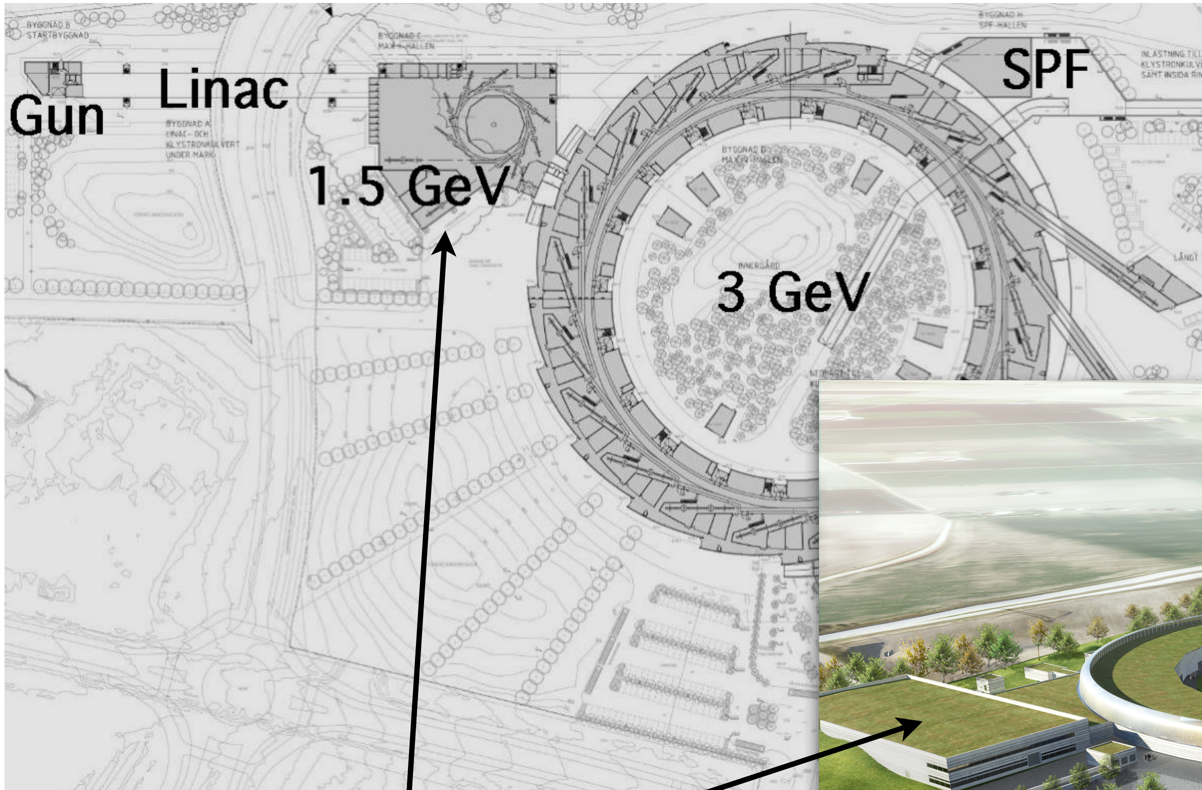
MAX IV 1.5 GeV Storage Ring

Recent Developments in Lattice, Optics, and Beam Dynamics

Simon C. Leemann

4th MAX IV MAC Meeting, May 29-30, 2012

Reminder: 1.5 GeV Storage Ring

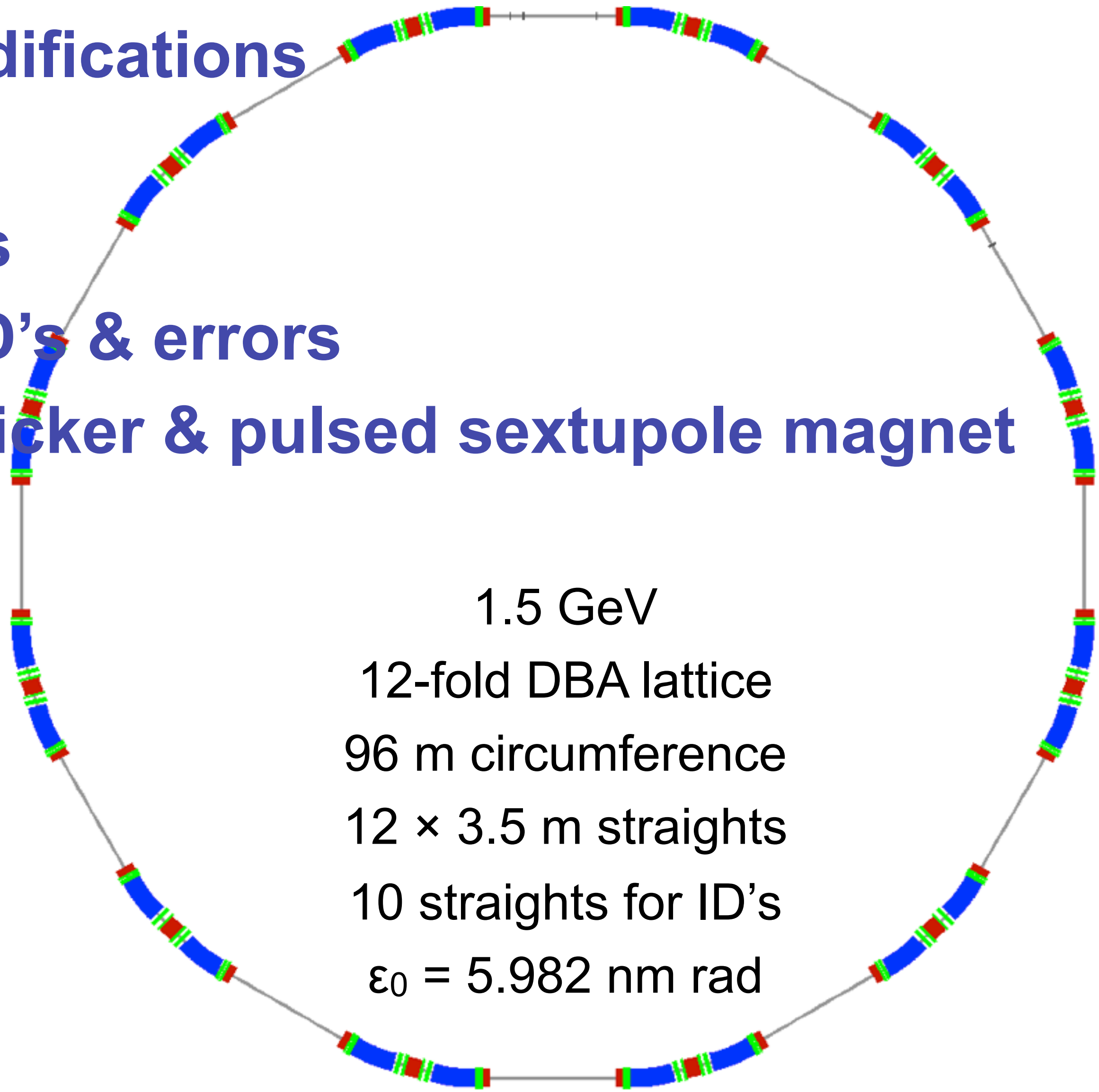


"No problem is too small or too trivial if we can really do something about it."

— Richard P. Feynman

Outline

- **Recent lattice/model modifications**
- **Updated linear optics**
- **Updated nonlinear optics**
- **Realistic performance: ID's & errors**
- **Injection: single dipole kicker & pulsed sextupole magnet**



1.5 GeV

12-fold DBA lattice

96 m circumference

12 × 3.5 m straights

10 straights for ID's

ε_0 = 5.982 nm rad

Lattice Modifications

- **Lattice model completed**
  - Pingers, dipole kicker, and PSM included
- **Magnet engineering feedback**
  - Shifted sextupoles to make room for coils & field clamps
  - Hard-edge magnet lengths closer to mechanical lengths

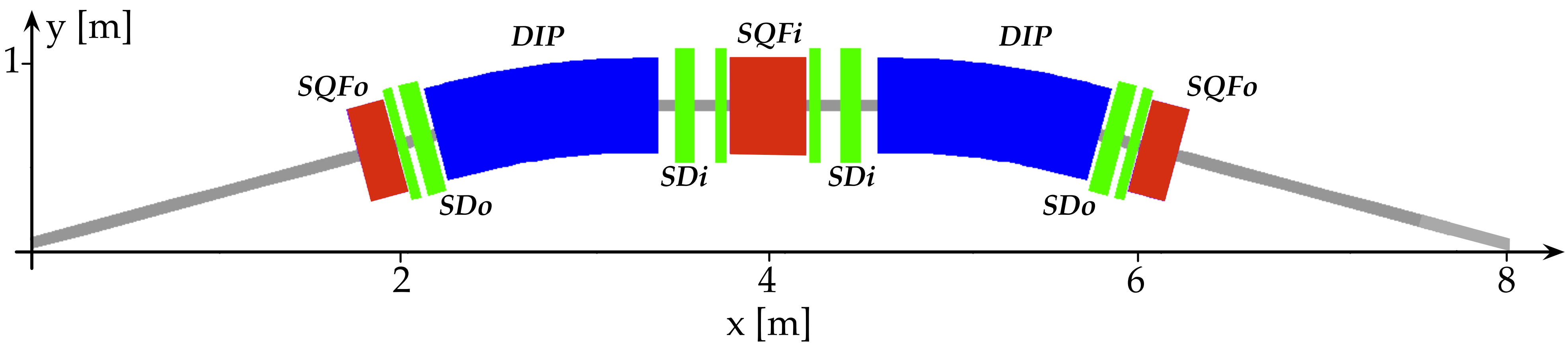
IPAC'11, WEPO016

- **Vacuum engineering feedback**
  - Realistic vacuum apertures in model (incl. septum)
- **Slice model**
  - 28 slices to model gradient dipoles
  - 3/4 slices to model focusing quads with sextupole component
  - ➡ Longitudinal field profiles properly modeled (can also include crosstalk and systematic multipoles)

➡ **Restore linear optics, re-optimize nonlinear optics, revisit injection, verify expected performance...**

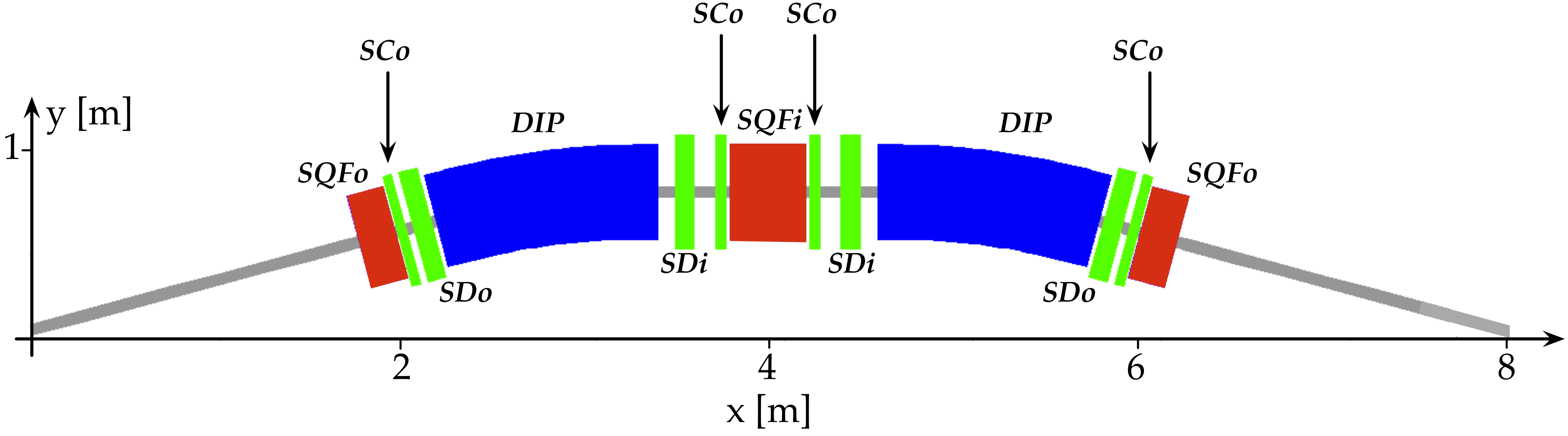
Updated Linear Optics (1)

- Gradient dipoles
- Focusing quadrupoles contain sextupole component
- Discrete sextupoles for defocusing



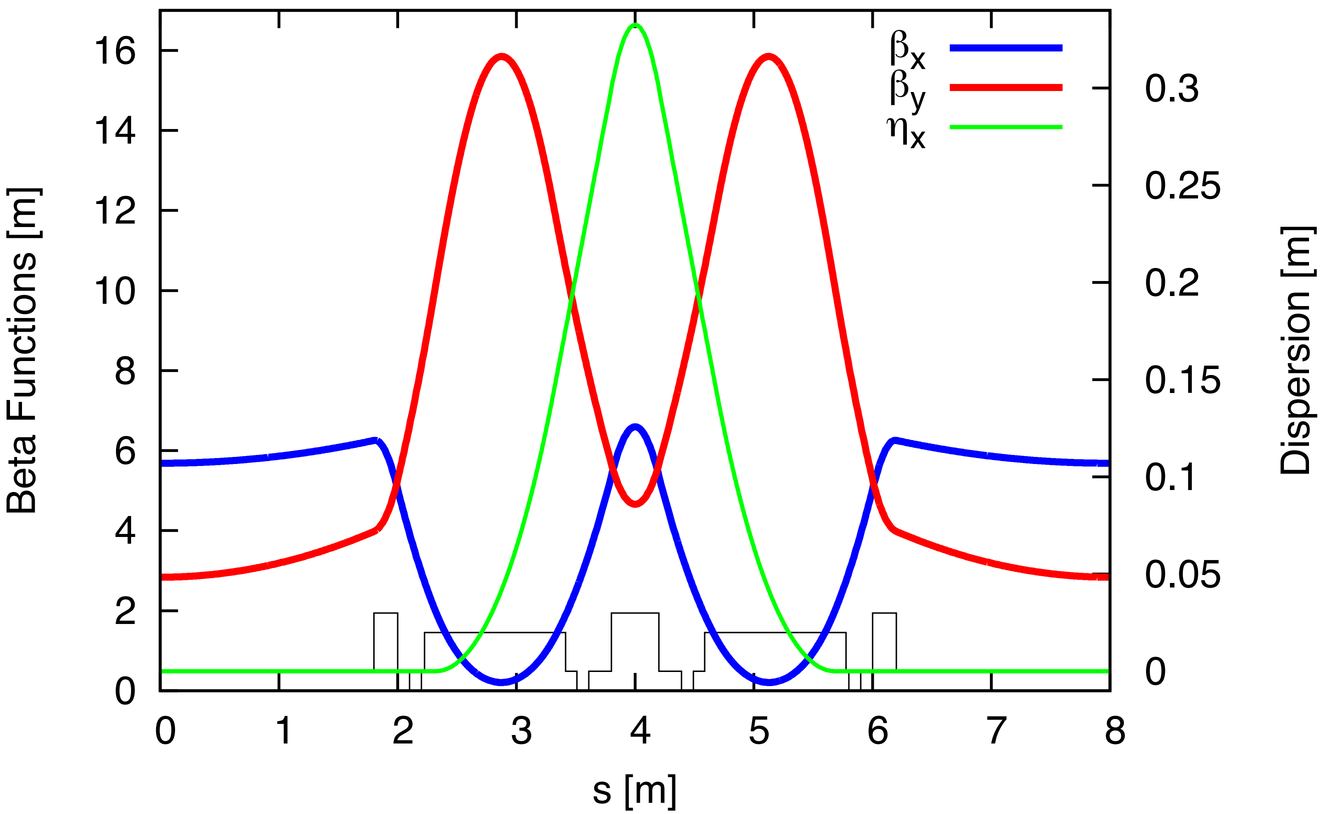
Updated Linear Optics (2)

- **Corrections**
  - Pole-face strips to correct focusing gradient in dipoles
  - Correction sextupoles for correction of sextupole component in iron
  - Dipole corrector coils on SCi/o
  - Extra windings on SCi/o (skew quads, aux. sext) and SDi/o(aux. sext)
  - BBC: active shunts on SQFi/o (in addition to regular shunts)



Updated Linear Optics (3)

- **Original design optics restored**
  - ➡ Several iterations with magnet design in order to get ratios right
- **Vertical tune 3.14 → 3.15 (nonlinear optics optimization)**



ε_0 = 5.982 nm rad

ν_x = 11.22
ν_y = 3.15

ξ_x = –22.964
ξ_y = –17.154

σ_x^* = 184 μm
σ_y^* = 13 μm

η_x^* = 33 cm

Updated Nonlinear Optics

- **Follow “standard MAX IV“ optimization process:**
  - Correct natural chromaticities
  - Minimize RDT’s via weighted SVD
  - Tailor tune shifts over relevant range by tweaking (b_3L)
  - Adjust linear optics (if necessary)
  - Verify (DA, MA, FMA, etc.)
  - Iterate...

PRST-AB **12**, 120701 (2009)

PRST-AB **14**, 030701 (2011)

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  - Reduce chromatic and amplitude-dependent tune shifts

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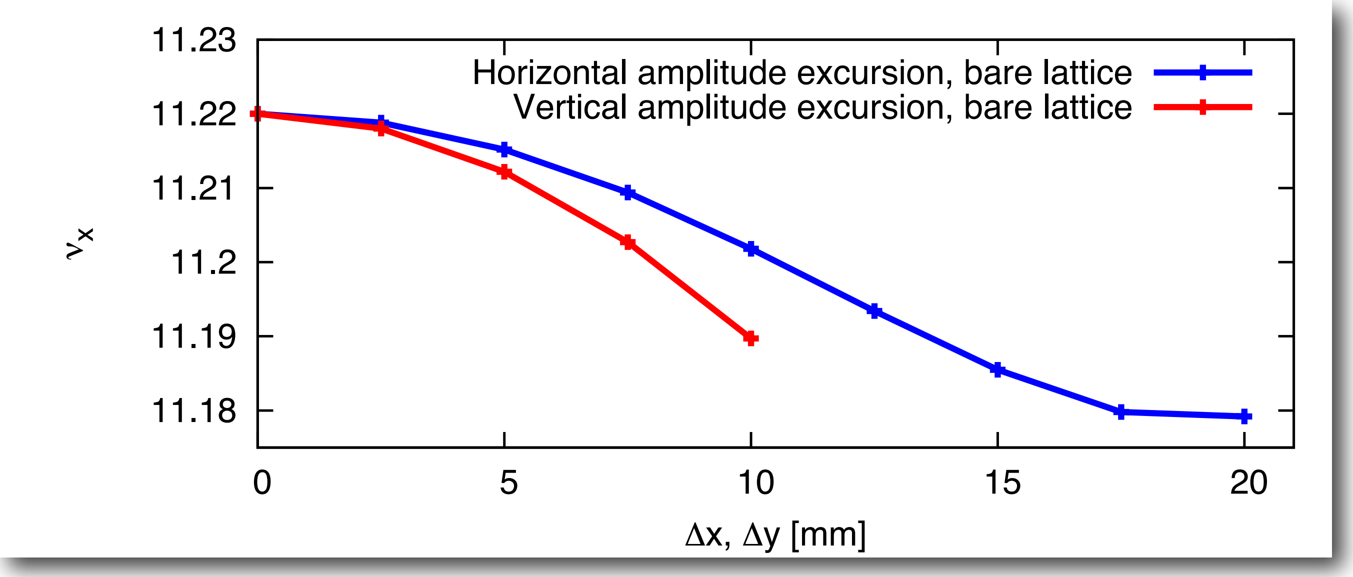

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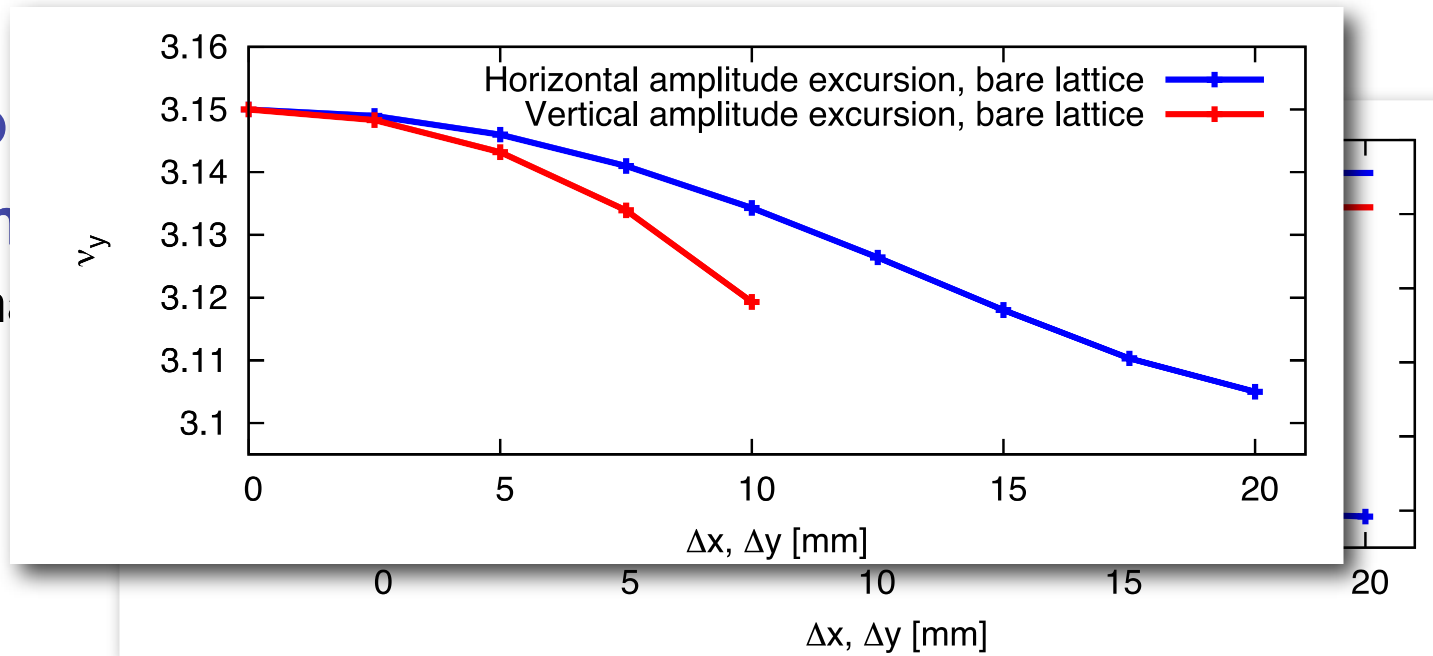

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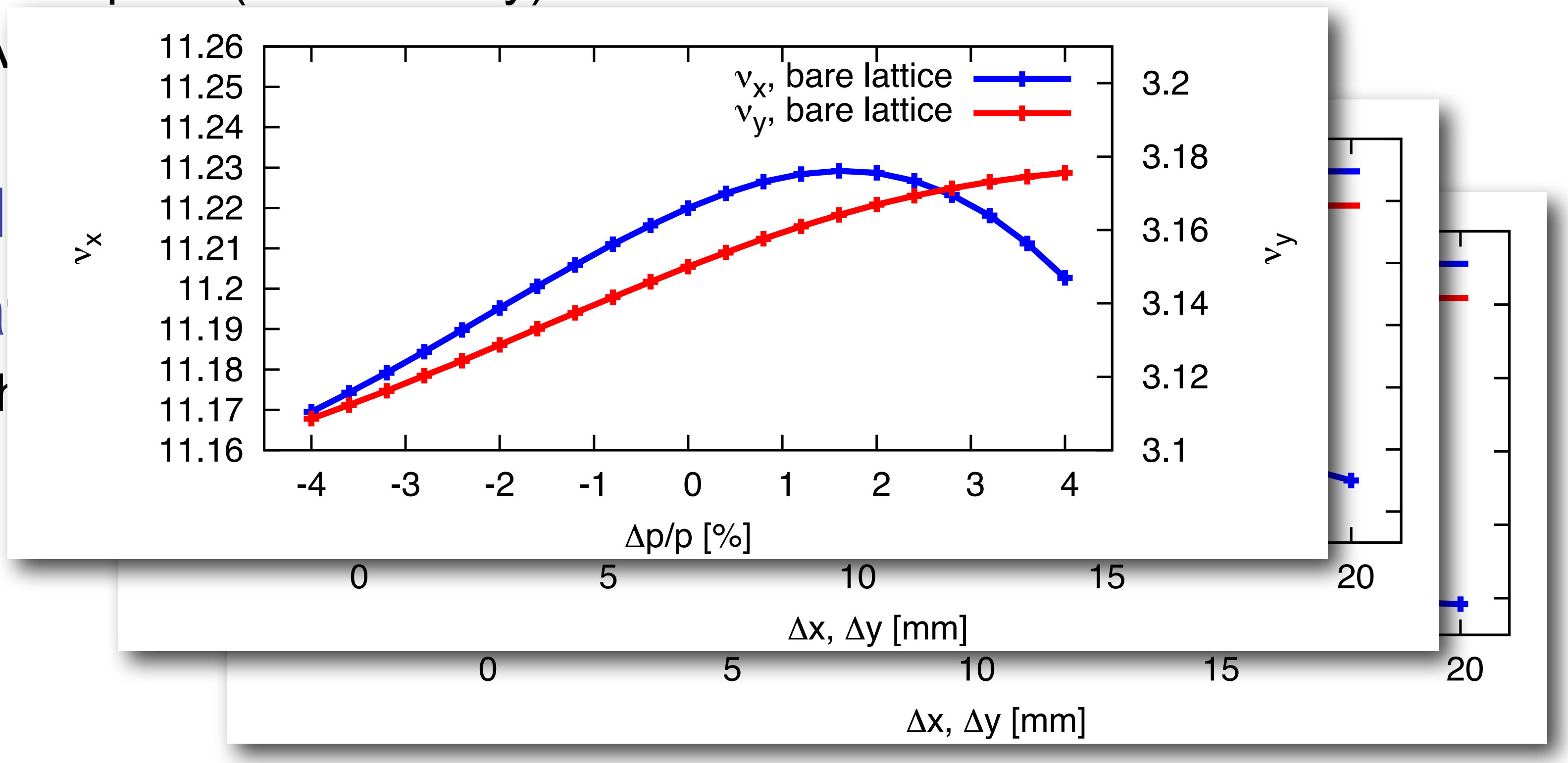

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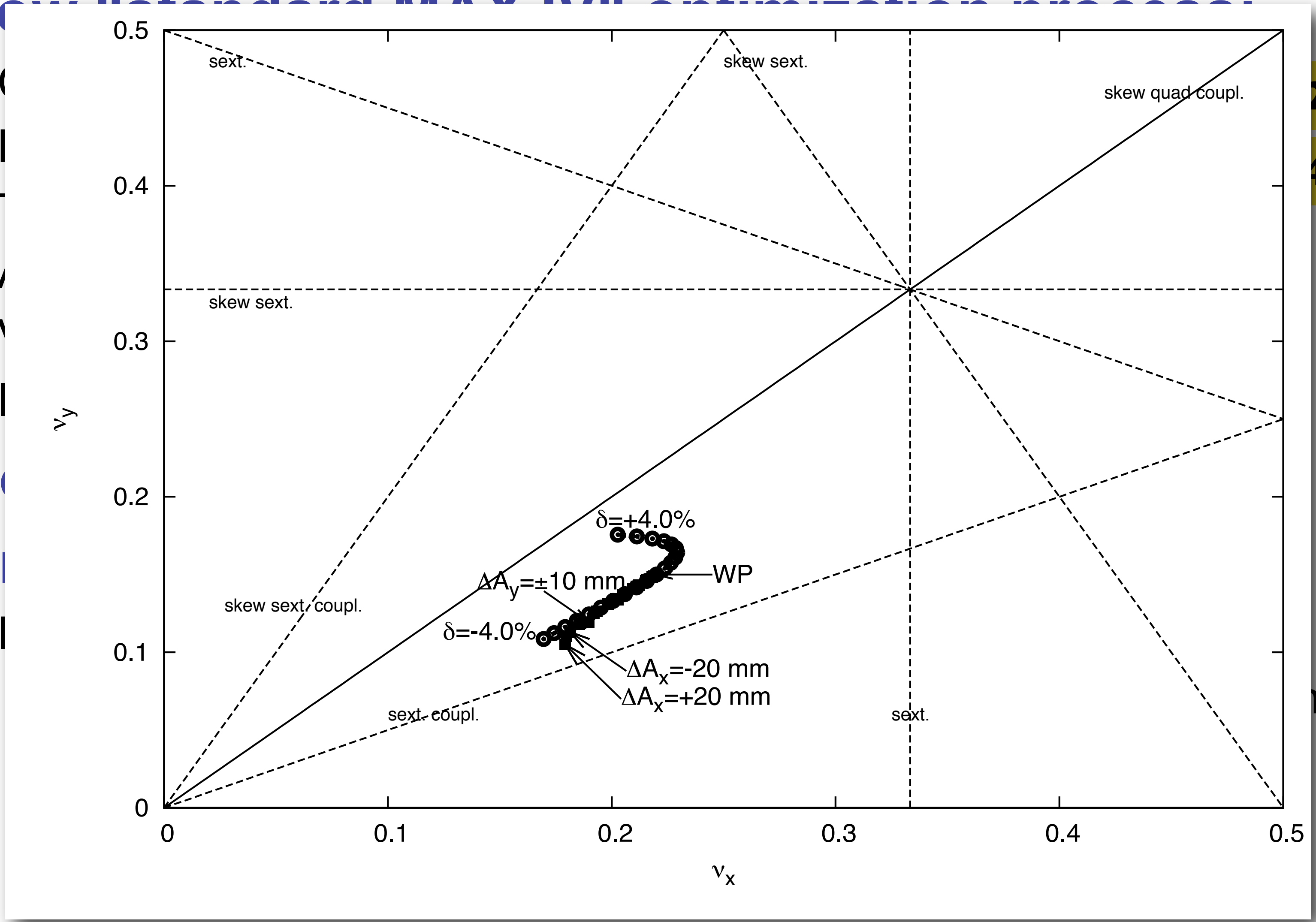

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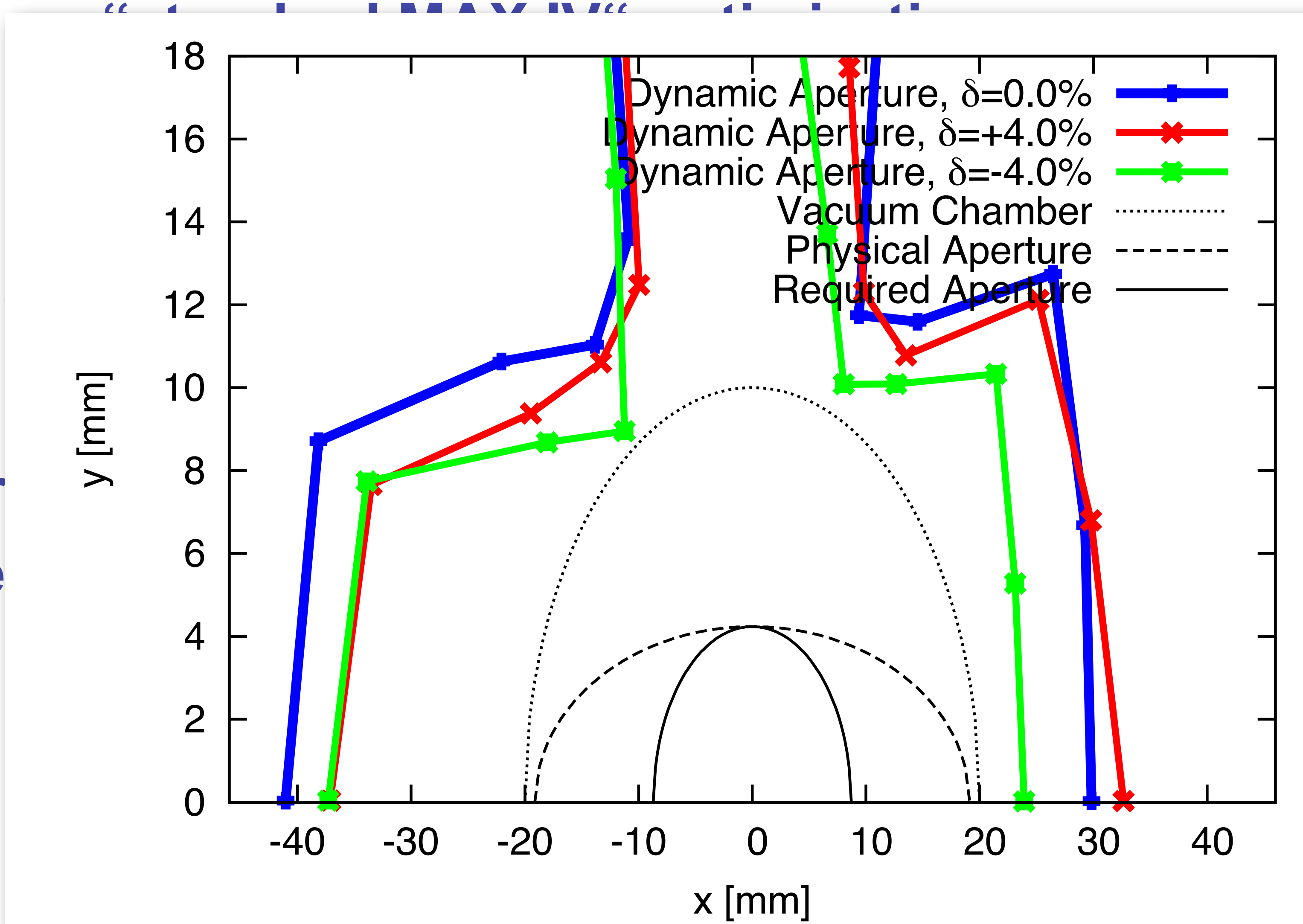

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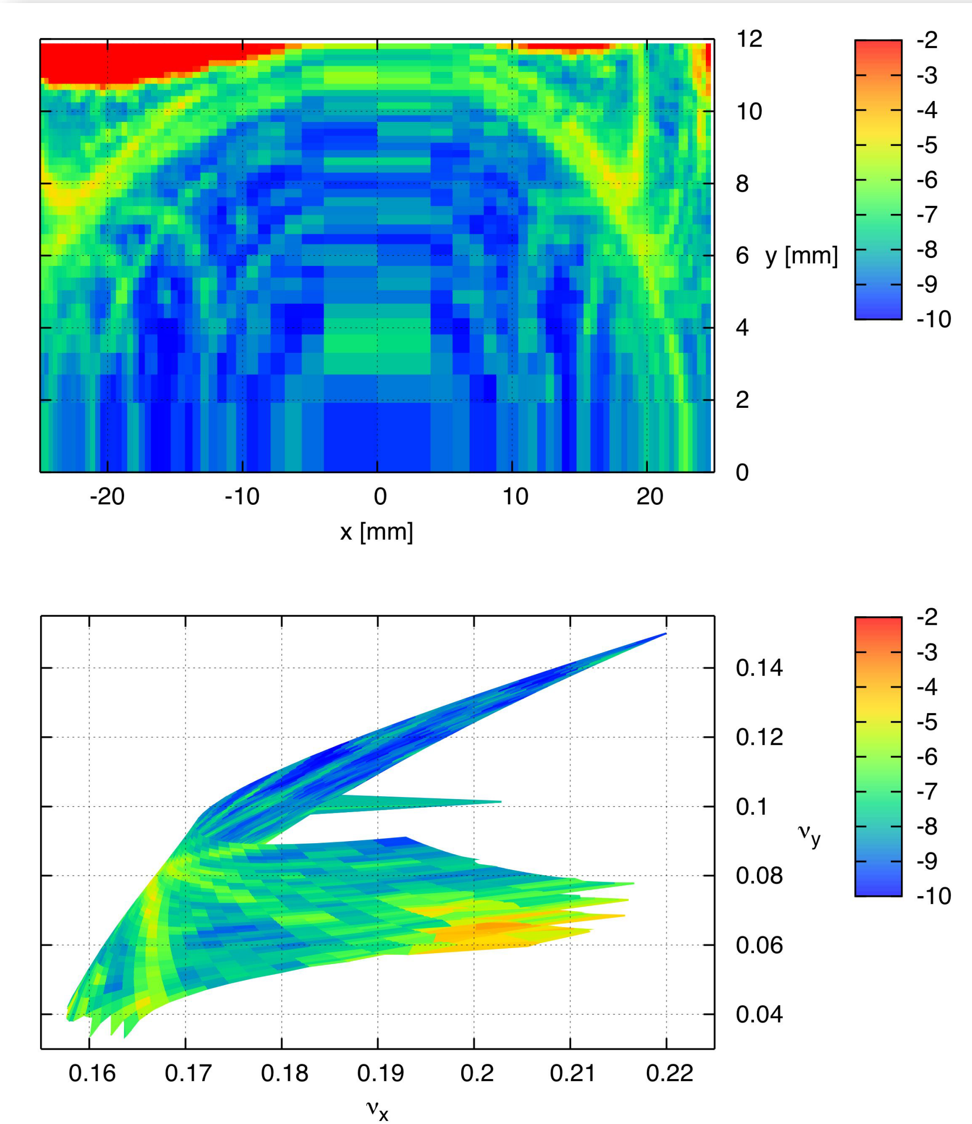

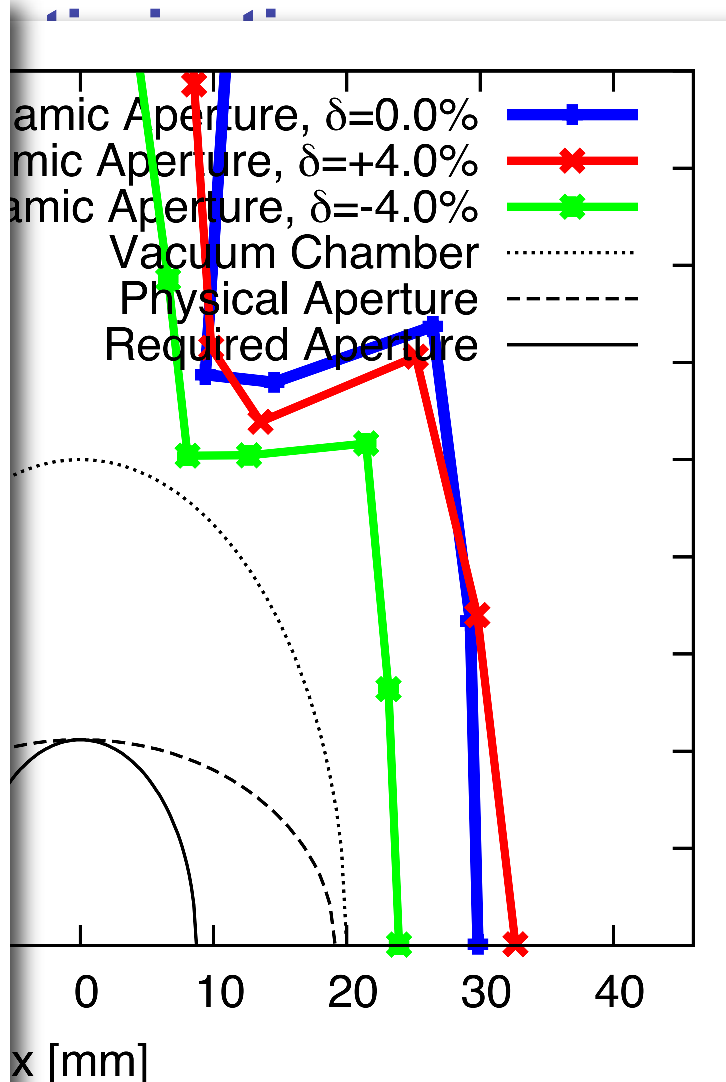

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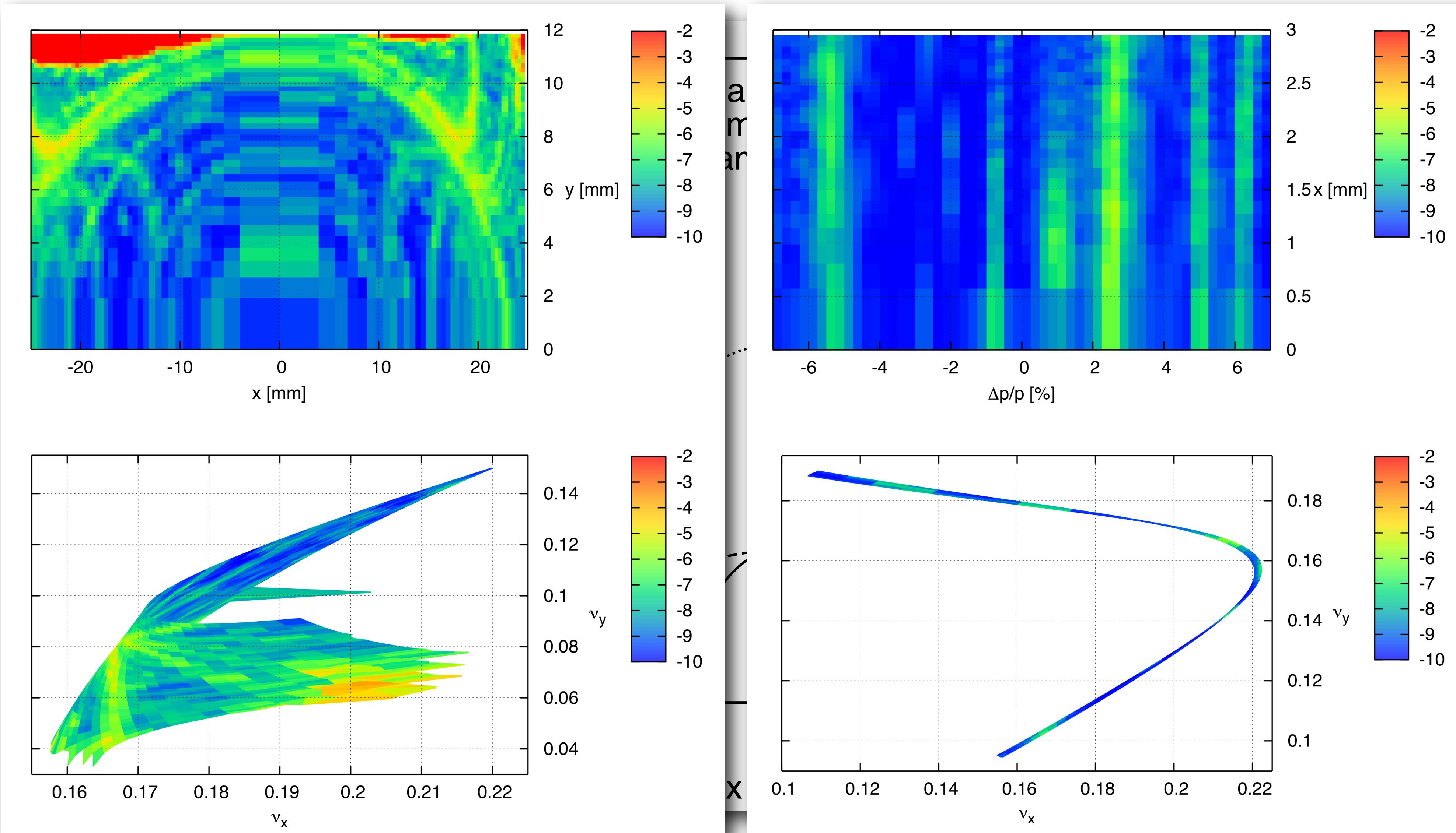

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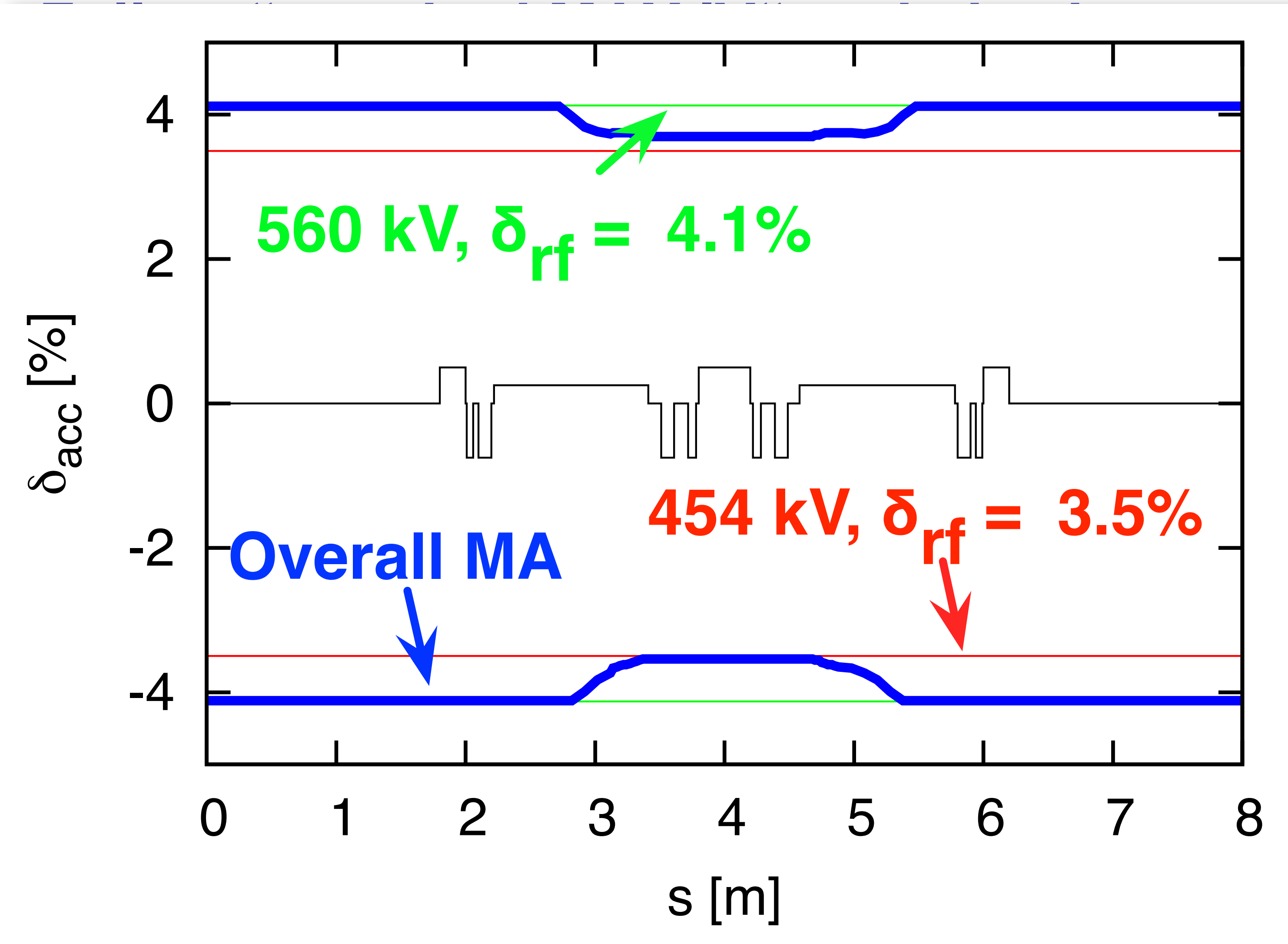

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Standard BSC:
±20 mm × ±10 mm

SQFi & SCi BSC:
±28 mm × ±14 mm

Septum:
a_x = -13.5 mm

/o, $\xi_{x,y}$ = +1.0

resonances

MA)

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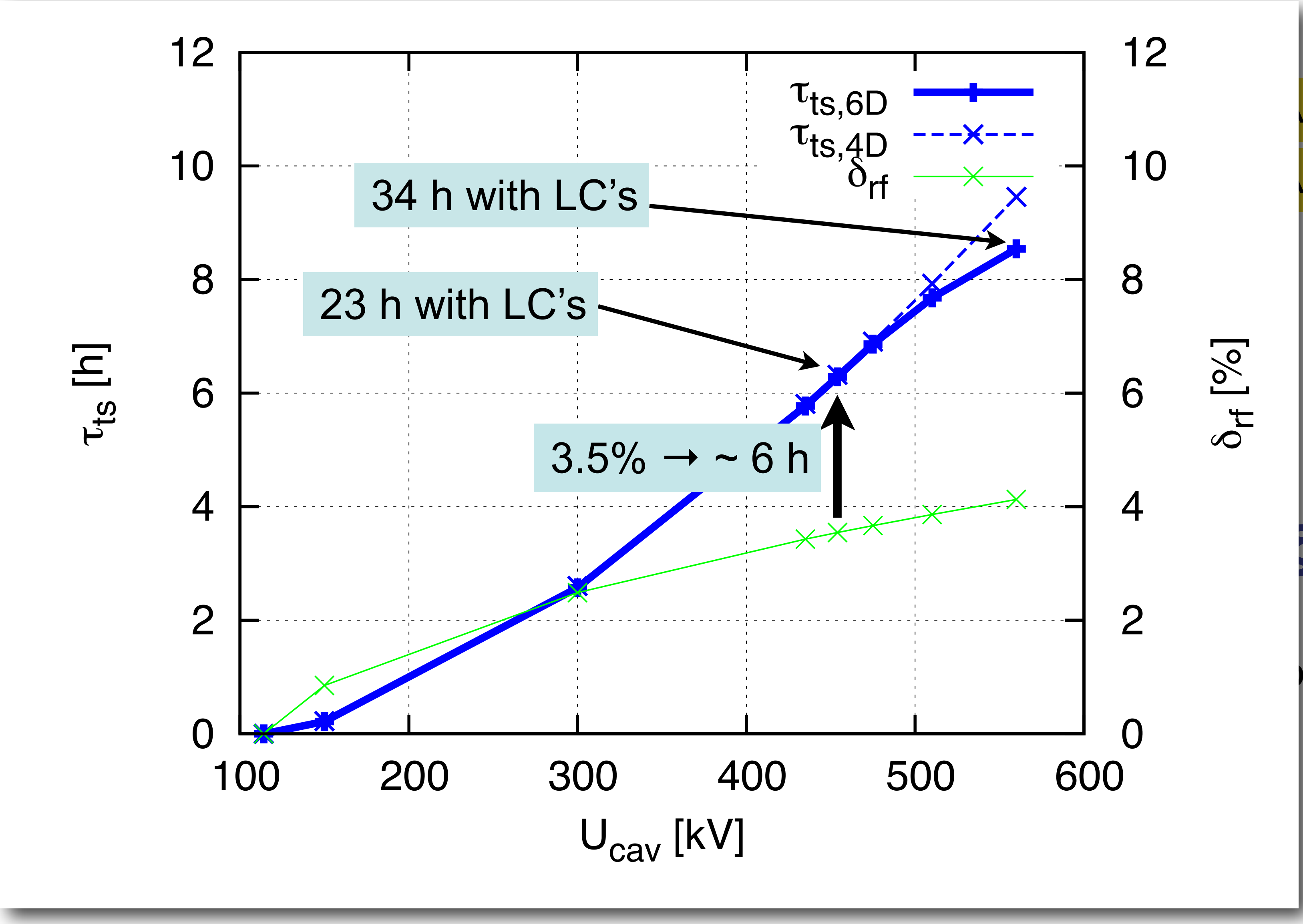
        - ➡ Good Touschek lifetime

Updated Nonlinear Optics



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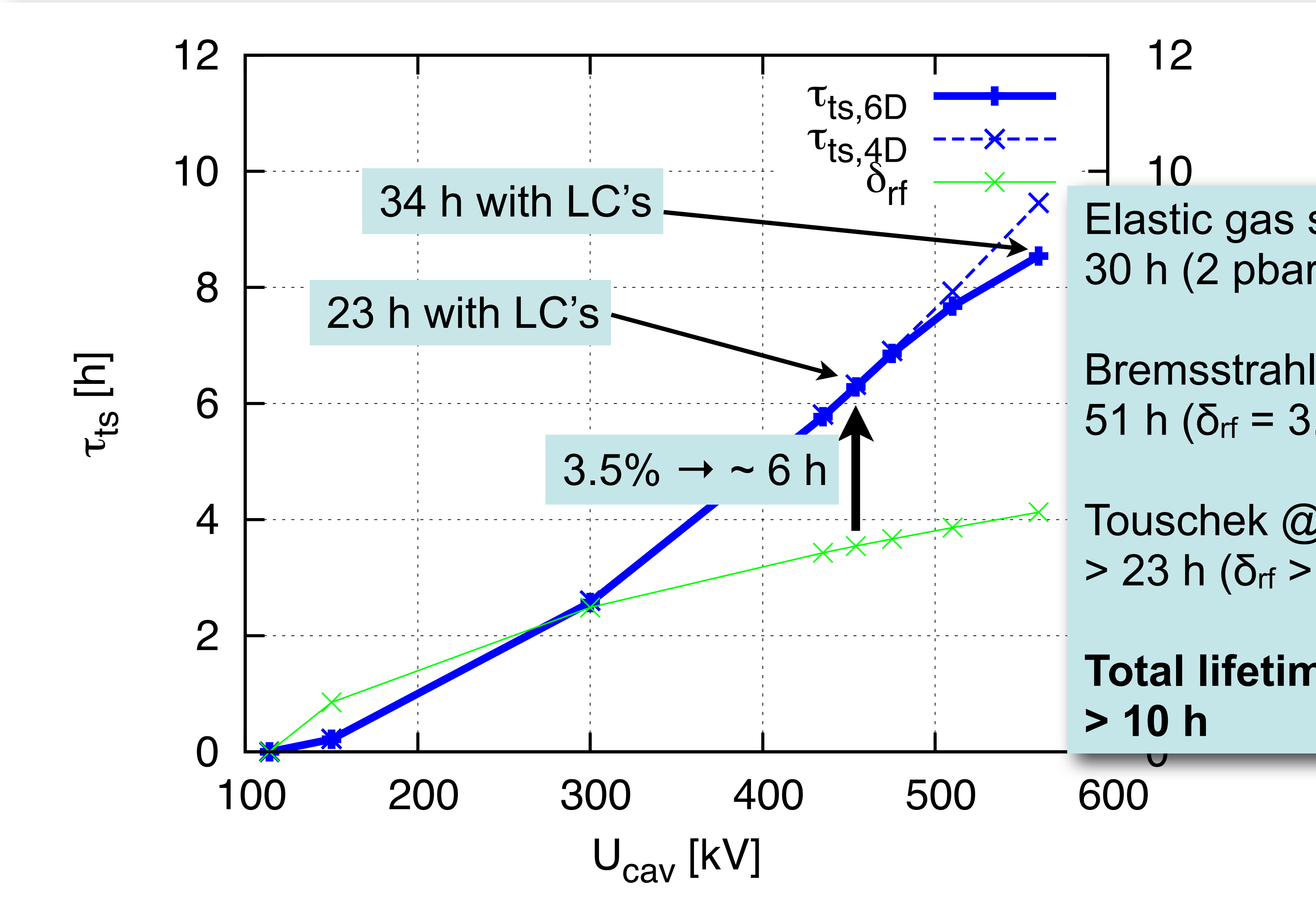

B 12, 120701 (2009)

(2011)

Elastic gas scattering:
30 h (2 pbar CO)

Bremsstrahlung:
51 h (δ_{rf} = 3.7%)

Touschek @ 500 mA:
> 23 h (δ_{rf} > 3.5%)

Total lifetime:
> 10 h

Realistic Performance

- **Is the lattice stable?**
- **How do perturbed optics behave?**
  - Machine with misalignments, field errors & multipole errors
  - Machine with strong ID's (Solaris) → matching?

Realistic Performance: Errors

- **Misalignments**
  - Similar to updated model for 3 GeV ring

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Gaussian, 2σ cutoff

	Transverse displacements	Roll error
Girders (magnet blocks)	50 micron rms	0.2 mrad rms
Dipole slices (!)	25 micron rms	0.2 mrad rms
Quadrupole slices (!)	25 micron rms	0.2 mrad rms
Sextupoles	25 micron rms	0.2 mrad rms
Correctors	25 micron rms	0.2 mrad rms
BPM calibration	3 micron rms	0.1 mrad rms

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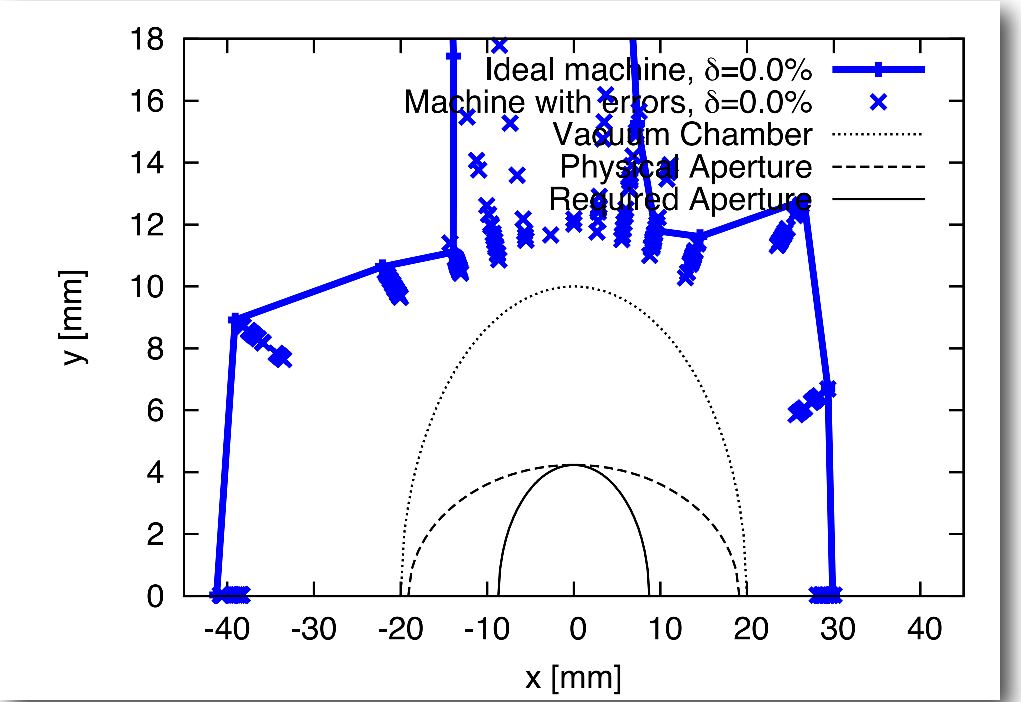

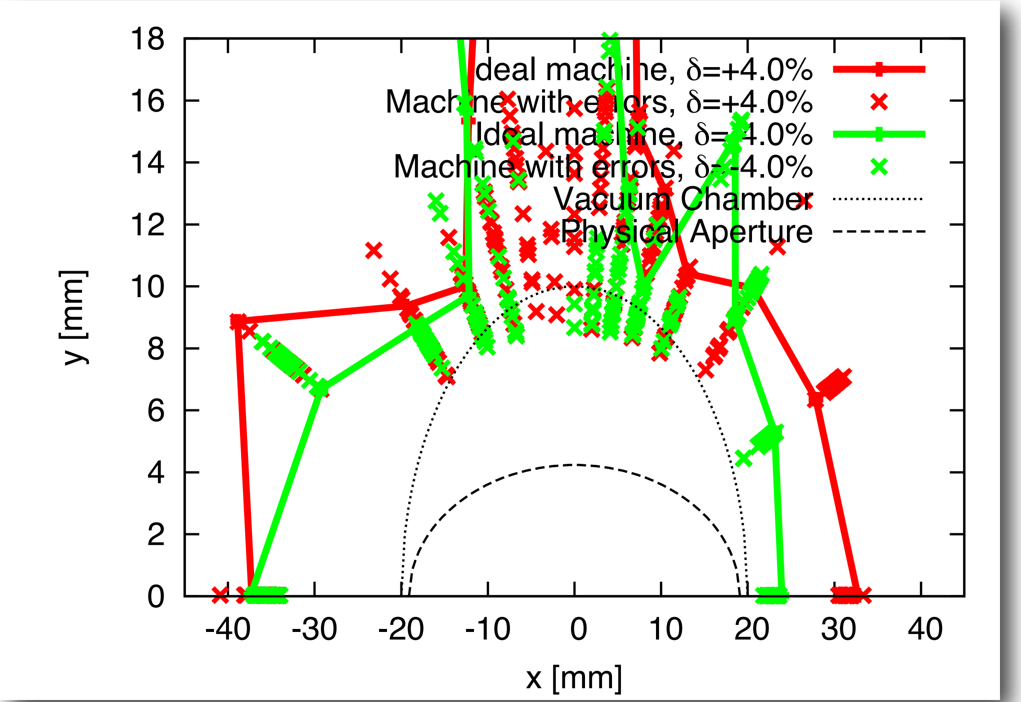

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- Quadrupole gradients:
  - 1 PS for PFS's, SQFi, and SQFo
  - 10^{-4} jitter on PS will lead to tune jitter of roughly 1×10^{-3} (H/V)
- Sextupole gradients:
  - 1 PS for SQFi, SQFo, SDi, and SDo
  - 10^{-4} jitter on PS will lead to chromaticity jitter below 0.01 (H/V)

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- **Random field errors**
  - Work in progress, modeling issues (slices, girder hierarchies)
  - Likely: need low gradient spread among dipoles → shunt to gradients

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  - To-do: include systematic contributions per magnet design report (crosstalk)

APAC'01, THP017

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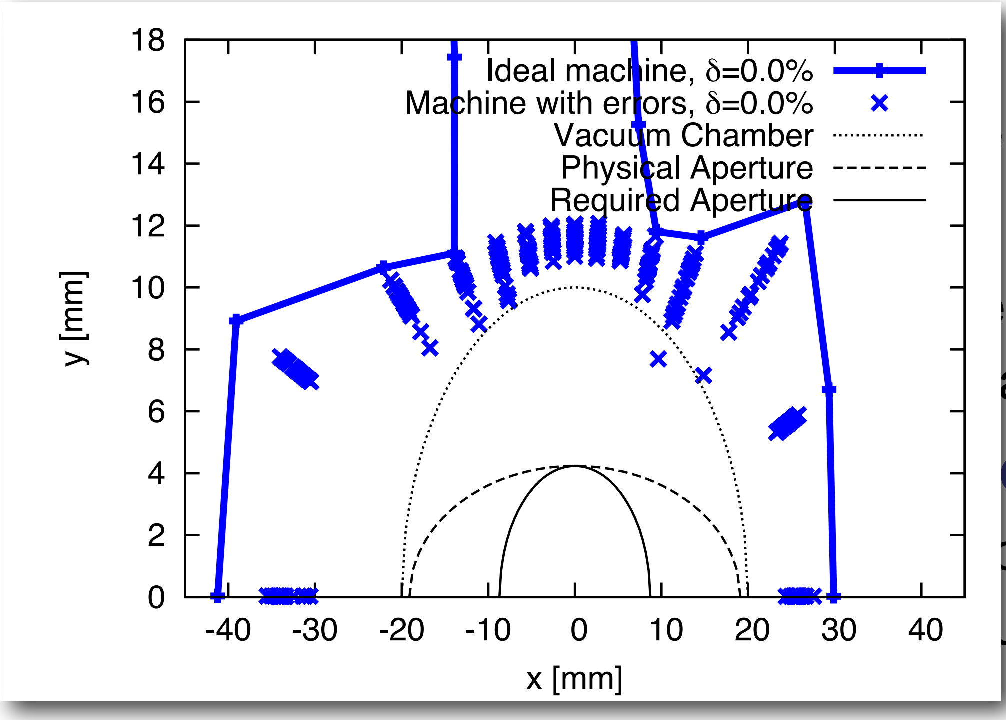

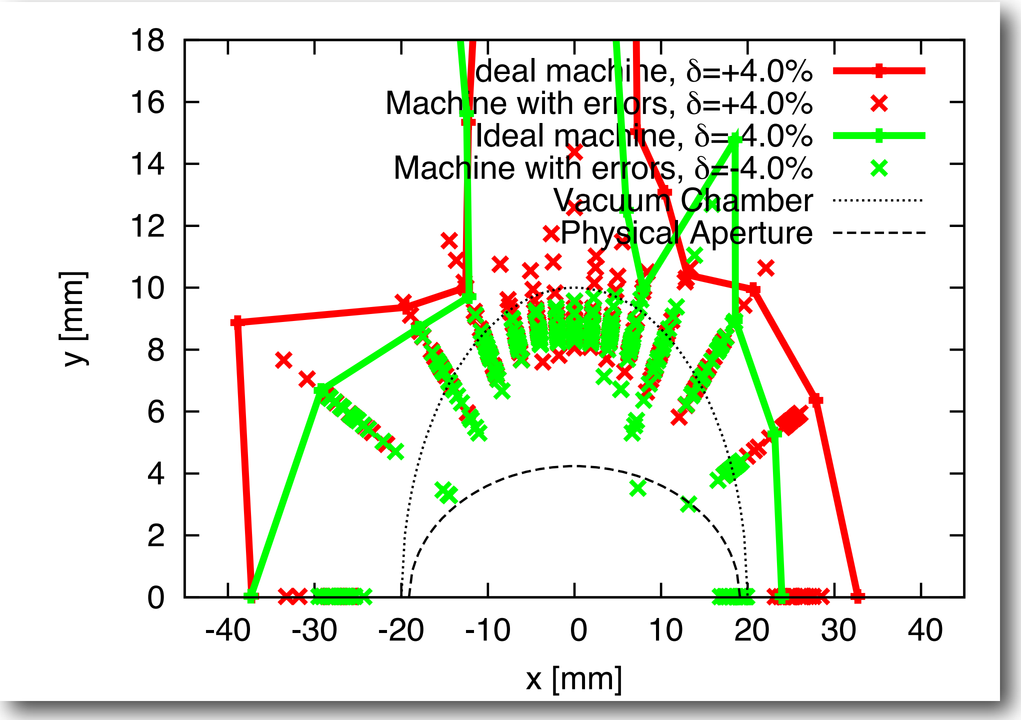

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- **Lattice with SCW**
  - 3.5 T, 25 x 61 mm, 10.2 mm gap
  - Local: optics matching → 4.5% on local gradients via PFS
  - Global: restore working point (–0.17 on ν_y) → 0.5% on all gradients via PFS
    - Tune shifts very close to bare lattice → comparable tune footprint

PAC'11, TUP235

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PAC'11, TUP235

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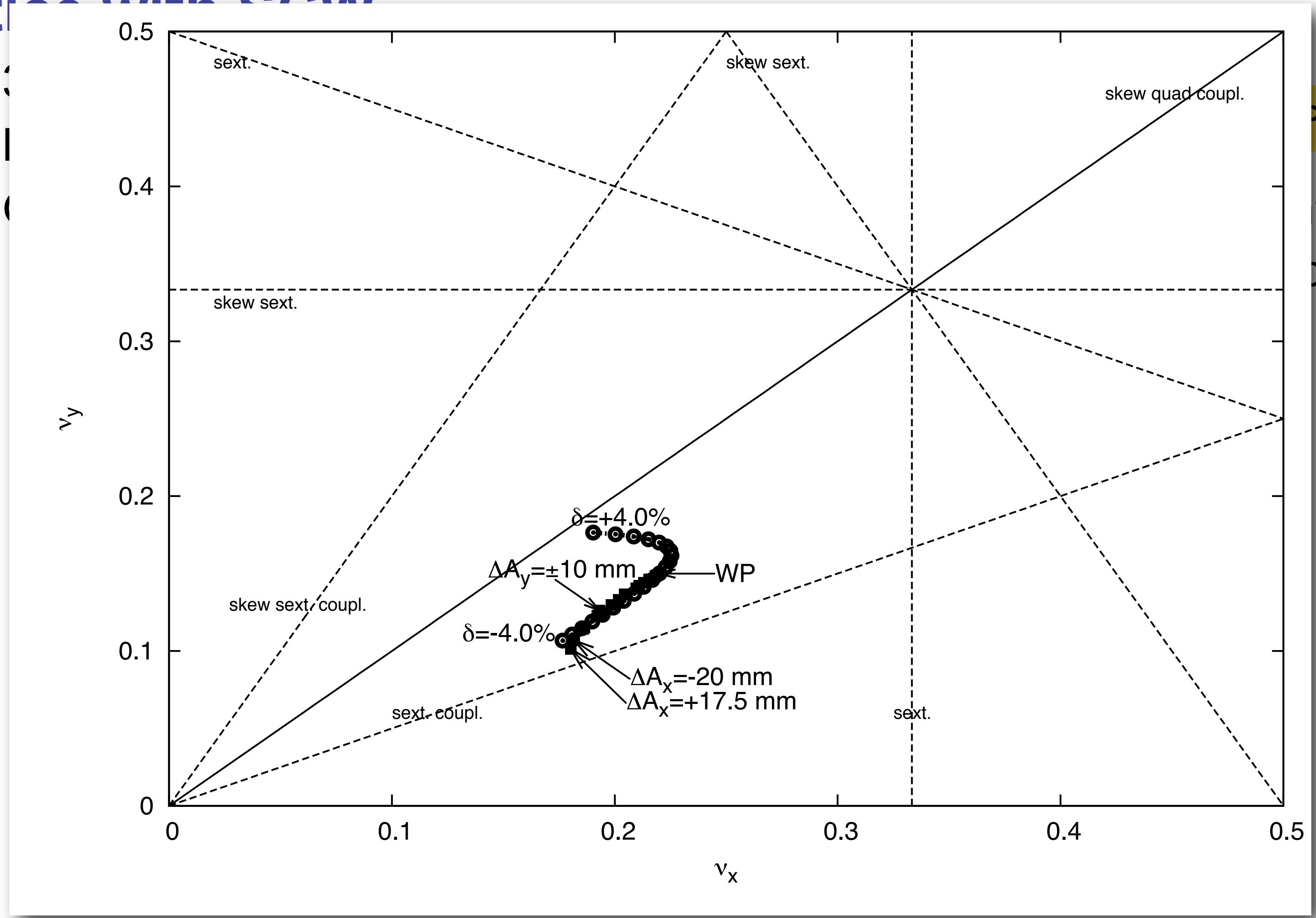

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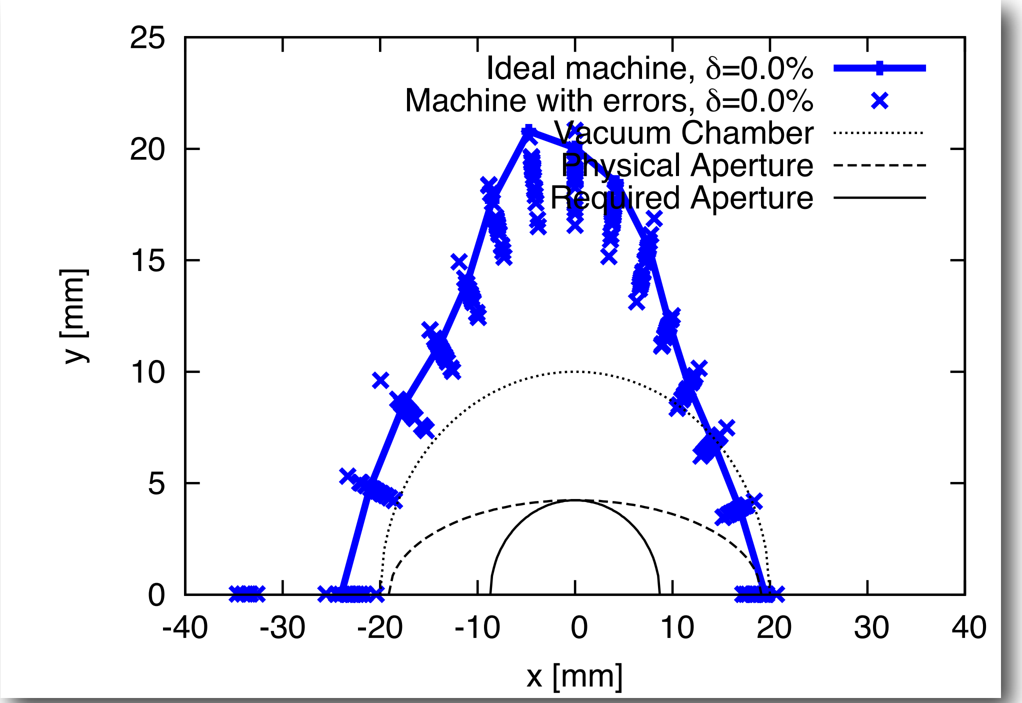

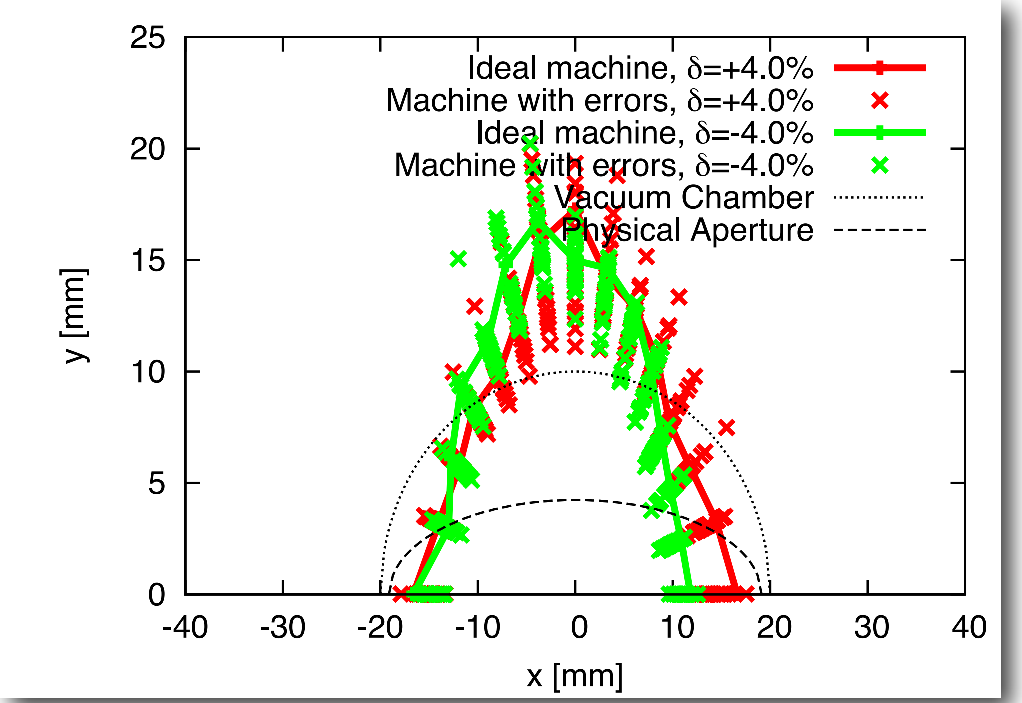

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    - MA & lifetime still fine

PAC'11, TUP235

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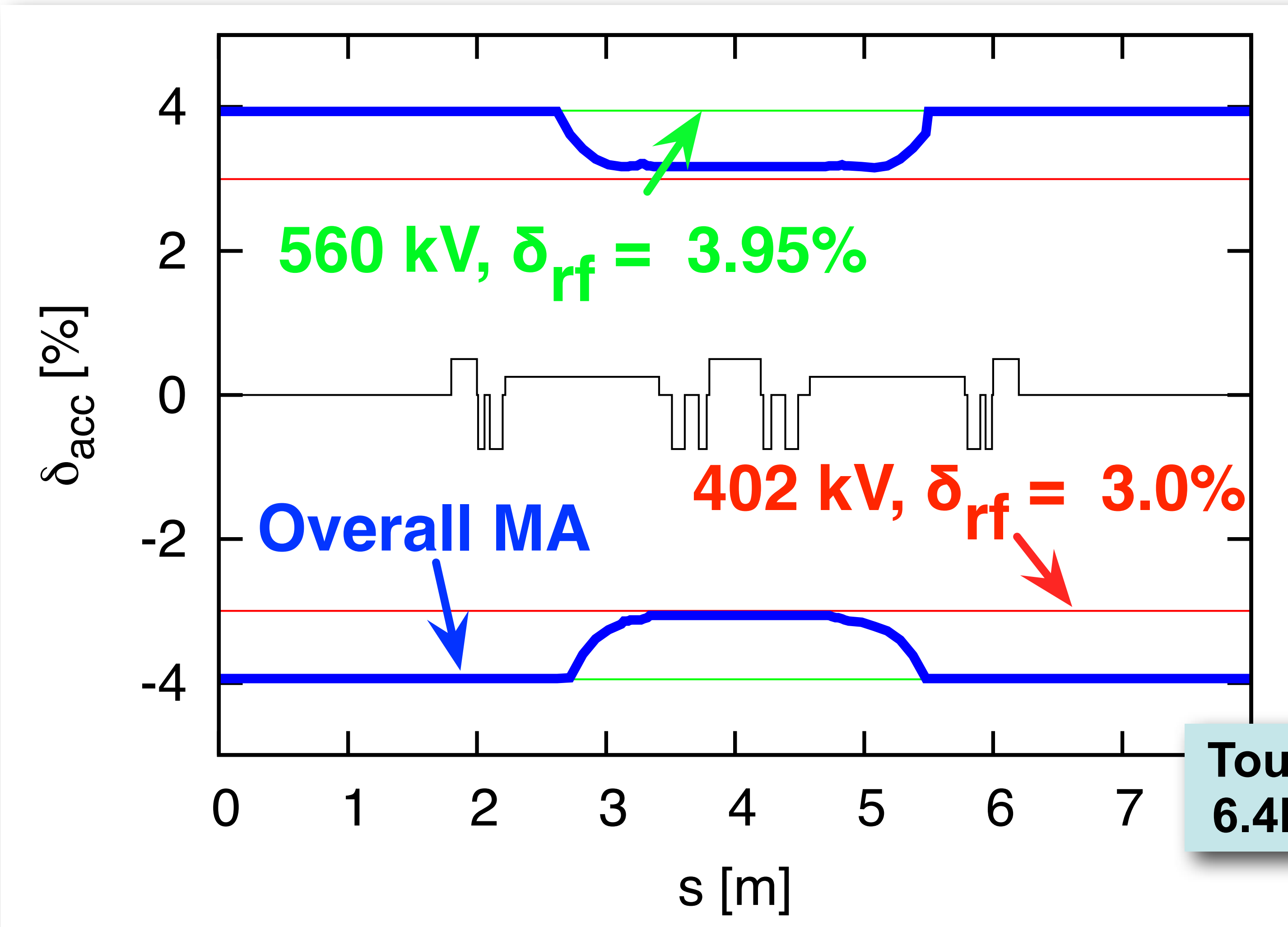

PAC'11, TUP235

PFS
all gradients via PFS
e tune footprint

Touschek lifetime: 6.4h / 23.7 h (LCs)

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PAC'11, TUP235

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PAC'11, TUP235

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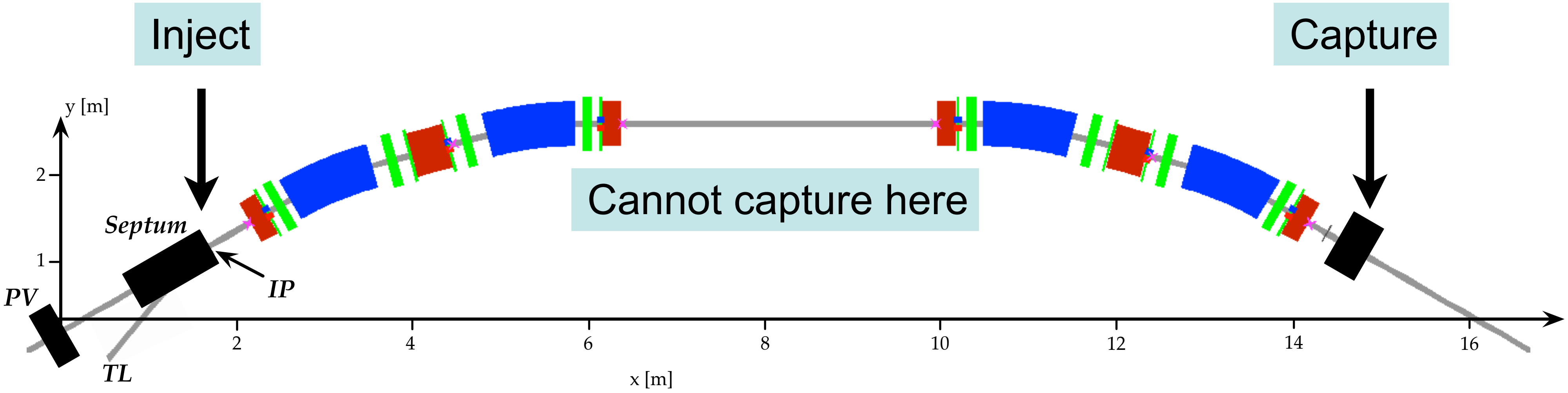
- **Work in progress**
  - No show-stoppers discovered so far
  - But we see need for strong (local) tuning to properly match strong ID's
  - Narrow-gap chambers? In-vacuum ID's? Vertical acceptance?

Injection

- Modified optics → update injection (retaining strategy)



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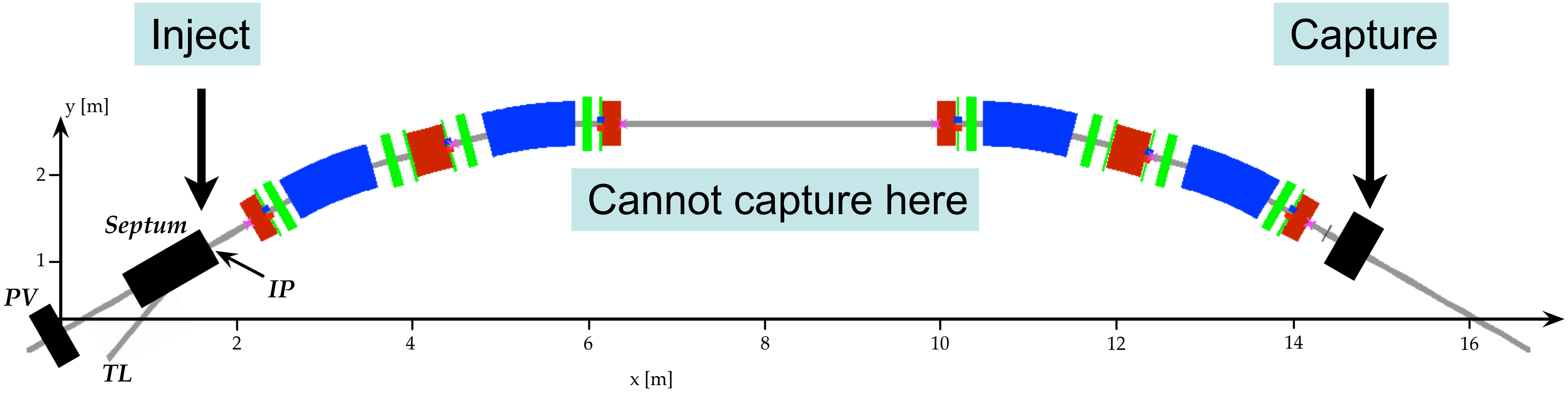
- **Pulsed sextupole magnet (PSM) for top-up injection**
  - Excellent performance: high capture efficiency, transparent to users
  - But tricky in new machine? → want robust injection for commissioning
- **Single dipole kicker (KI) for commissioning**
  - User operation: single dipole kicker becomes horizontal pinger (adjacent dedicated vertical pinger)



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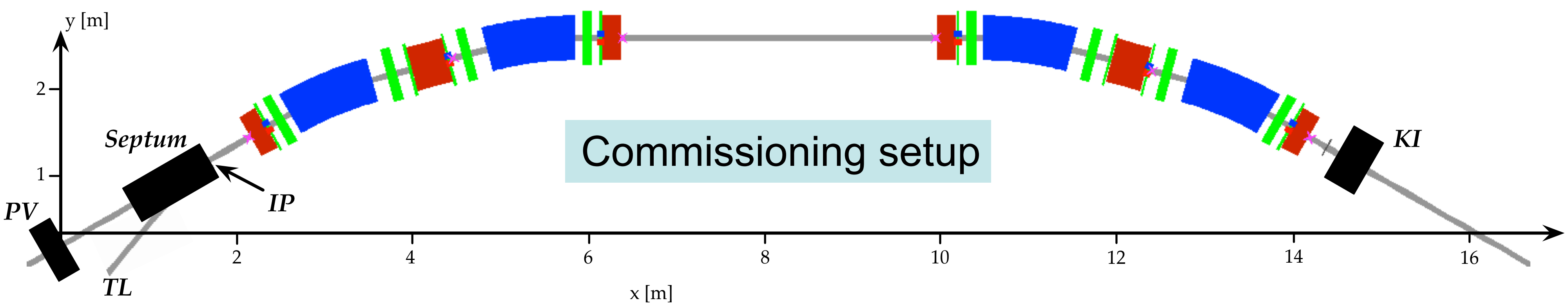

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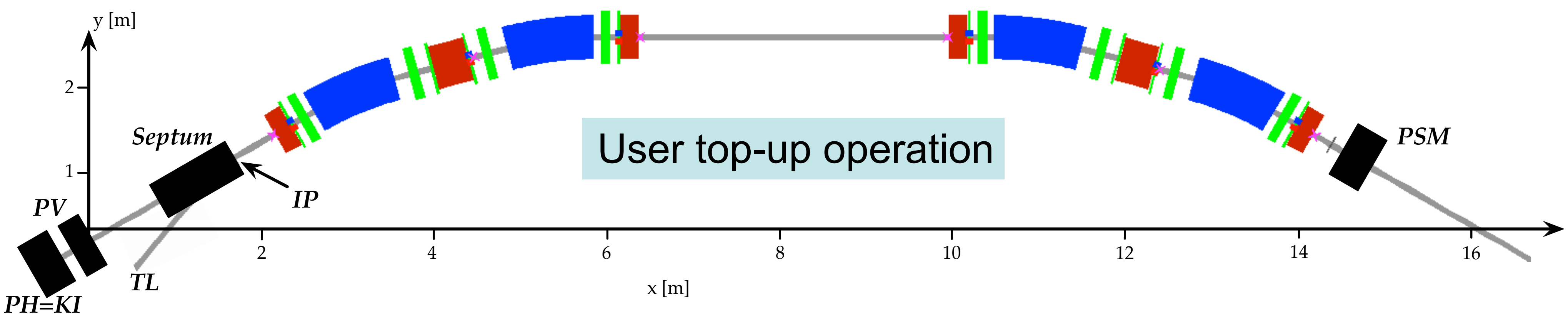
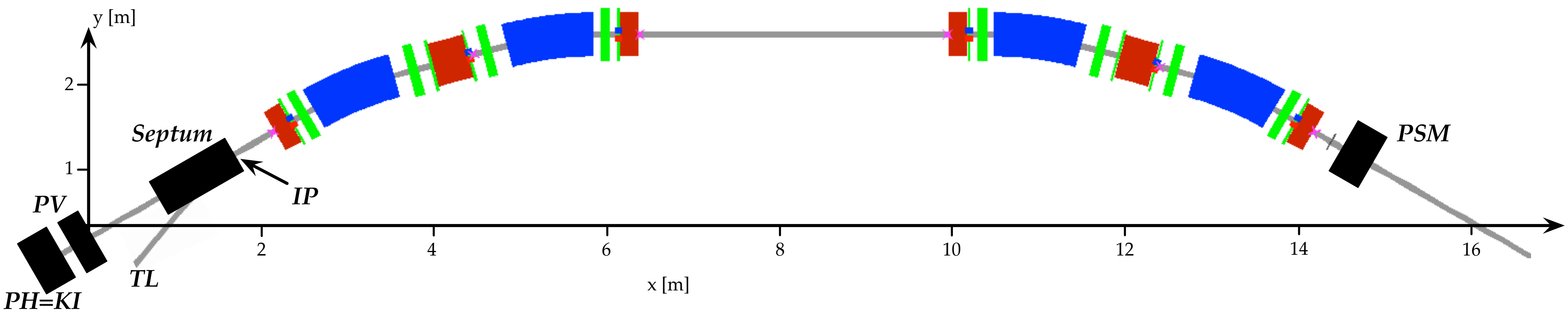
  - But tricky in new machine? → want robust injection for commissioning
- **Single dipole kicker (KI) for commissioning**
  - User operation: single dipole kicker becomes horizontal pinger (adjacent dedicated vertical pinger)



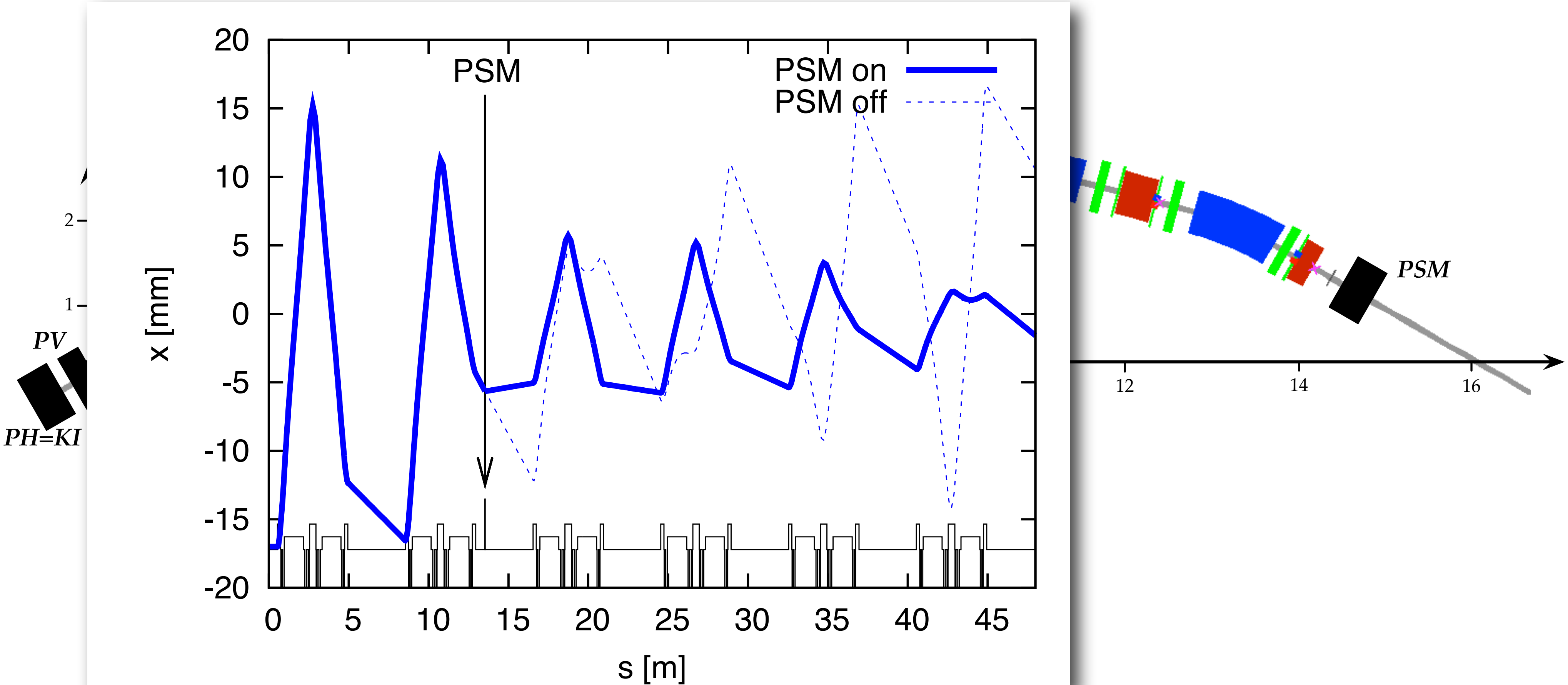
Injection: Pulsed Sextupole Magnet

PRST-AB **15**, 050705 (2012)



Injection: Pulsed Sextupole Magnet

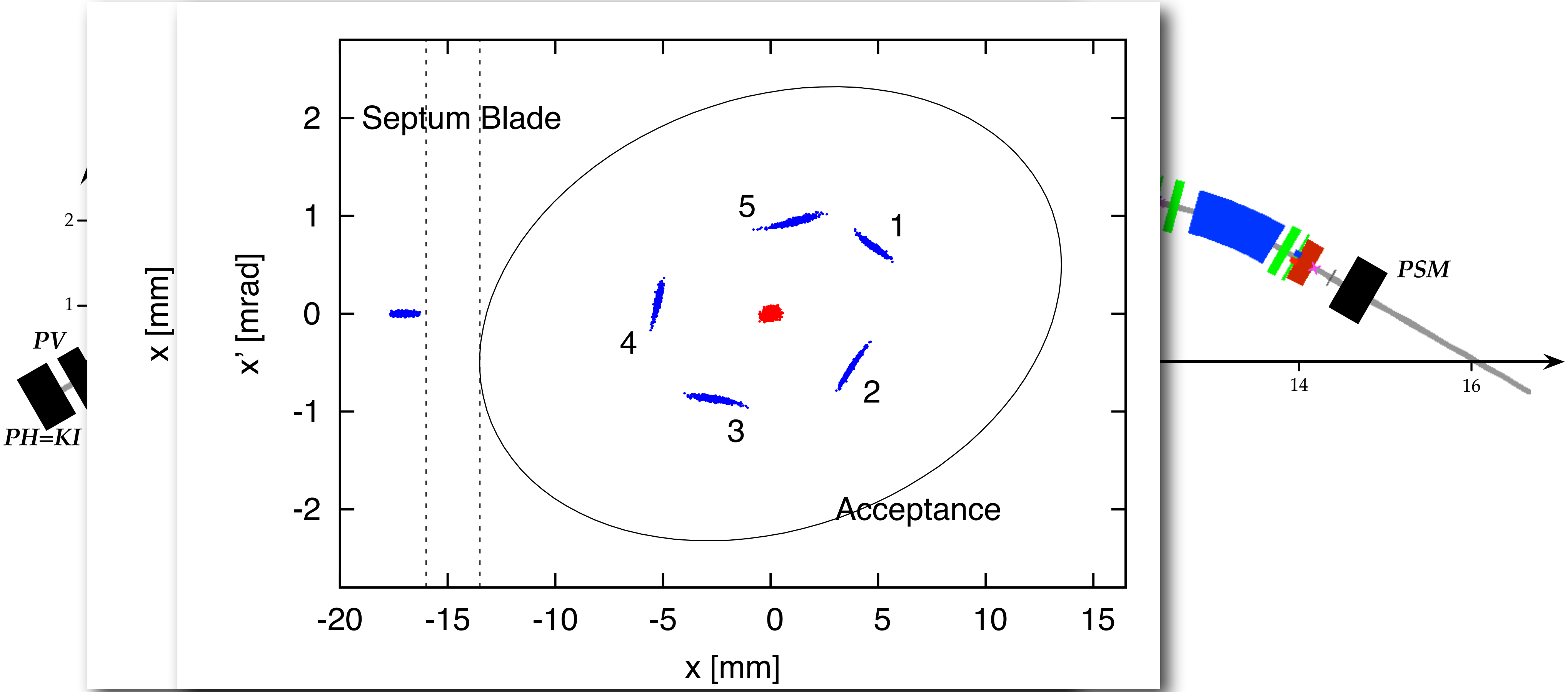
PRST-AB **15**, 050705 (2012)



Optimum settings: $(b_3L) = 74\ m^{-2}$ for $\theta_{pm} = +2.36$ mrad

Injection: Pulsed Sextupole Magnet

PRST-AB **15**, 050705 (2012)

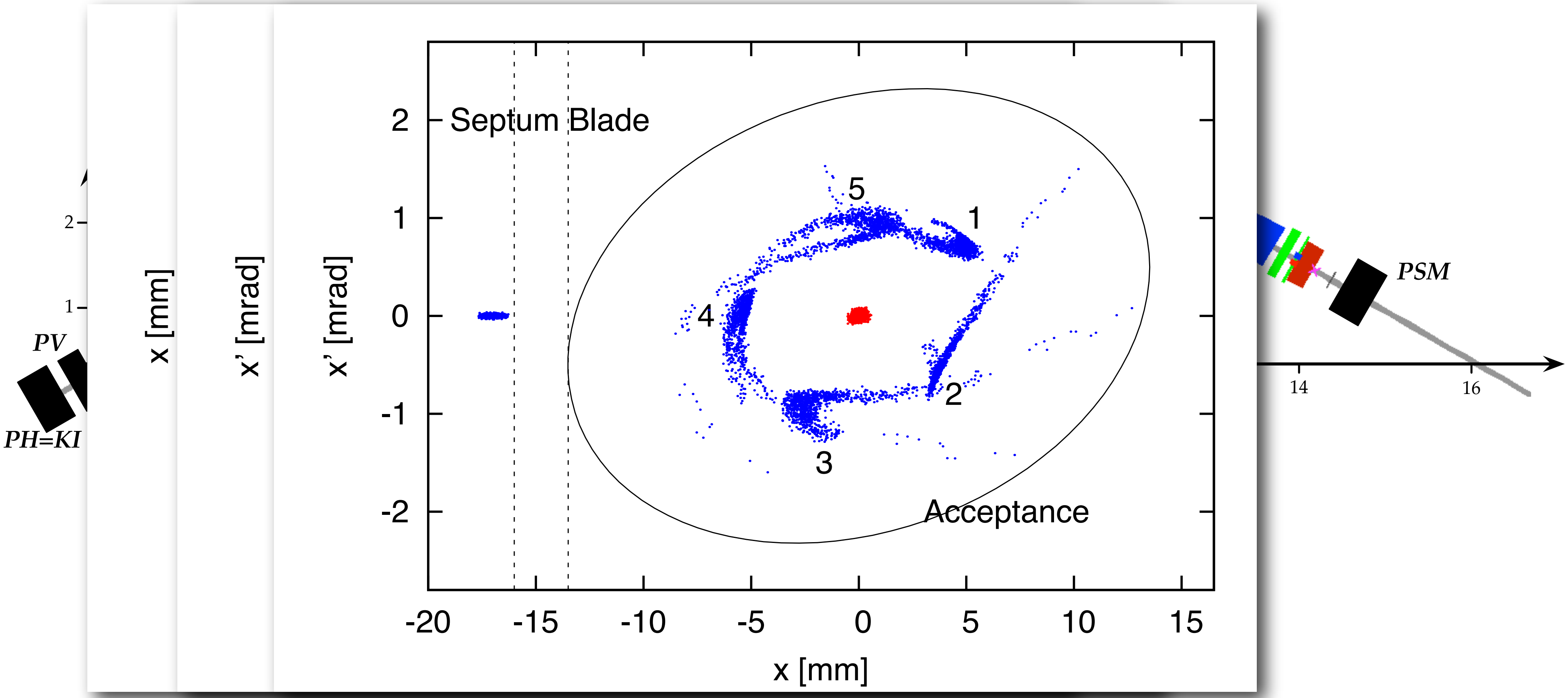


Optimum settings: $(b_3L) = 74\ m^{-2}$ for $\theta_{pm} = +2.36$ mrad

Simon C. Leemann

Injection: Pulsed Sextupole Magnet

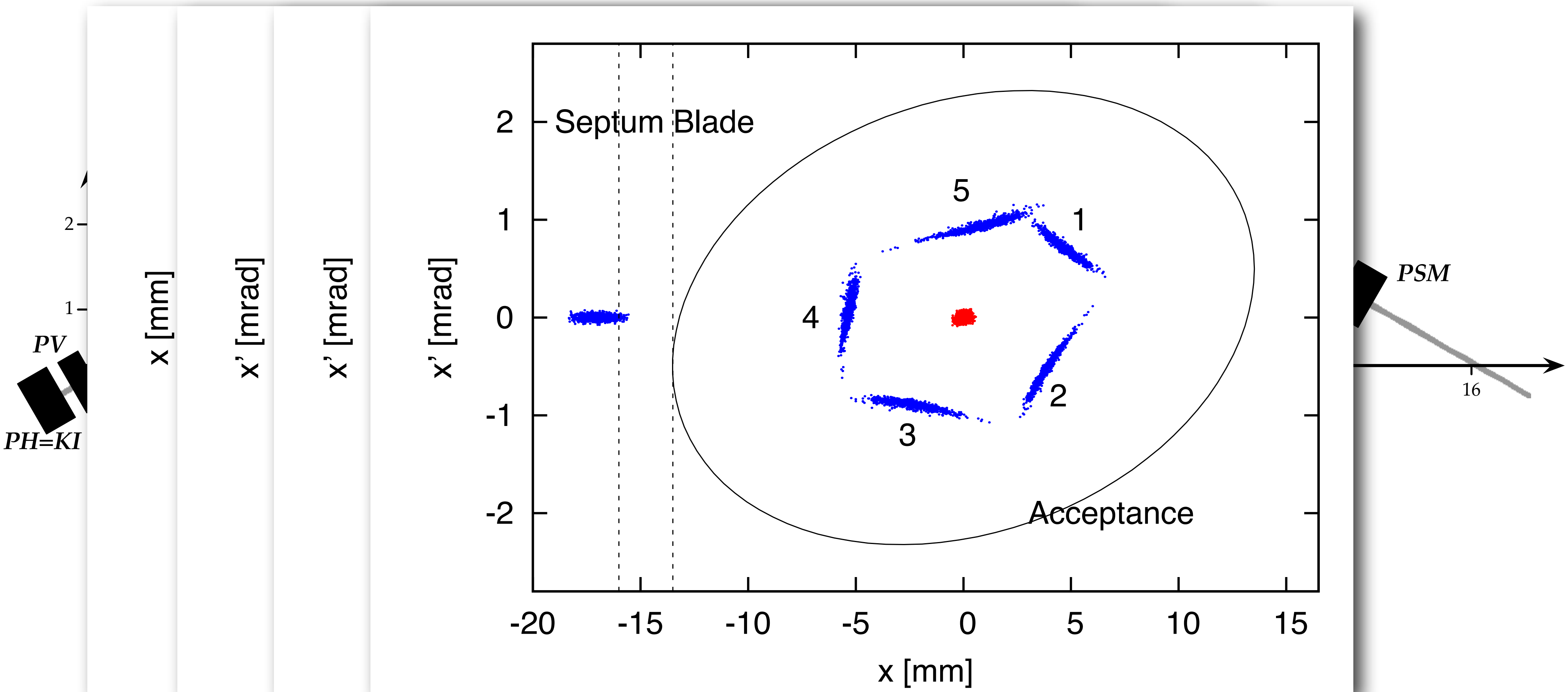
PRST-AB **15**, 050705 (2012)



Error tolerance: bunch energy spread increased to $\sigma_\delta = 1.8\%$

Injection: Pulsed Sextupole Magnet

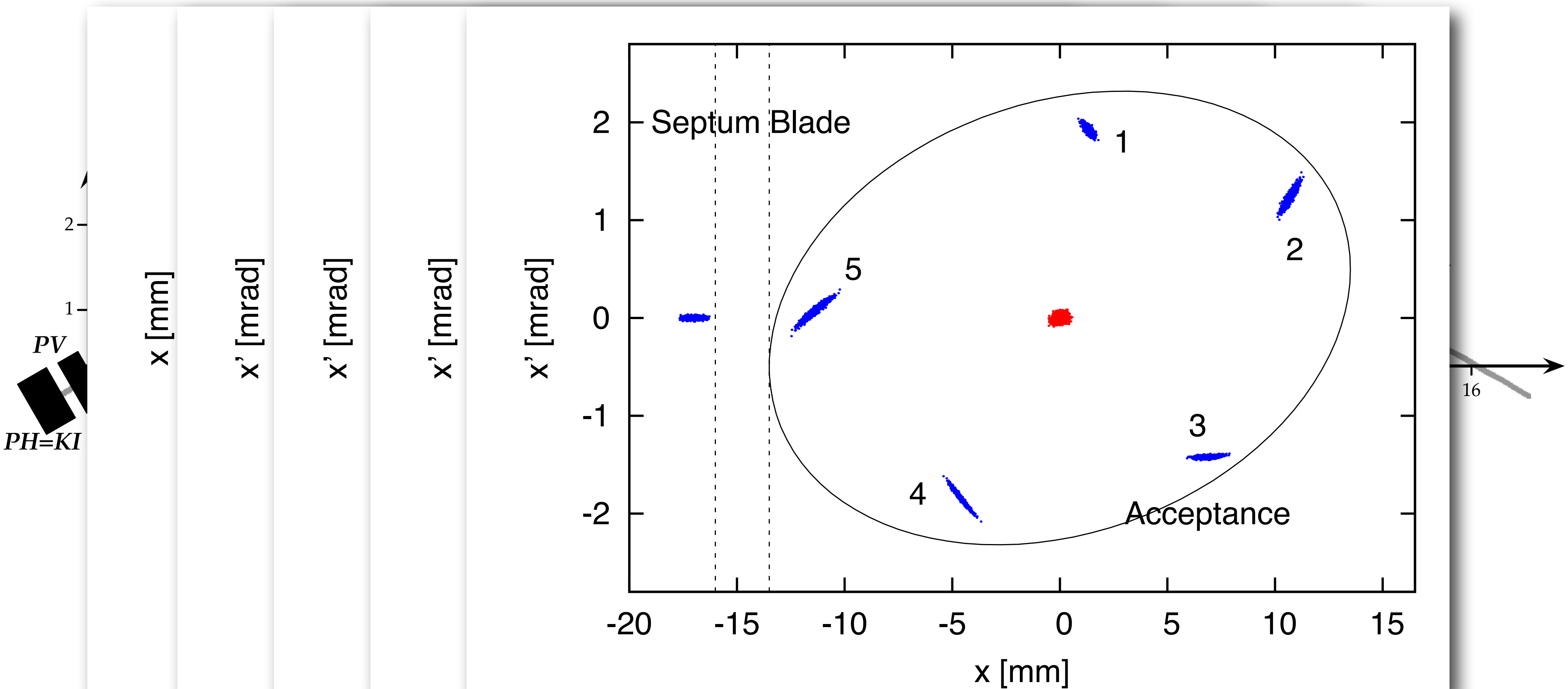
PRST-AB **15**, 050705 (2012)



Error tolerance: bunch emittance increase (4-fold) / optics mismatch

Injection: Pulsed Sextupole Magnet

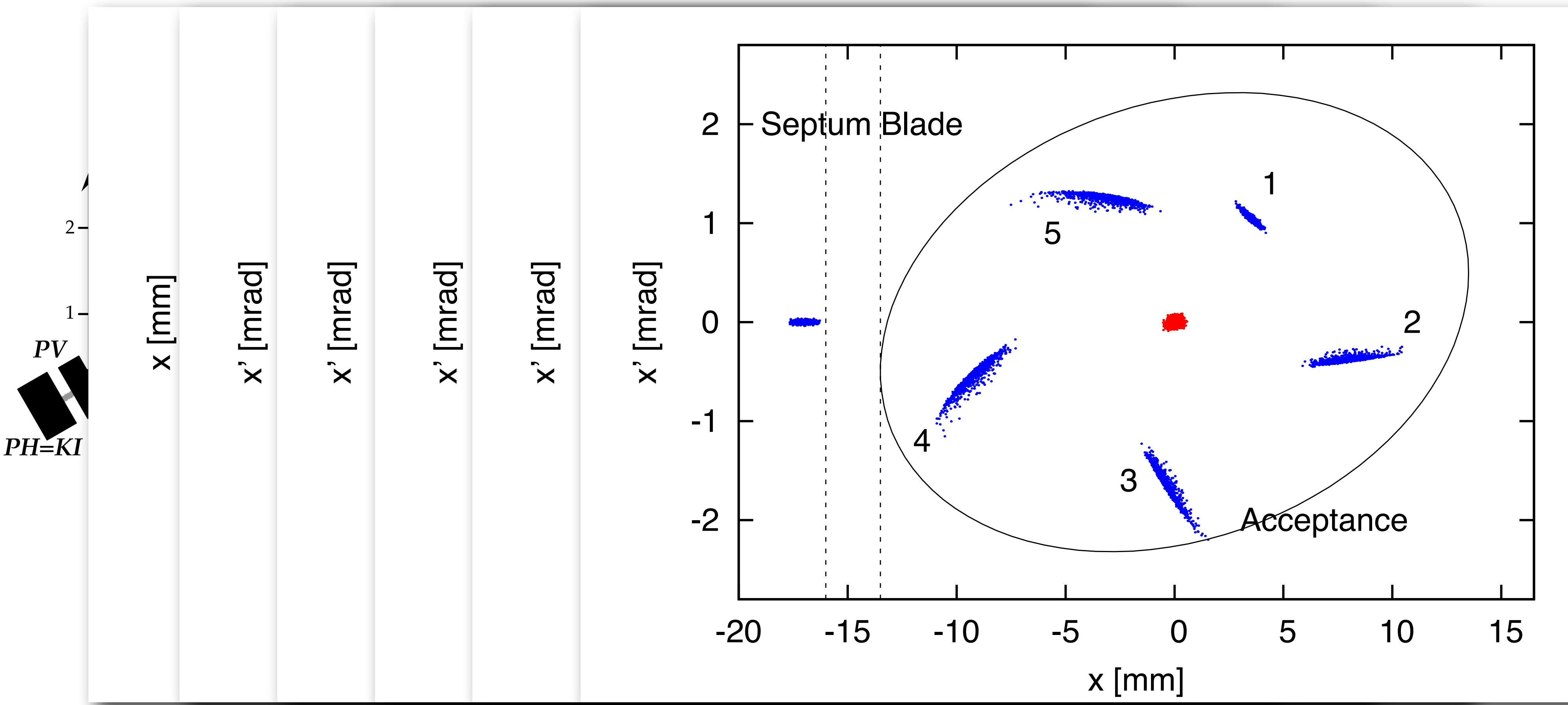
PRST-AB **15**, 050705 (2012)



Reduced strength: $(b_3L) = 27\ m^{-2}$ for $\theta_{pm} = +0.85$ mrad

Injection: Pulsed Sextupole Magnet

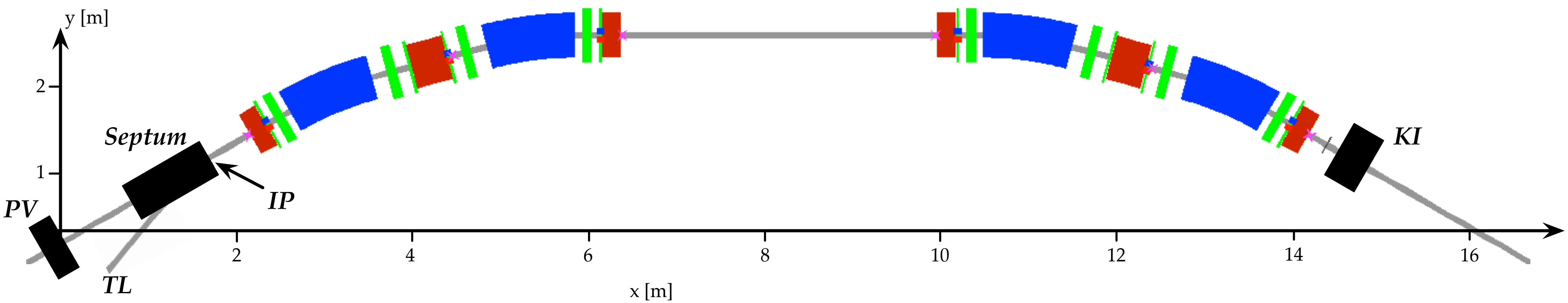
PRST-AB **15**, 050705 (2012)



Two-turn injection with reduced strength: $(b_3L) = 59\ m^{-2}$ for $\theta_{pm} = +1.9$ mrad

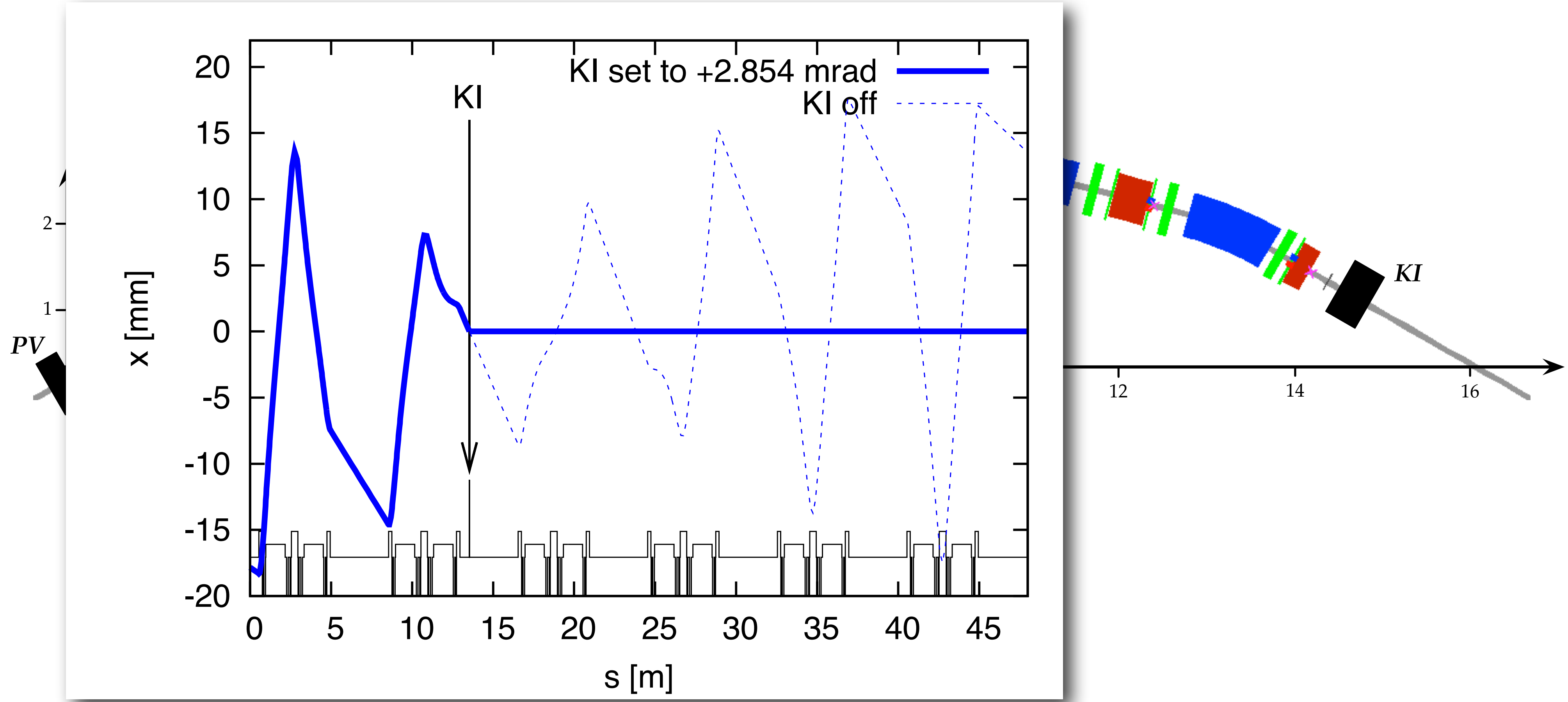
Injection: Single Dipole Kicker

Submitted to NIM-A



Injection: Single Dipole Kicker

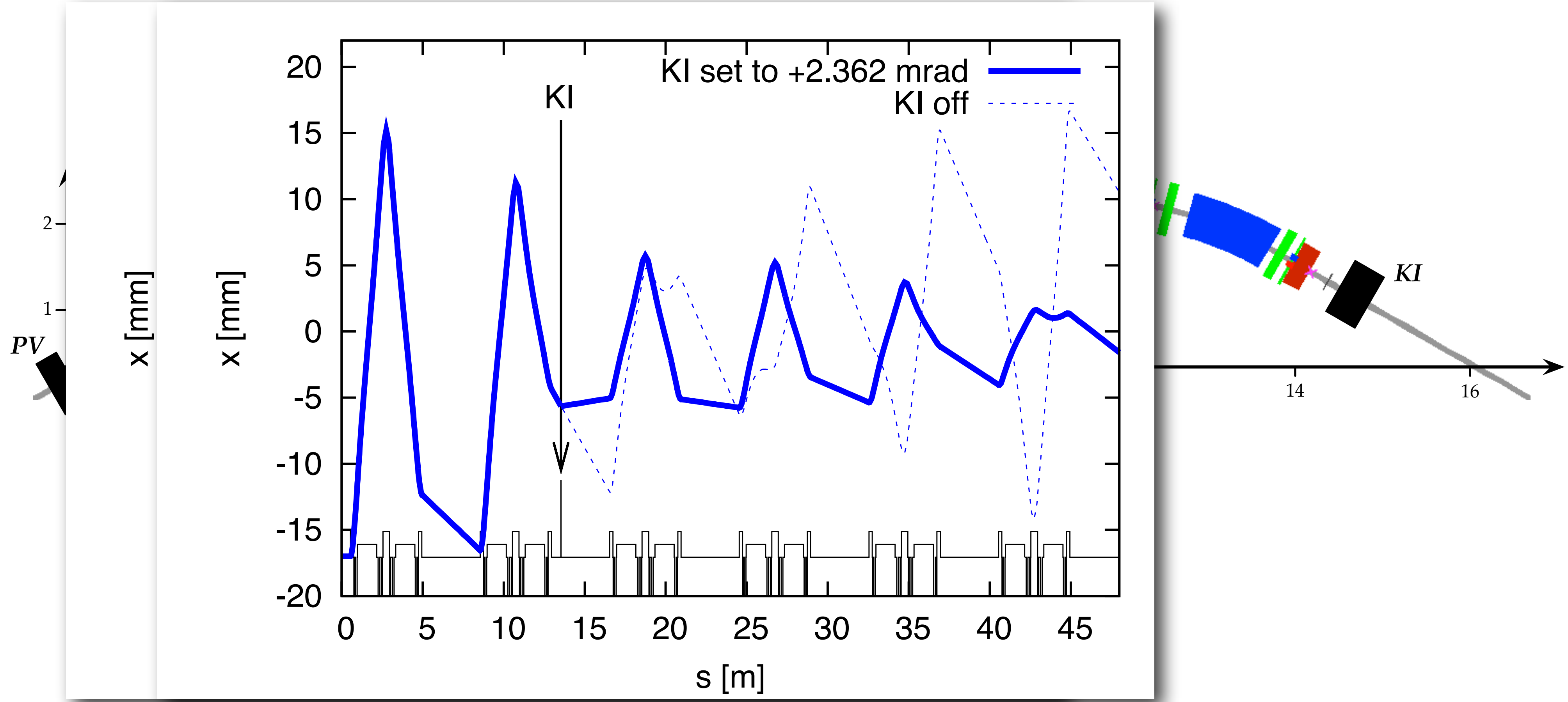
Submitted to NIM-A



On-axis injection: θ_{ki} = +2.9 mrad (inject at -0.84 mrad)

Injection: Single Dipole Kicker

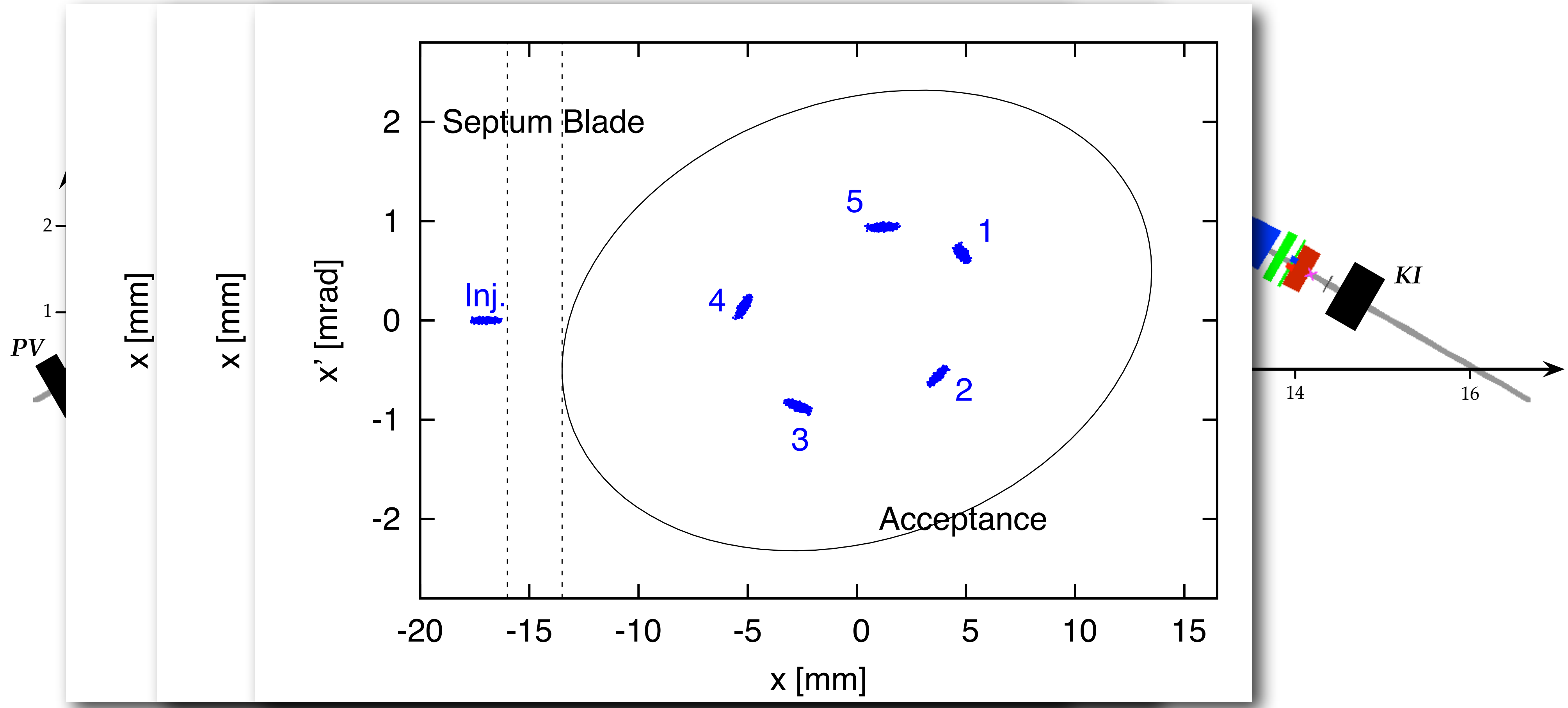
Submitted to NIM-A



Standard injection: θ_{ki} = +2.4 mrad

Injection: Single Dipole Kicker

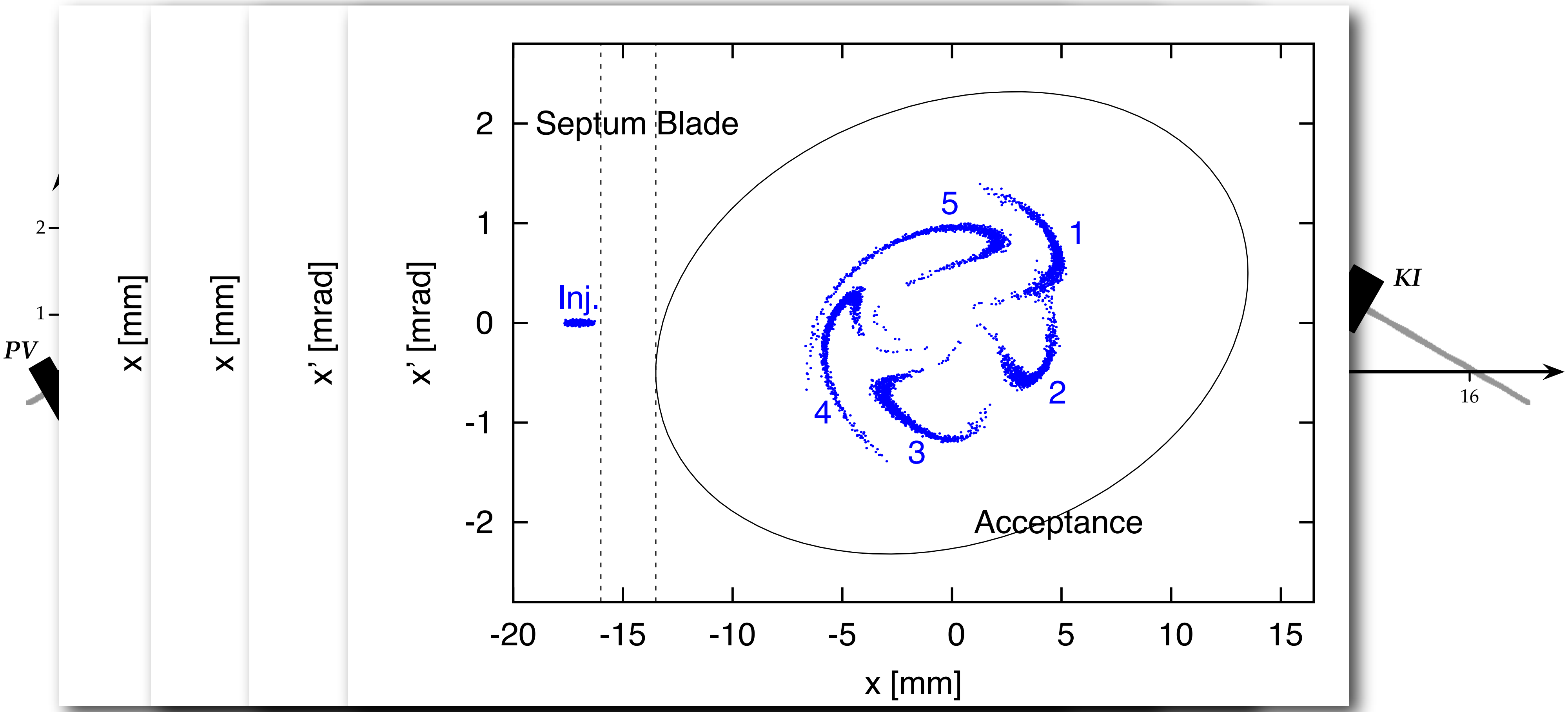
Submitted to NIM-A



Optimum settings: θ_{ki} = +2.4 mrad

Injection: Single Dipole Kicker

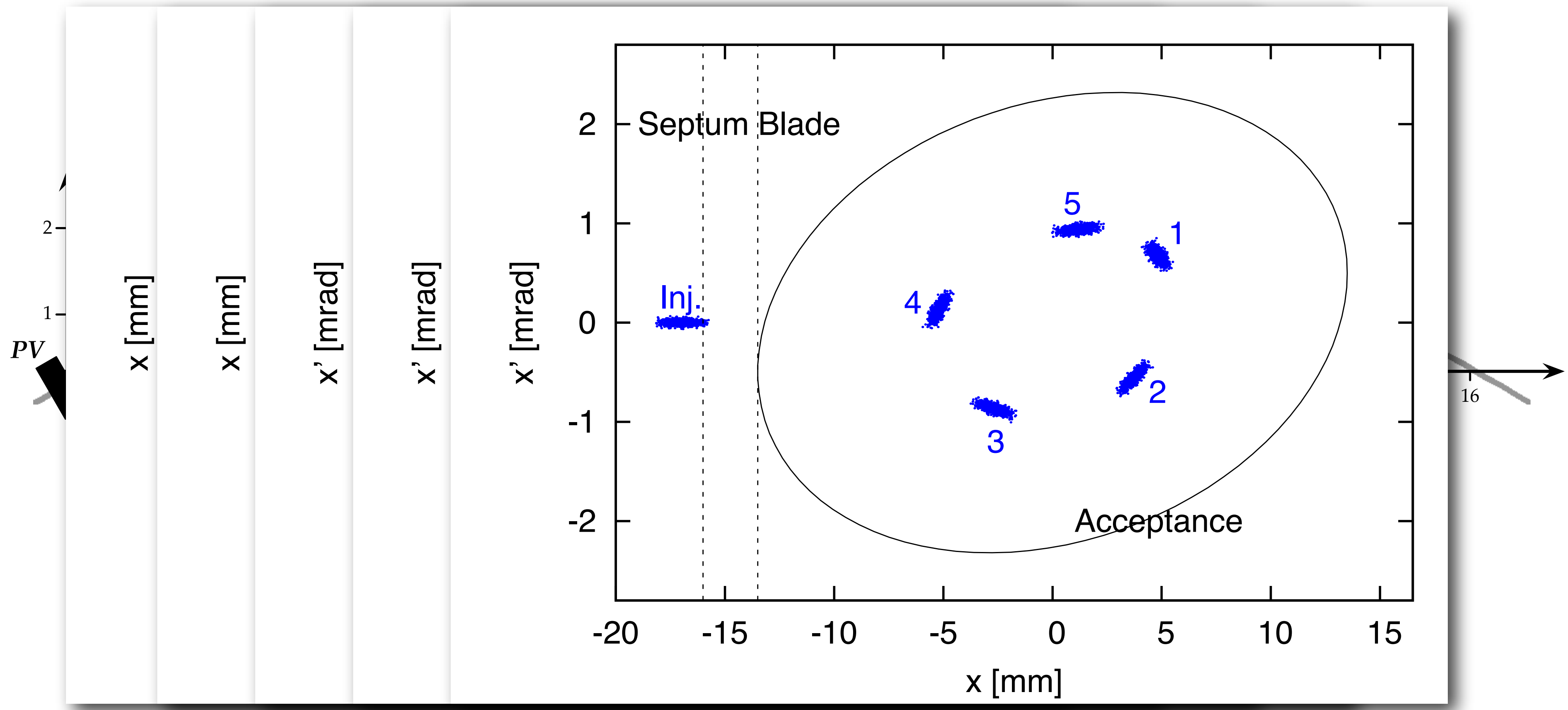
Submitted to NIM-A



Error tolerance: bunch energy spread increased to σ_δ = 2.0%

Injection: Single Dipole Kicker

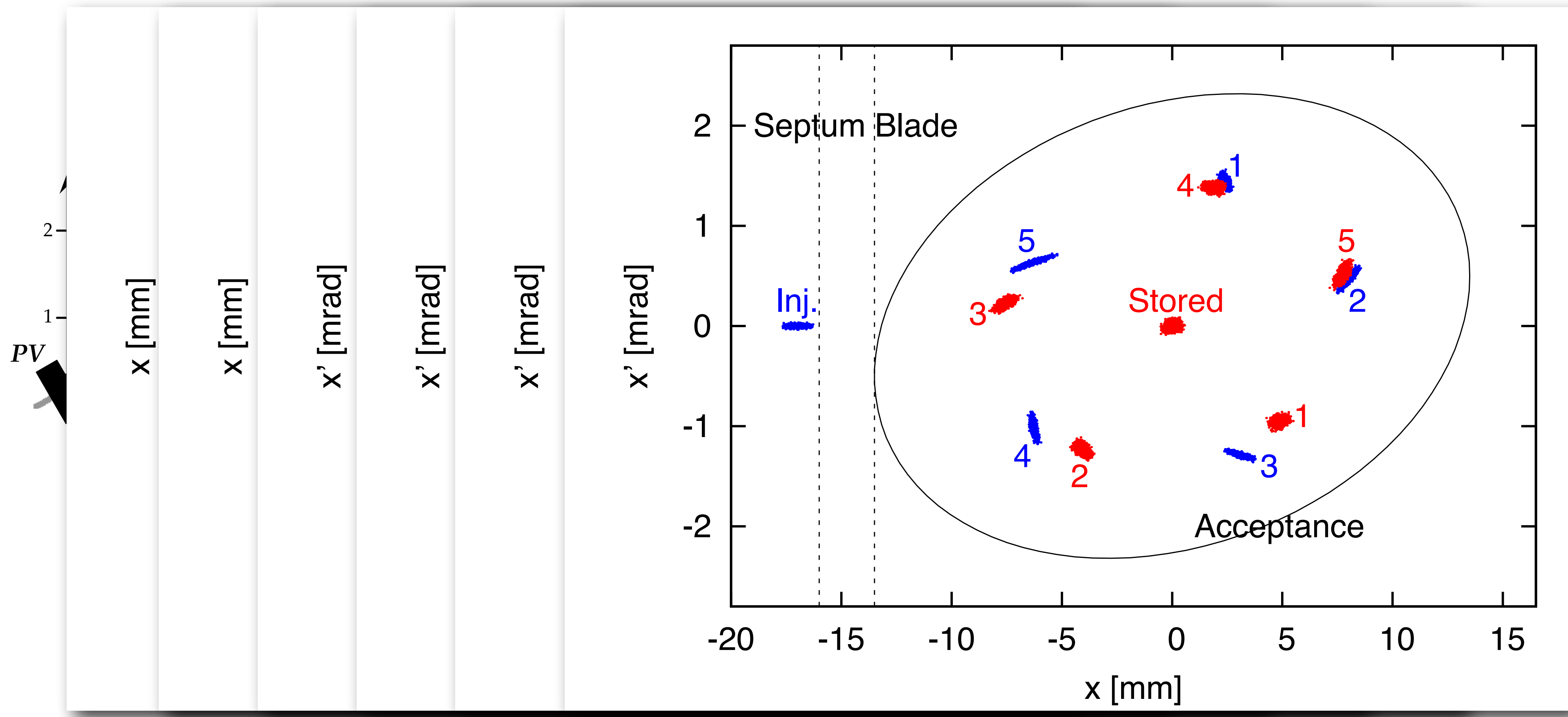
Submitted to NIM-A



Error tolerance: bunch emittance increase (3-fold) / optics mismatch

Injection: Single Dipole Kicker

Submitted to NIM-A



Reduced strength θ_{ki} = +1.4 mrad → allows for accumulation!

"Where's the Beef?"

– DDR Chapter 3: "**MAX IV 1.5 GeV Storage Ring**"
http://www.maxlab.lu.se/maxlab/max4/DDR_public

– MAX-lab Internal Note 20120313: "**Updates to the MAX IV 1.5 GeV Storage Ring Lattice**"
http://www.maxlab.lu.se/maxlab/max4/max_iv_reports_public

– Lattice **m5-20120313-521-bare.lat** & **m5-20120313-523-bare.lat**
http://www.maxlab.lu.se/maxlab/max4/max_iv_reports_public

– **Effect of strong ID's** on lattice optimization: IPAC'12, TUPPC025
http://www.ipac12.org/proceedings.htm

– **Pulsed sextupole injection** into MAX IV rings: PRST-AB **15** 050705 (2012)
http://prst-ab.aps.org/abstract/PRSTAB/v15/i5/e050705