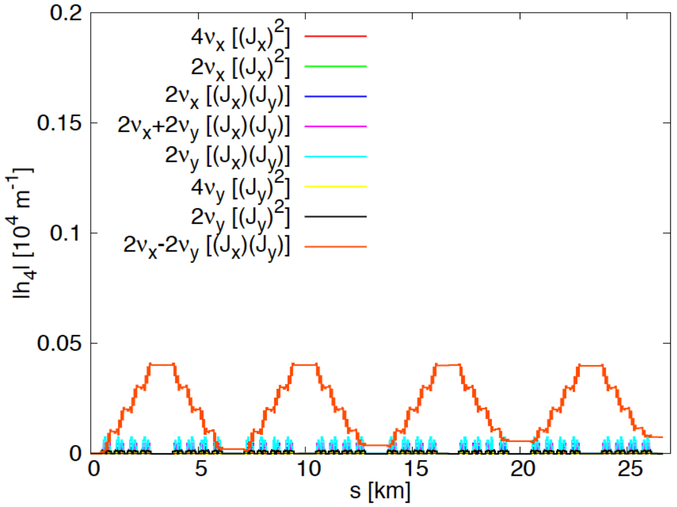
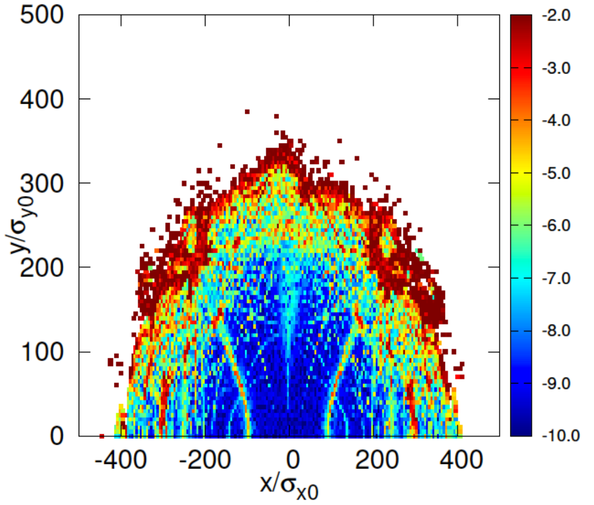
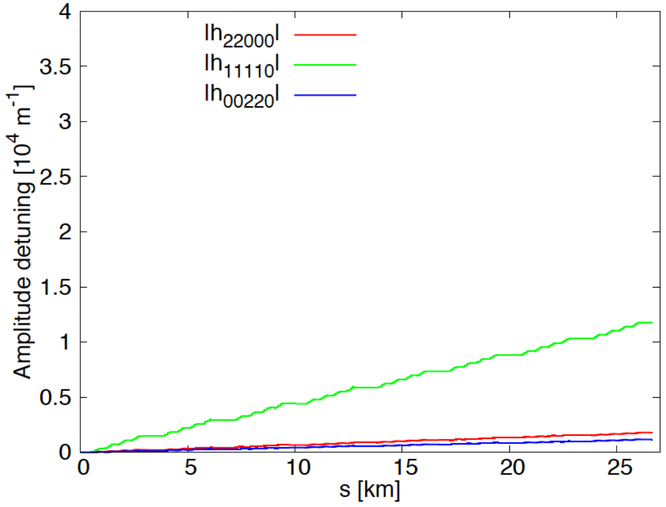
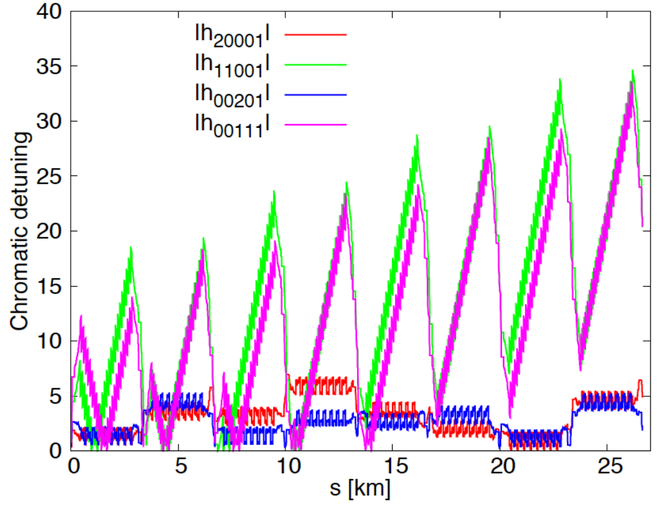
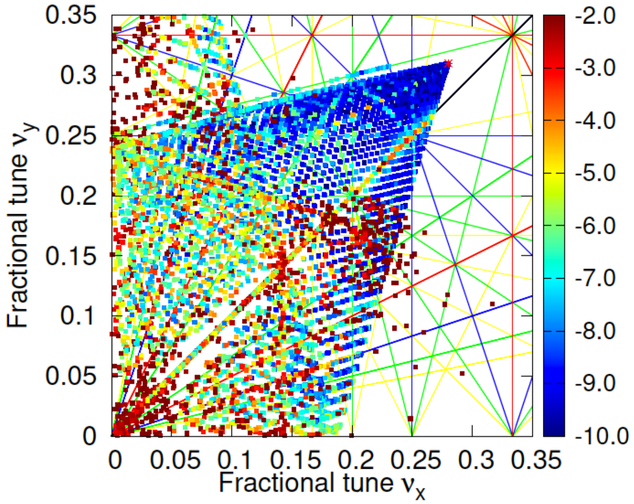








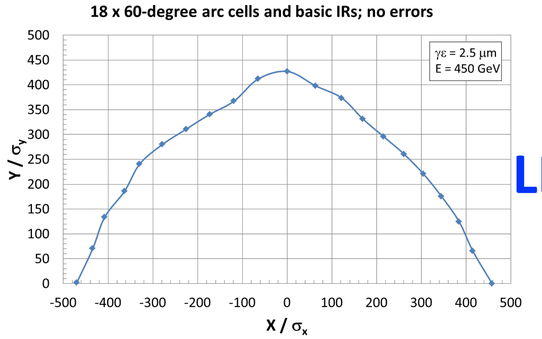




2. RDT and DA calculation

➤ Injection lattice with 18x 60-deg arcs (by Y.N.)

- Use basic IRs
- Working point (37.28, 39.31)



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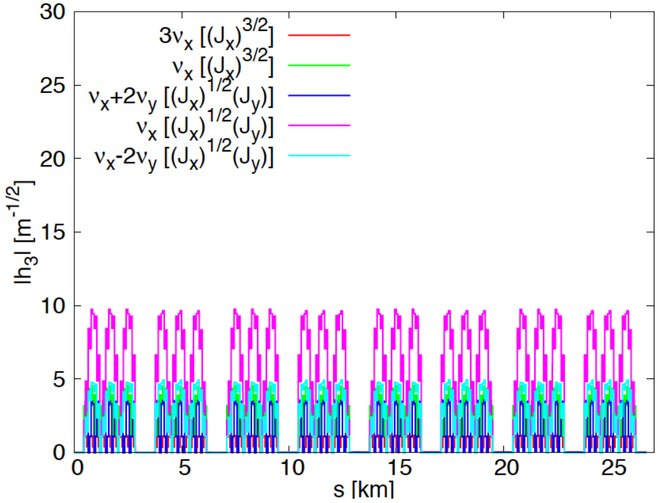
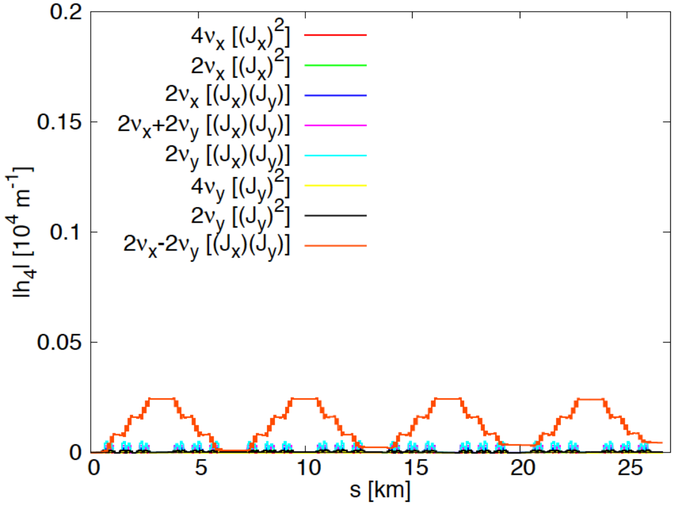
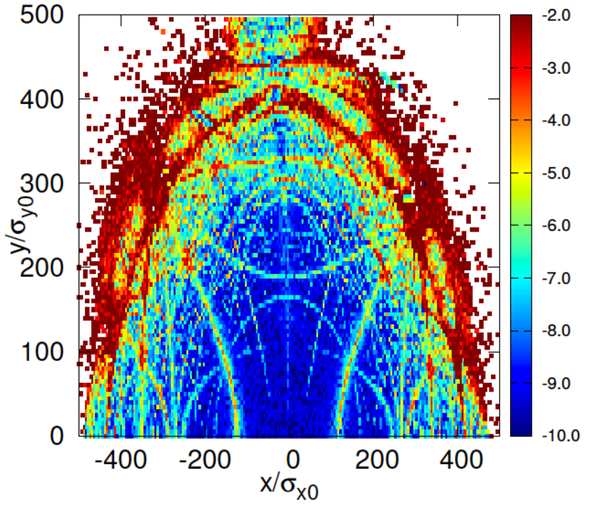
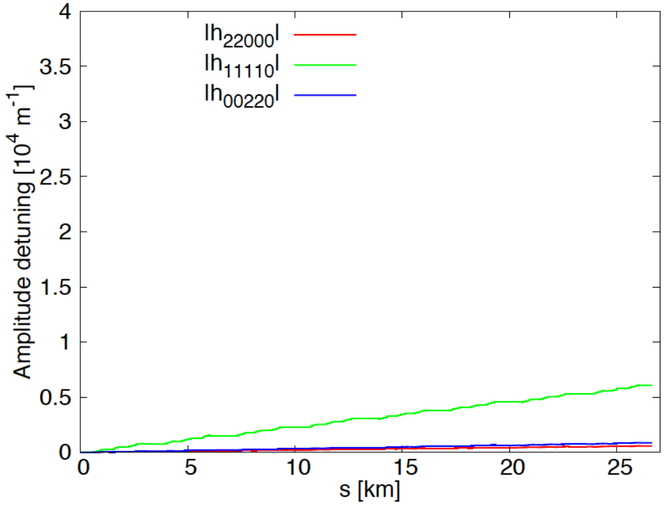
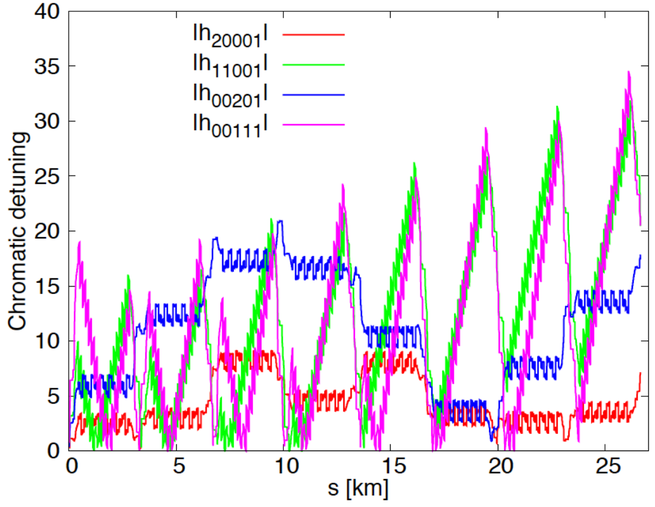
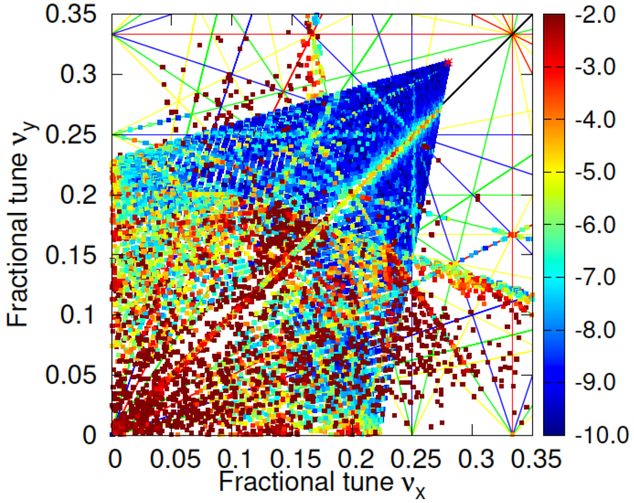








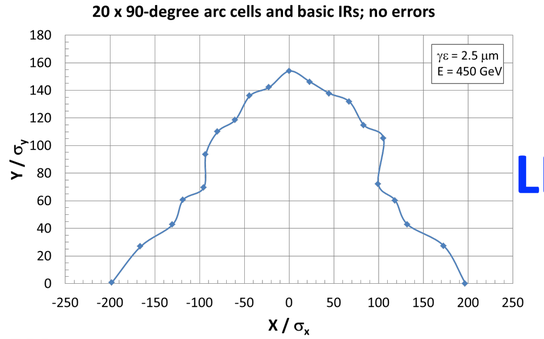




2. RDT and DA calculation

➤ Injection lattice with 20x 90-deg arcs (by Y.N.)

- Use basic IRs
- Working point (56.28, 57.31)



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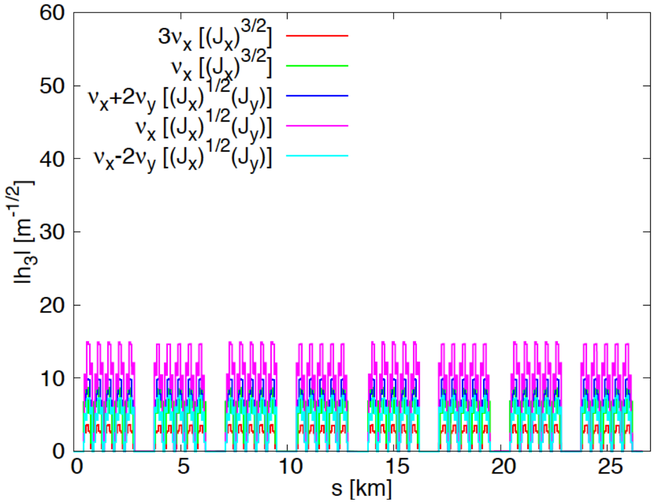
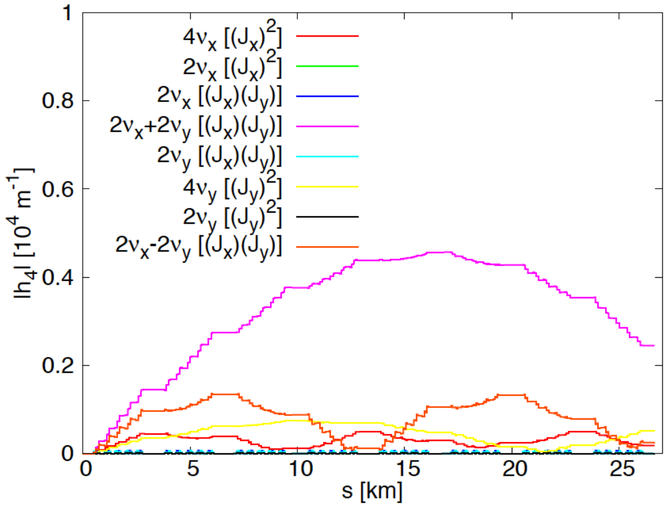
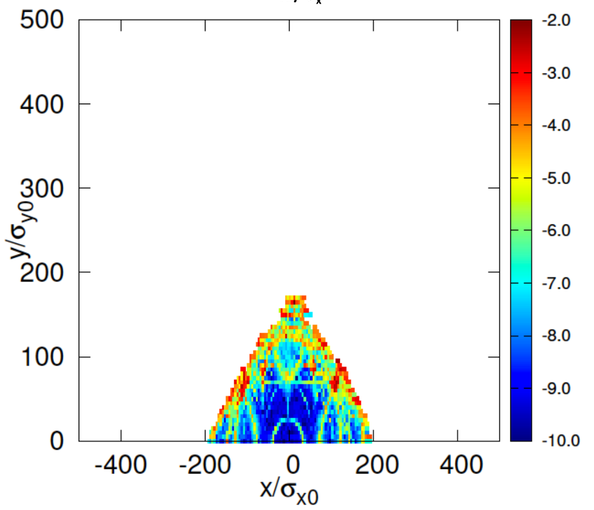
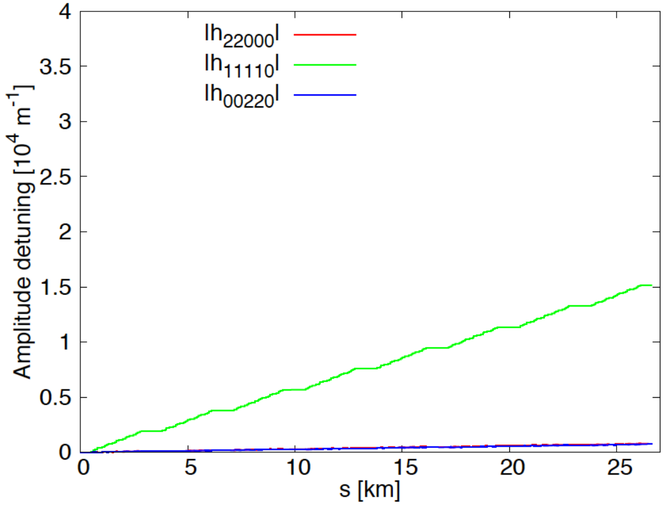
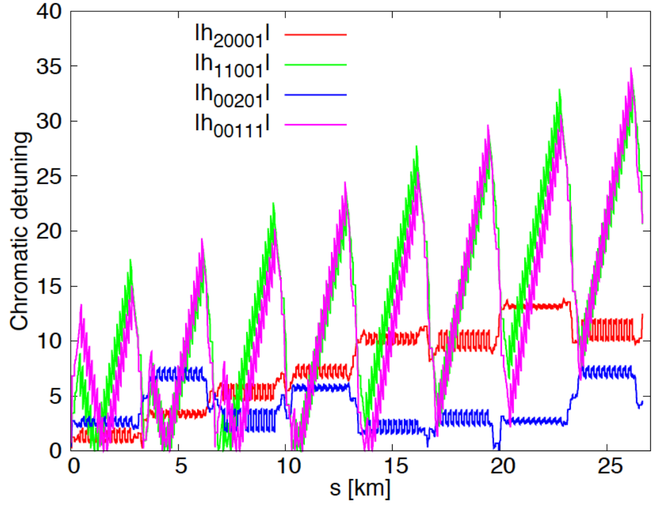
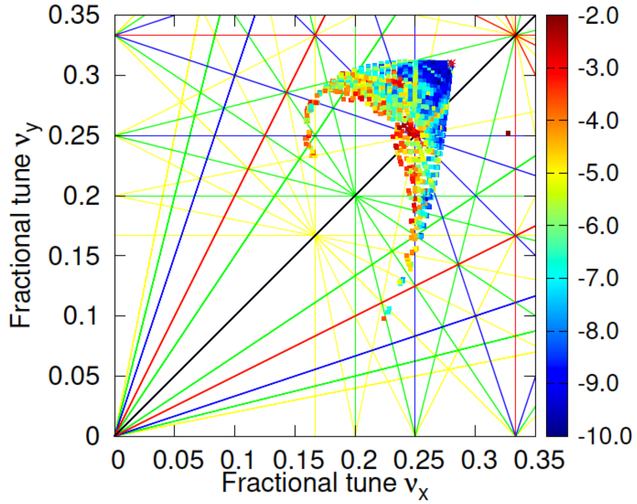








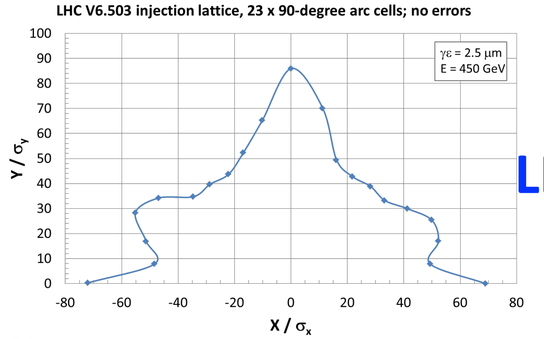




2. RDT and DA calculation

➤ LHC injection lattice (Ver. V6.503)

- 23x ~90-deg arcs, same dipole for both arcs and DSs
- Working point (64.28, 59.31)



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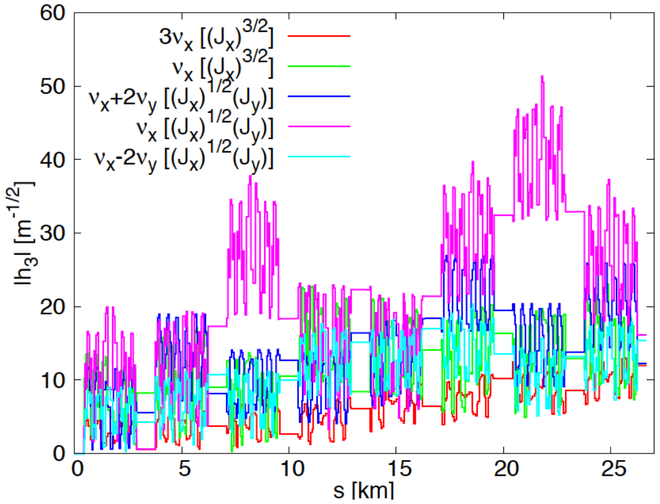
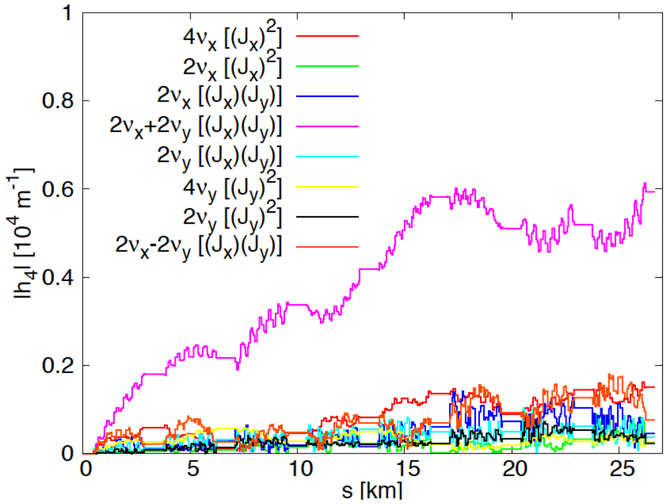
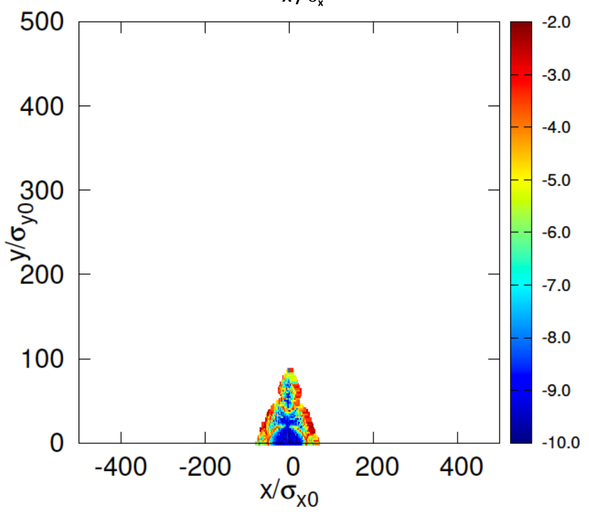
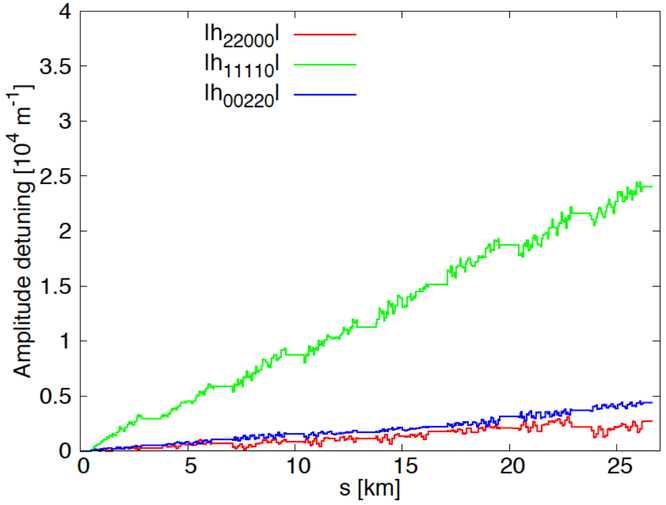
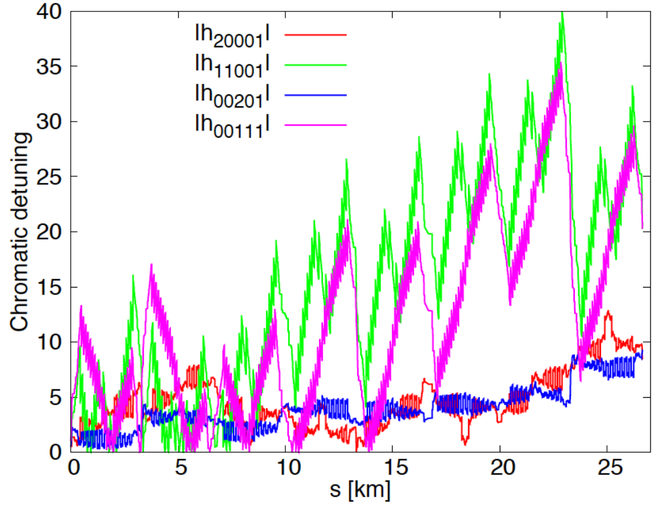
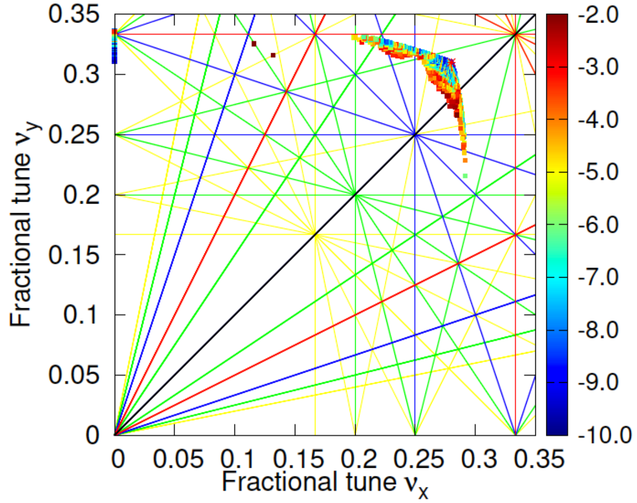








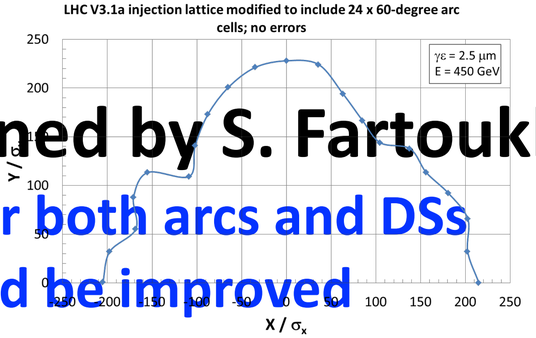


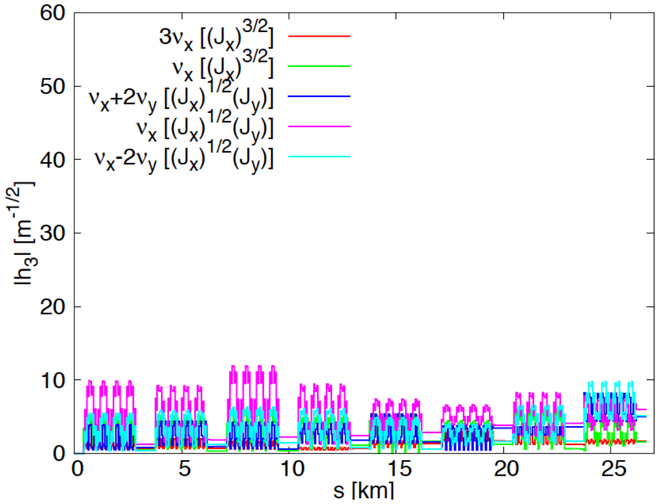


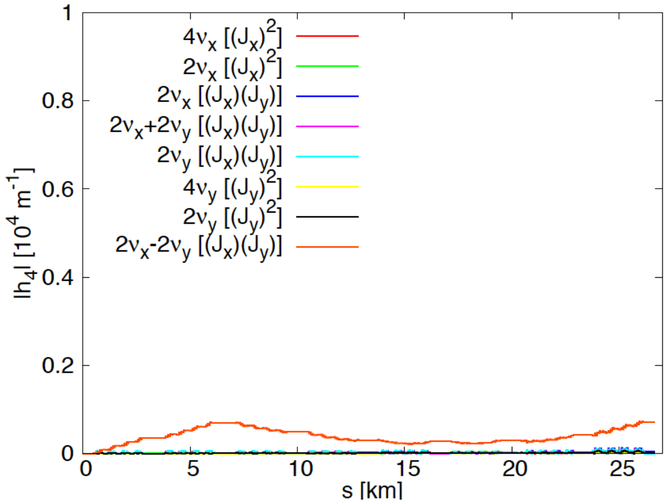
2. RDT and DA calculation

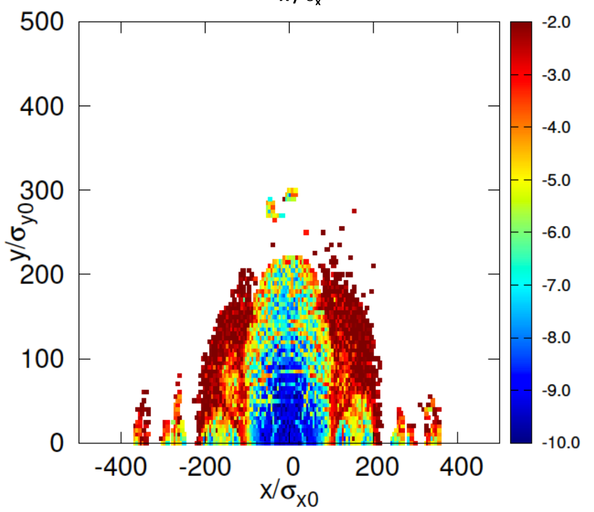
➤ Modified HL-LHC injection lattice (SLHCV3.1a designed by S. Fartoukh)

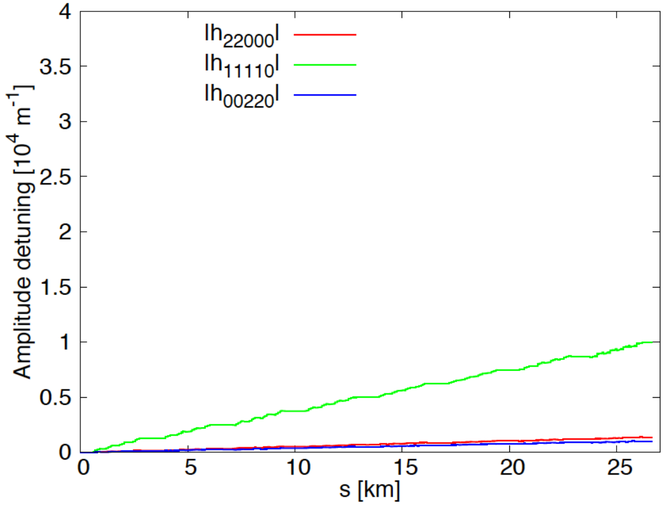
- Use 24x 60-deg arcs (developed by T. Risselada), same dipole for both arcs and DSs
- Tune matched to (46.28, 45.31). No nonlinear optimization could be improved

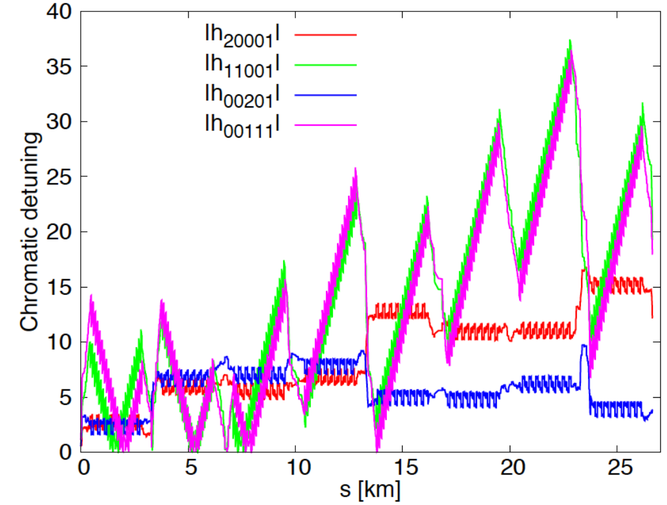


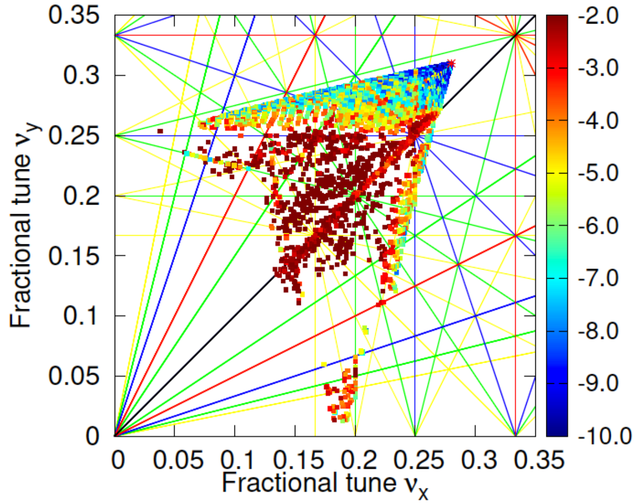












2. RDT and DA calculation

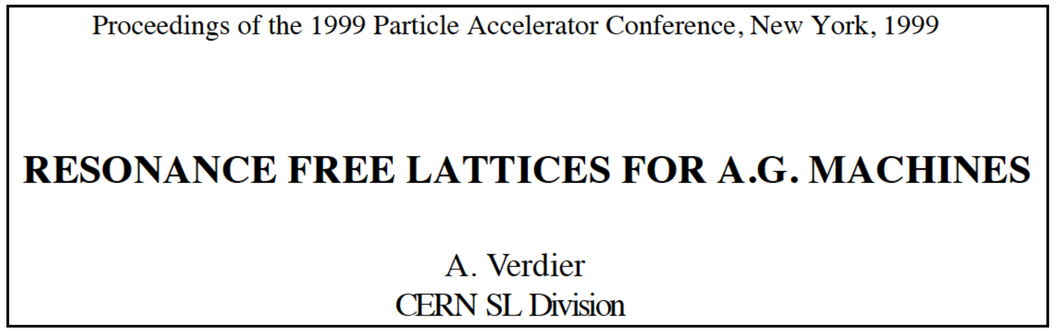
➤ Theory of resonance cancelation

- **Cancellation condition (C.C.):**

  $N_c(n_x\mu_{xc}+n_y\mu_{yc})=2k\pi$ & $(n_x\mu_{xc}+n_y\mu_{yc})\neq 2k'\pi$

  N_c: number of cell; μ_{xc}, μ_{yc}: Phase advance per cell

- **60-deg cell:**
  - * C.C.: $N_c=6N$
  - * Lowest order resonances: $n_x-n_y=0$ and $n_x+n_y=6$
- **90-deg cell:**
  - * C.C.: $N_c=4N$
  - * Lowest order resonances: $n_x-n_y=0$ and $n_x+n_y=4$


Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

RESONANCE FREE LATTICES FOR A.G. MACHINES

A. Verdier
CERN SL Division

3. Summary and outlook

➤ RDT and DA calculation for HE-LHC injection lattices w/o errors

- 60-deg arc cells show huge DAs mainly resulted from:
  - * Large beta and dispersion functions, and weaker sextupoles
  - * Well-suppressed 3rd and 4th RDTs
- 90-deg arc cells show relative smaller DAs mainly resulted from:
  - * Stronger sextuples
  - * 4th RDTs not well-suppressed

➤ Outlook

- Impact of errors and relevant tolerances to be investigated
- Integration of 60-deg arc cells to collision lattices (in parallel to design efforts on insertions of HE-LHC) to be investigated

Thank you for your attention!