MAX IV 3 GeV Storage Ring

Dynamic Aperture & Injection Revisited

Simon C. Leemann

3rd MAX MAC Meeting, October 20, 2011

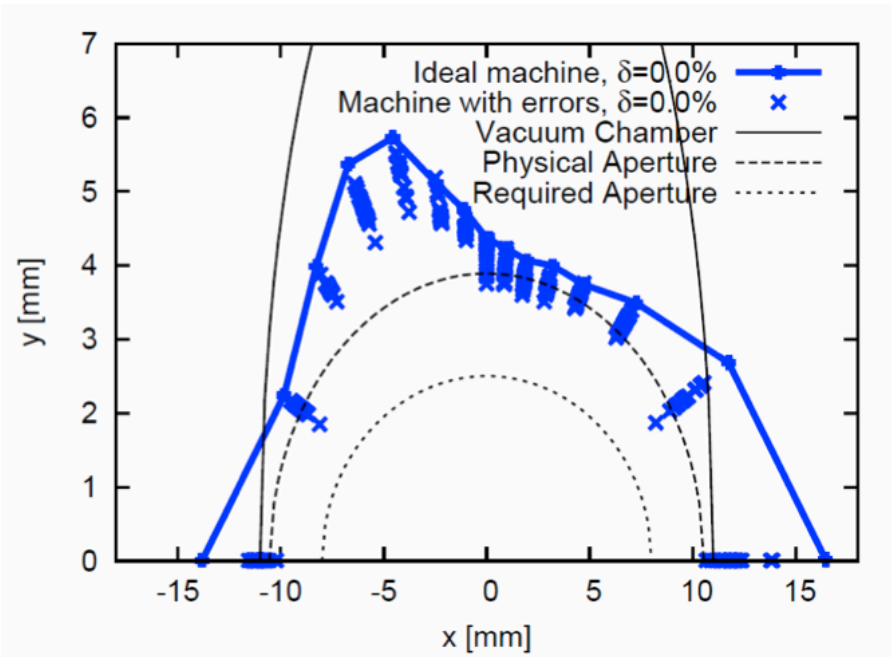
From the last MAC meeting

"... The tracking results including multipole and alignment errors show a significant reduction of the dynamic aperture. The committee is worried that the reduction in dynamic aperture may not allow accumulation of beam. ..."

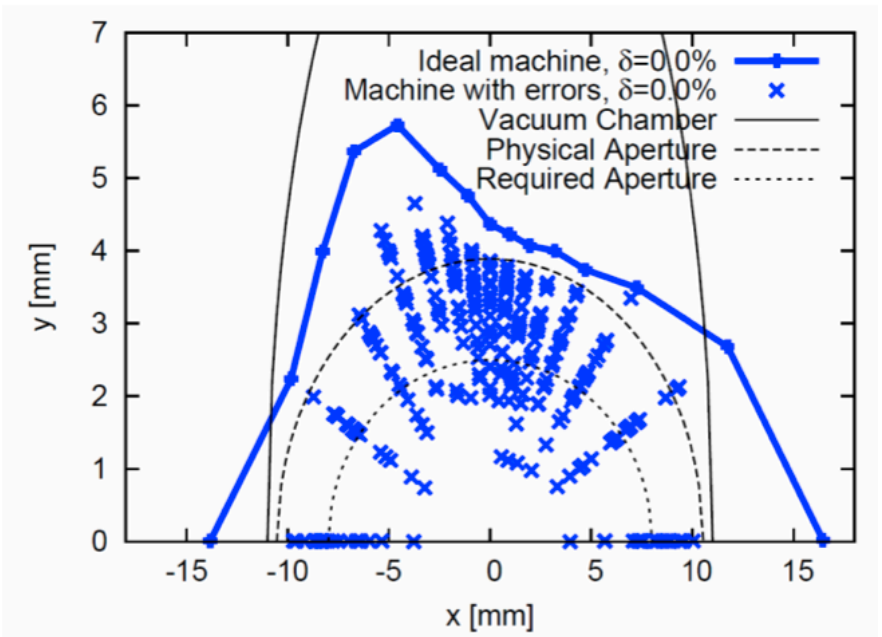
— Report on the 2nd MAX MAC Meeting

From the last MAC meeting

Field + Multipole Errors



Field + Multipole + Alignment Errors



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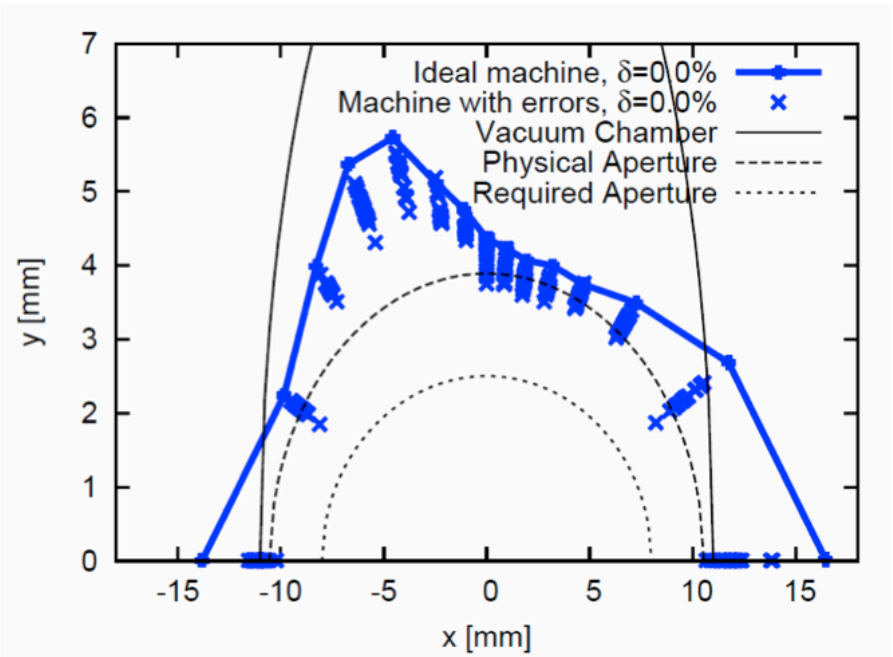

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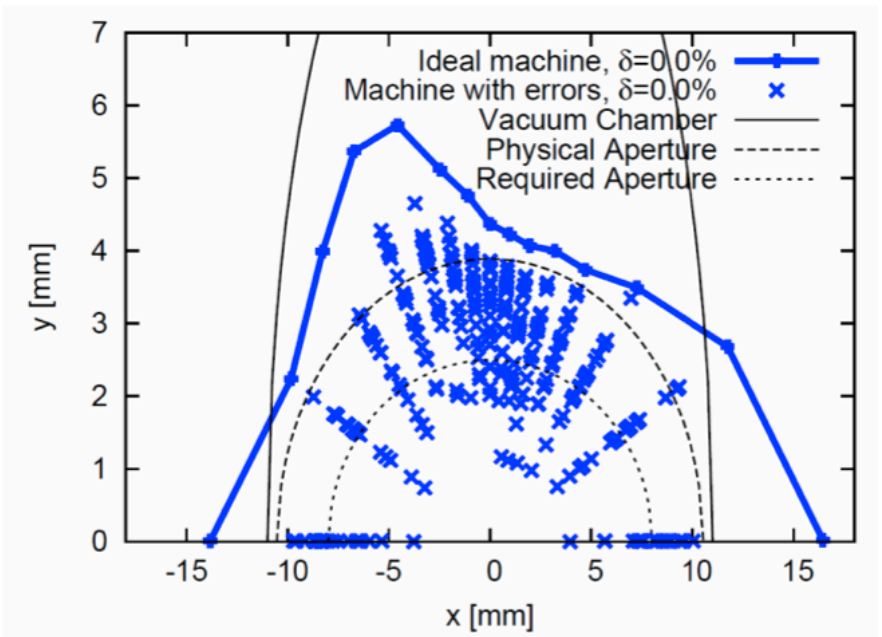
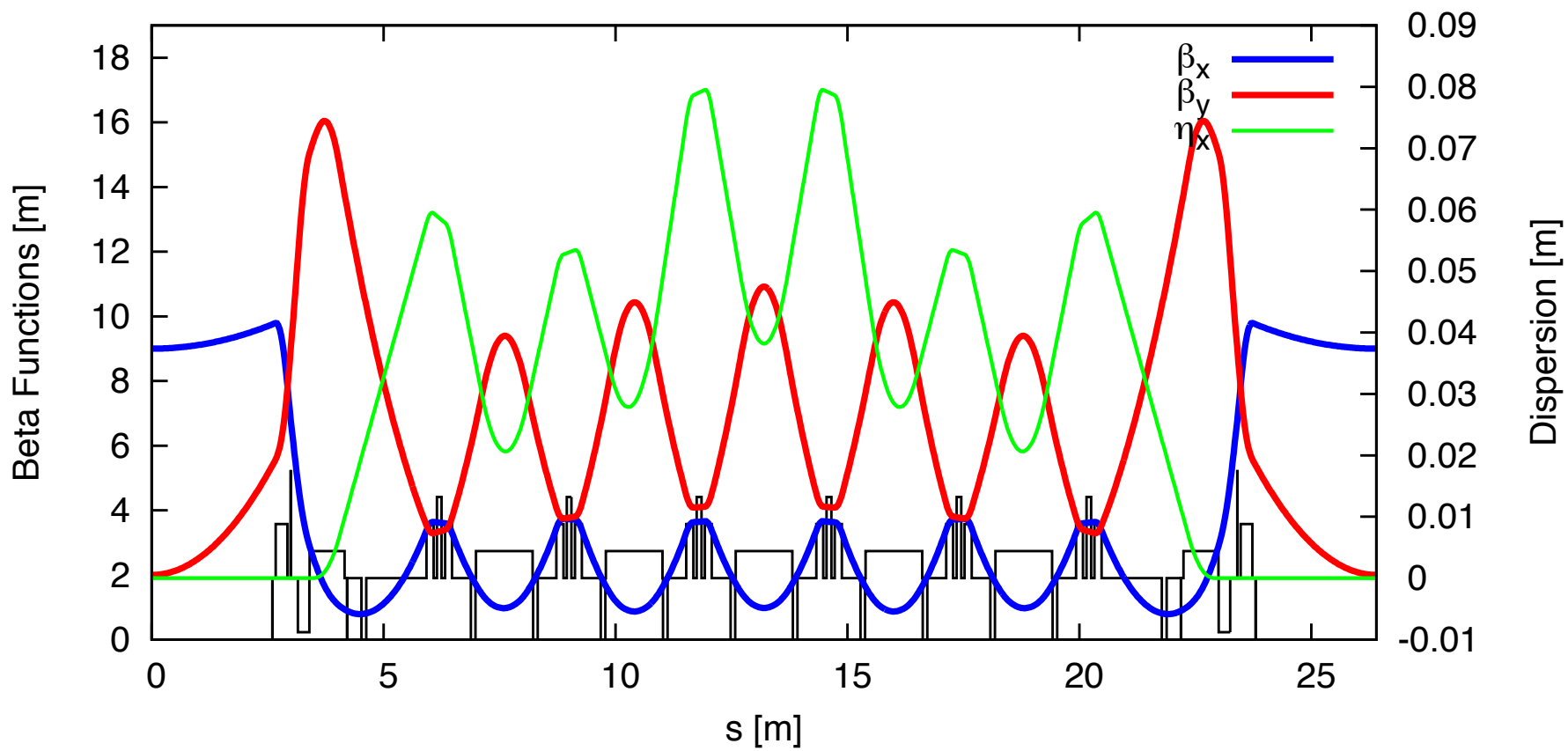


- **But this picture is inaccurate:**
  - Minor bug in Tracy-3
  - Required DA
  - Misalignment model
  - Field error model

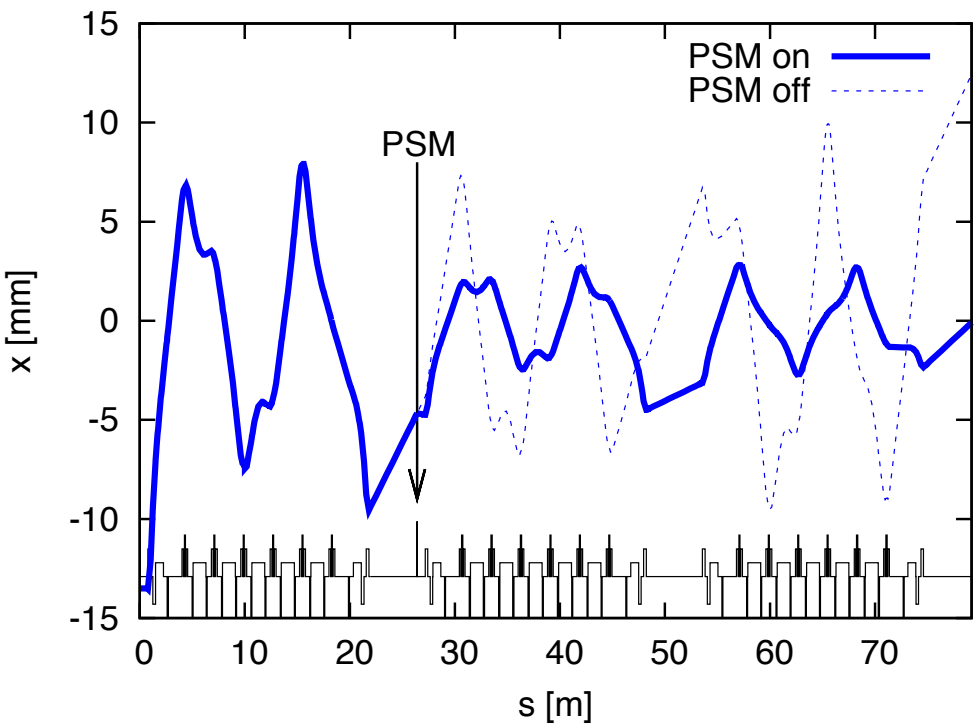
Required dynamic aperture

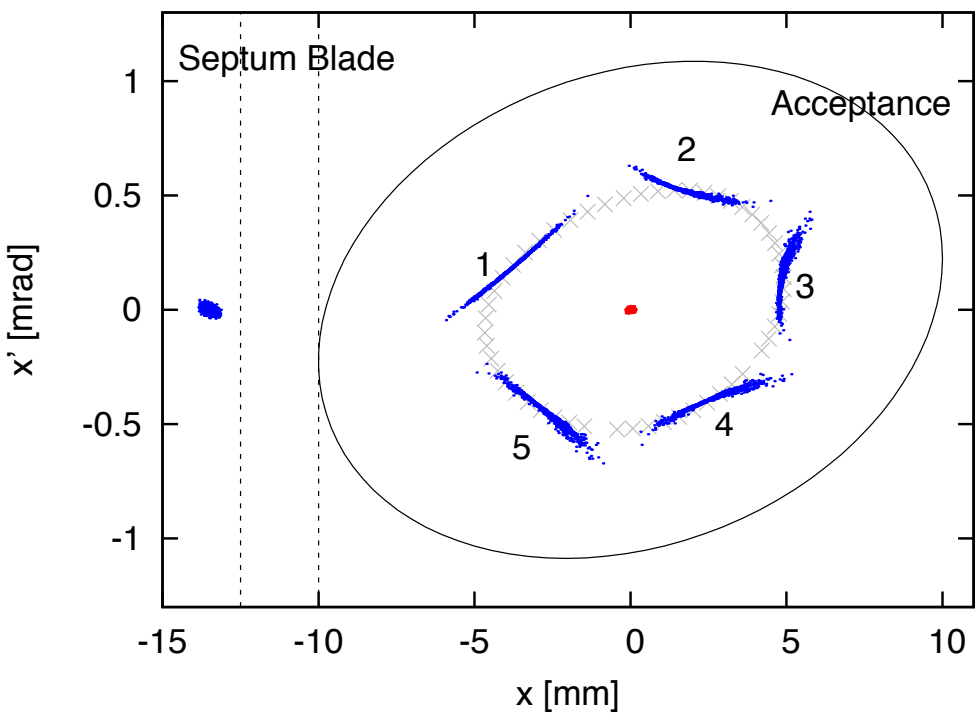
- **Acceptance limitations:**
  - Horizontal plane: septum blade in LS
  - Vertical plane: in-vacuum ID **pmuL** (min. gap 4.2 mm, total length 3.8 m)



Required dynamic aperture

- **Required DA horizontal plane:**
  - Injection process: ~5 mm maximum amplitude after PSM
  - Margin for error (misalignments, injection tuning)
  - ➡ ± 7 mm @ LS center





Required dynamic aperture

- **Required DA horizontal plane:**
  - Injection process: ~5 mm maximum amplitude after PSM
  - Margin for error (misalignments, injection tuning)
  - ➡ ± 7 mm @ LS center

- **Required DA vertical plane:**
  - Lifetime concern (coupling)
  - In-vacuum ID **pmuL**: min. gap 4.2 mm, total length 3.8 m
  - ➡ ± 2 mm @ LS center (incl. 0.5 mm safety margin)

Required dynamic aperture

- **Required DA horizontal plane:**
  - Injection process: ~5 mm maximum amplitude after PSM
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  - Lifetime concern (coup
  - In-vacuum ID **pmuL**: r
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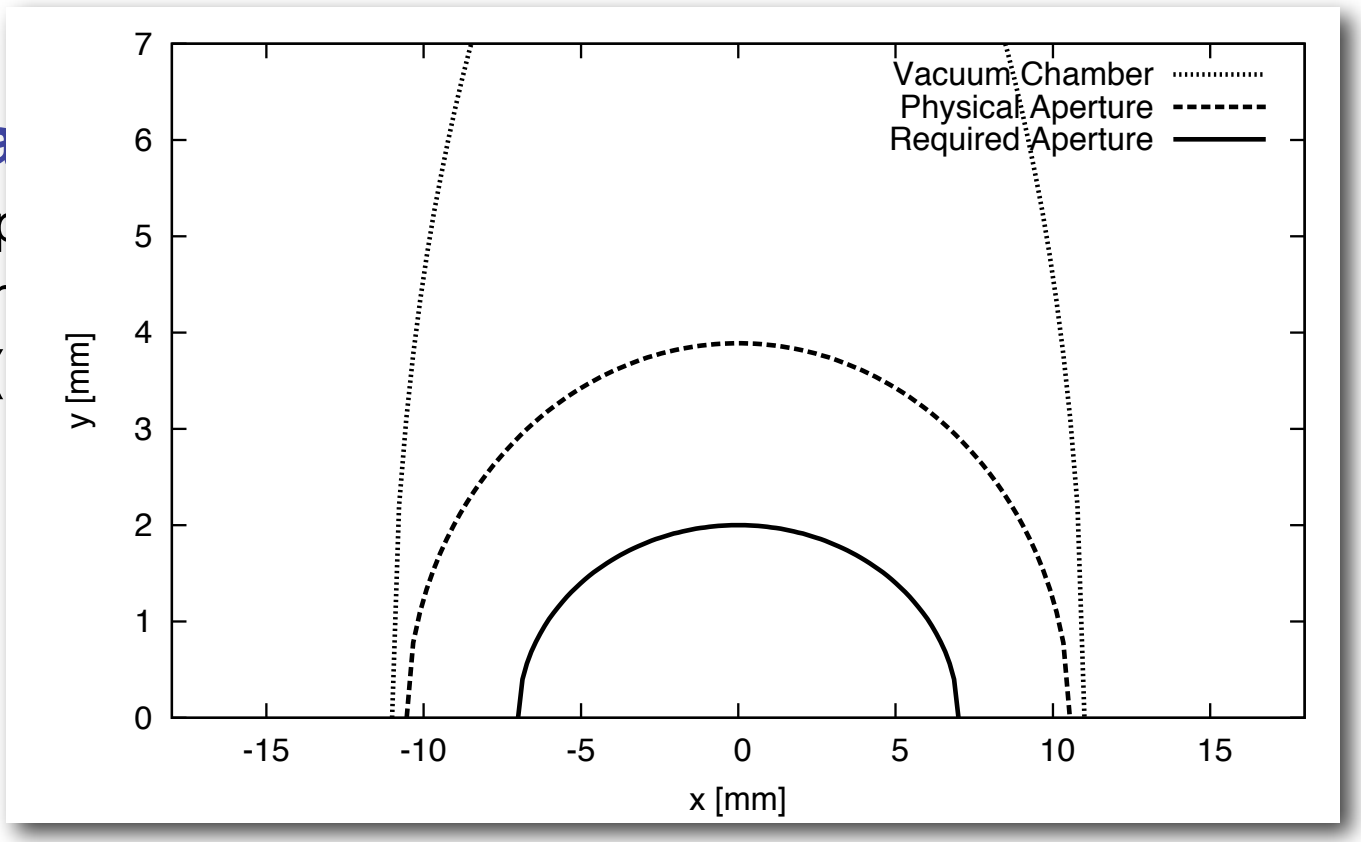


Misalignment modeling

- **Misalignments between girders (i.e. UC/MC blocks) previously modeled as Gaussian distribution**
  - 100 micron rms
  - Cut-off at ±2σ
  - ➡ Adjacent blocks could be misaligned by as much as 400 micron!

- **But MAX-lab alignment experts actually say**
  - That is too pessimistic
  - Adjacent blocks can be aligned better than 100 micron (laser tracker, software, alignment mechanism)

- ➡ **More realistic model (using Gaussian distribution)**
  - 50 micron rms
  - Cut-off at ±2σ

Revised misalignment model

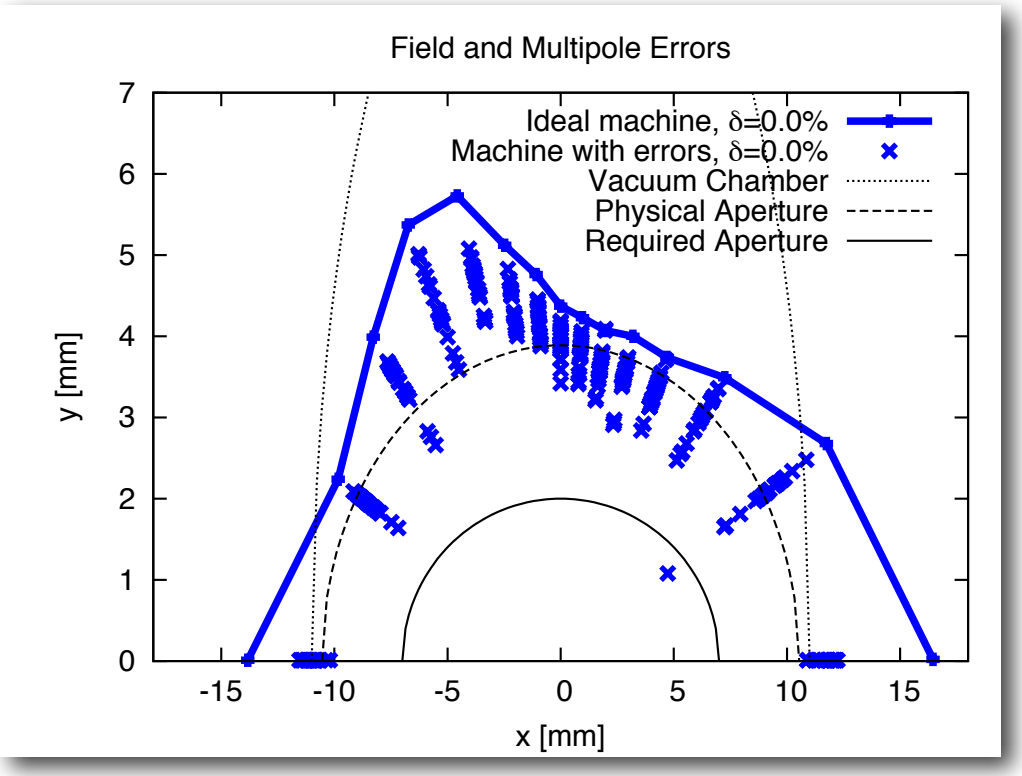
	Transverse displacements	Roll error
Girders (MC/UC blocks)	50 micron rms	0.2 mrad rms
Dipole slices (!)	25 micron rms	0.2 mrad rms
Quadrupoles	25 micron rms	0.2 mrad rms
Sextupoles	25 micron rms	0.2 mrad rms
Octupoles	25 micron rms	0.2 mrad rms
Correctors	25 micron rms	0.2 mrad rms
BPM calibration	3 micron rms	0.1 mrad rms

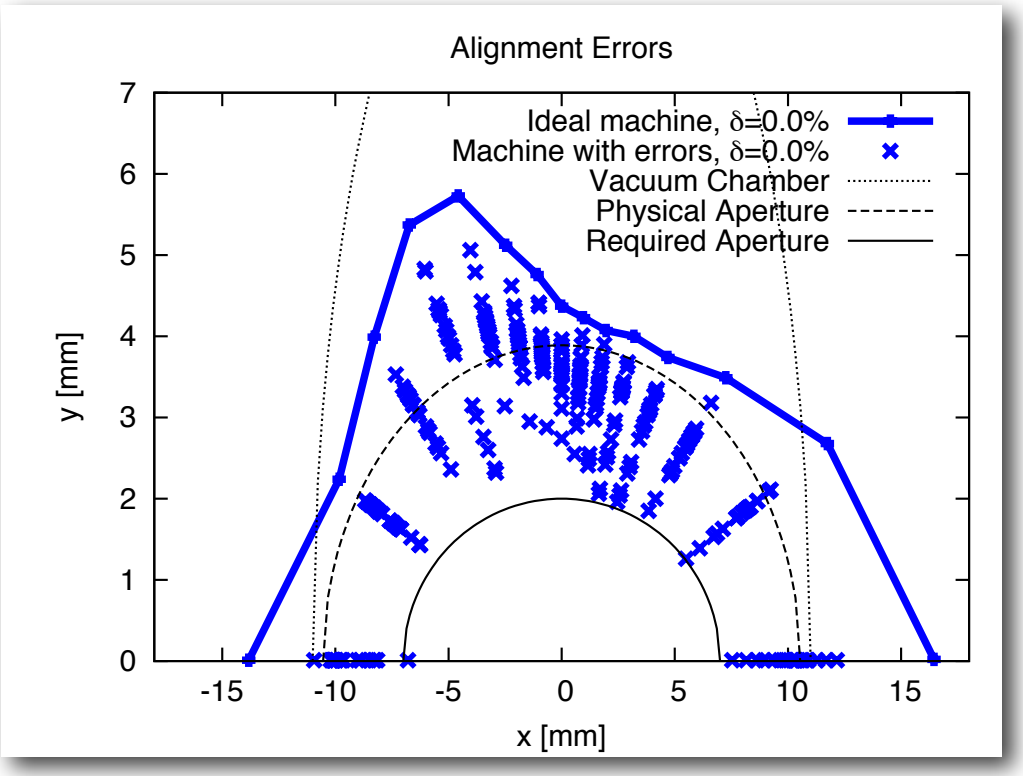
Field error modeling

- **Previously: assumed 0.02% rms field error within families**
- **More realistically:**
  - 20 micron peak-to-peak machining accuracy for magnet poles
  - Typical magnet gap is 20 mm
  - ➡ Model field errors with Gaussian, 0.05% rms, cut-off at ±2σ

Improved assessment of DA

- On momentum (dominated by misalignments)





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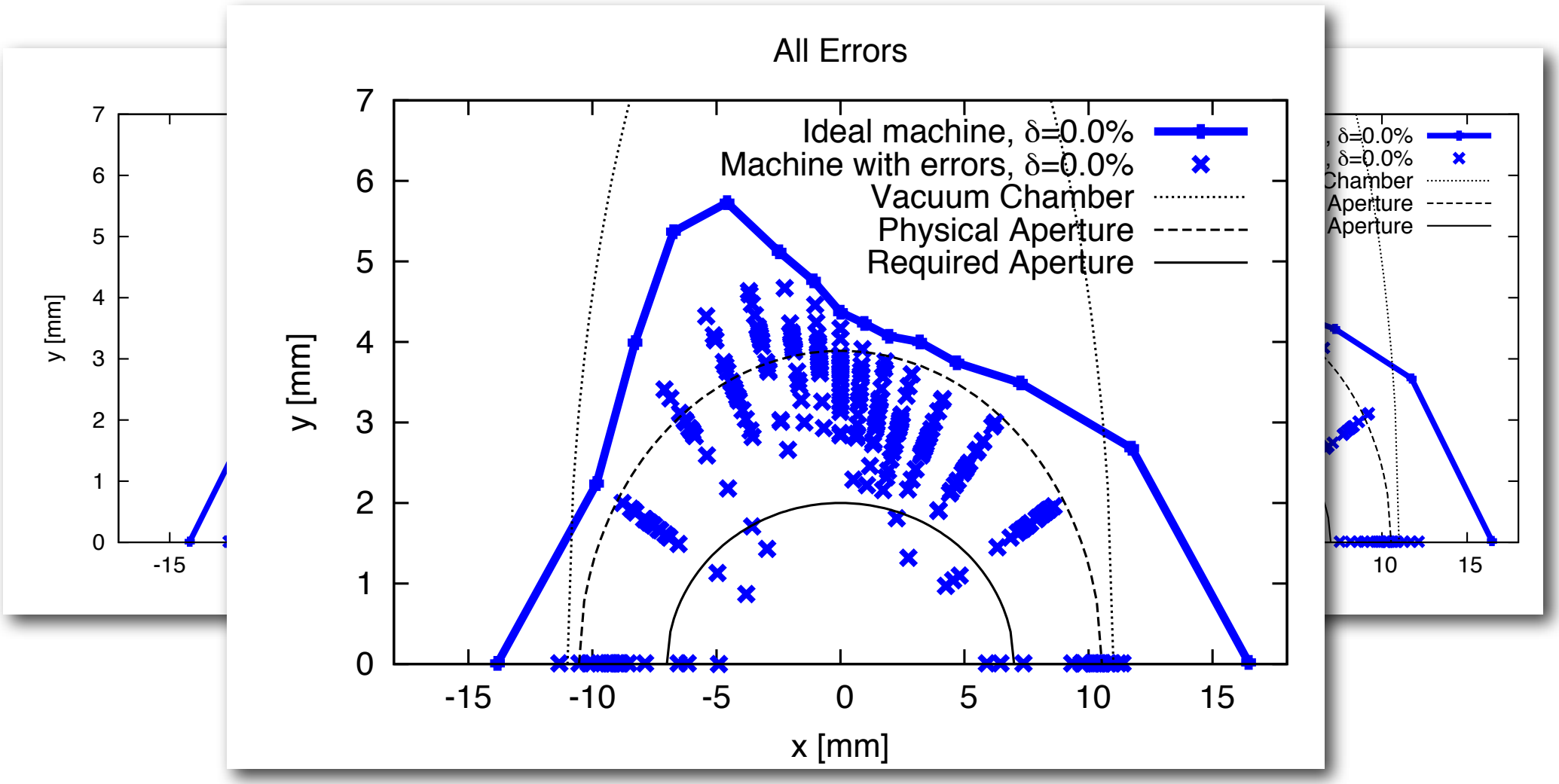

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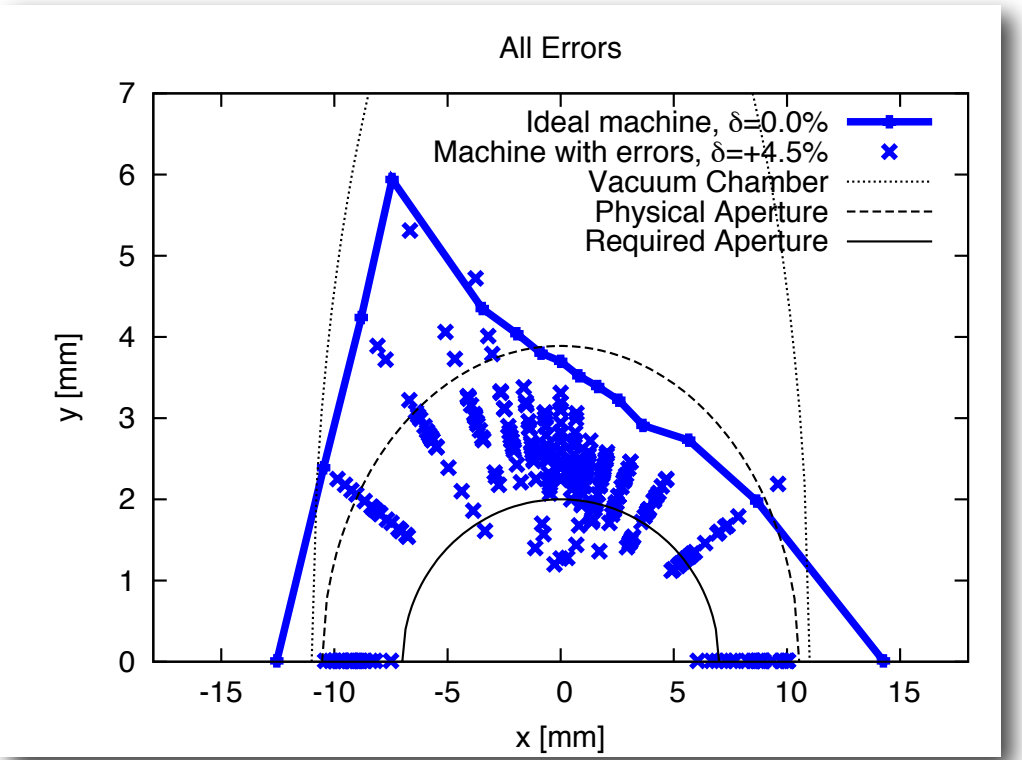

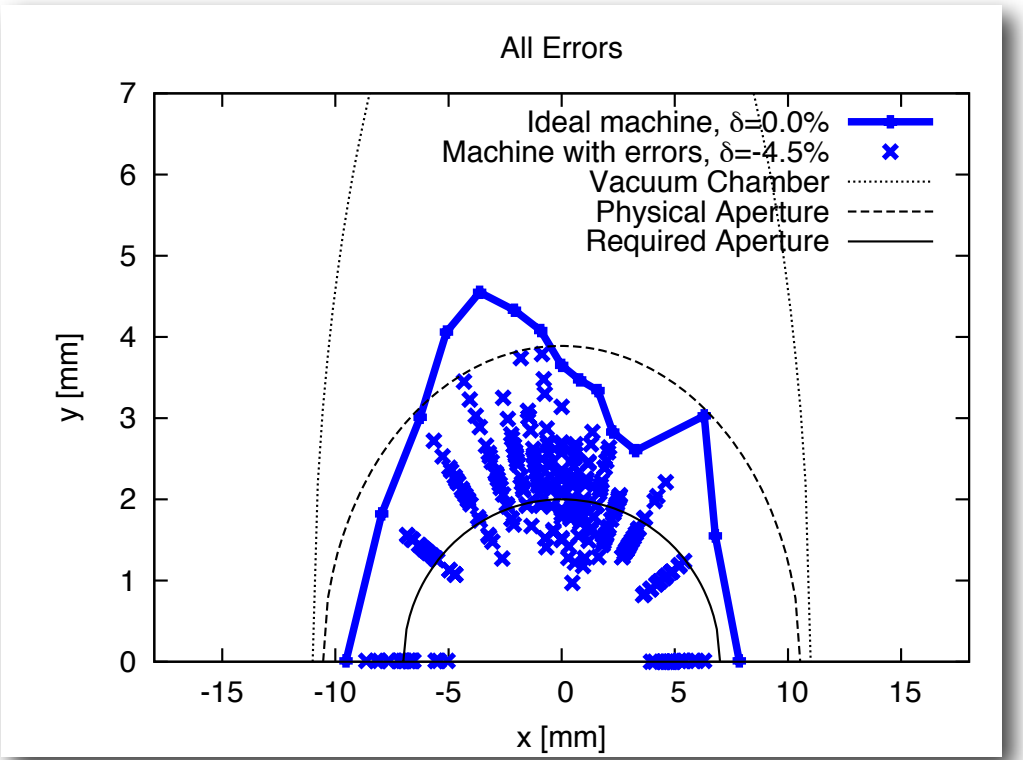

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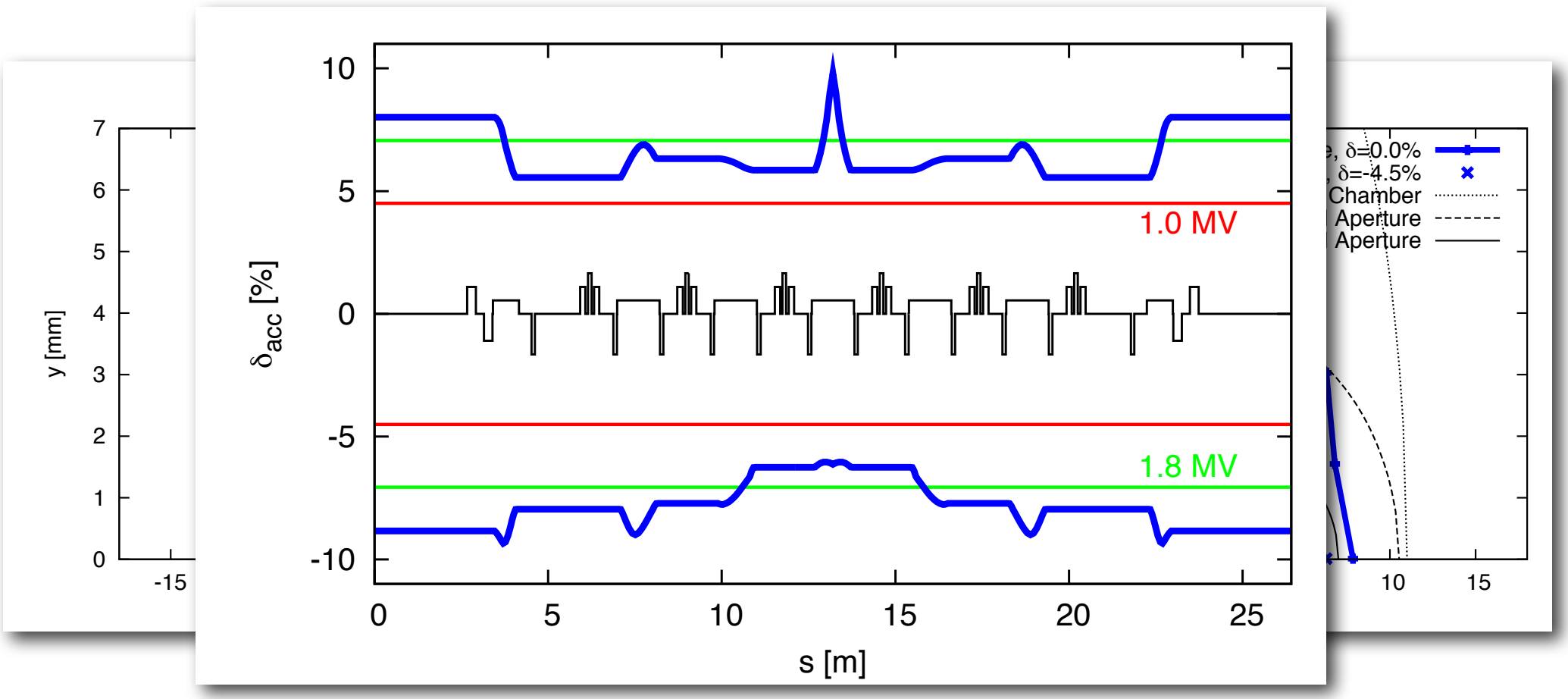
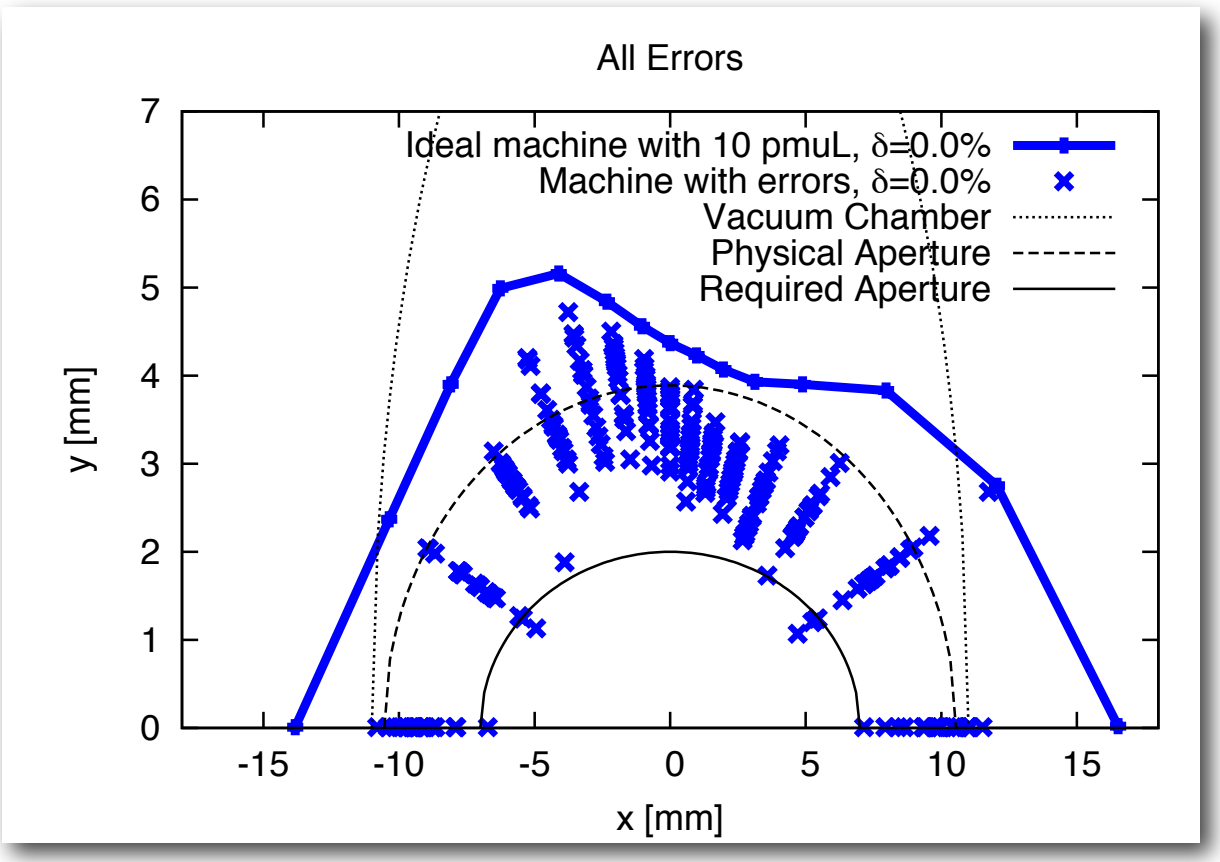


Improved assessment of DA

- On momentum (dominated by misalignments)
- Off momentum
- With IDs (ID model & Radia kick maps)

PAC'11, TUP235



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➡ DA appears adequate (despite pessimistic model!)

Improved assessment of DA

- **On momentum (dominated by misalignments)**
- **Off momentum**
- **With IDs (ID model & Radia kick maps)** PAC'11, TUP235
- ➡ **DA appears adequate (despite pessimistic model!)**

- **And once some beam has been accumulated:**
  - Correct linear optics (LOCO), misalignments
  - Nonlinear optics can be corrected to restore full DA PRST-AB **11**, 104002 (2008)
    - "Nonlinear LOCO" demonstrated at Diamond (we have 200 TBT BPMs)
    - Corrections via secondary coils on all sextupoles and octupoles
      - Auxiliary sextupoles (break symmetry → degenerate RDTs)
      - Skew quadrupoles (coupling, vertical dispersion)

From the last MAC meeting

"... Several changes in the injector linac design with respect to the last MAX MAC meeting and DDR were reported. One of the changes was the introduction of a thermionic RF gun as a more reliable and robust alternative for the top-up injection into the storage rings. ... The MAC recommends detailed simulations are carried out to determine the sensitivity of injection into the two storage rings to the emittance provided by the injector. ..."

— Report on the 2nd MAX MAC Meeting

Injection

- **Pulsed sextupole magnet**

PRST-AB **13**, 020705 (2010)

- **Significant advantages**

PAC'11, THP214

  - Reduce perturbation of stored beam
  - Lower reduced invariant compared to injection with local bump
  - Only a single device to re-align and synchronize

- **But need to take care**
  - Large amplitudes between IP (end of septum) and PSM
  - Amplitude trade-off at PSM
  - Pulser requirements (revolution period in 1.5 GeV ring is 320 ns)

Injection

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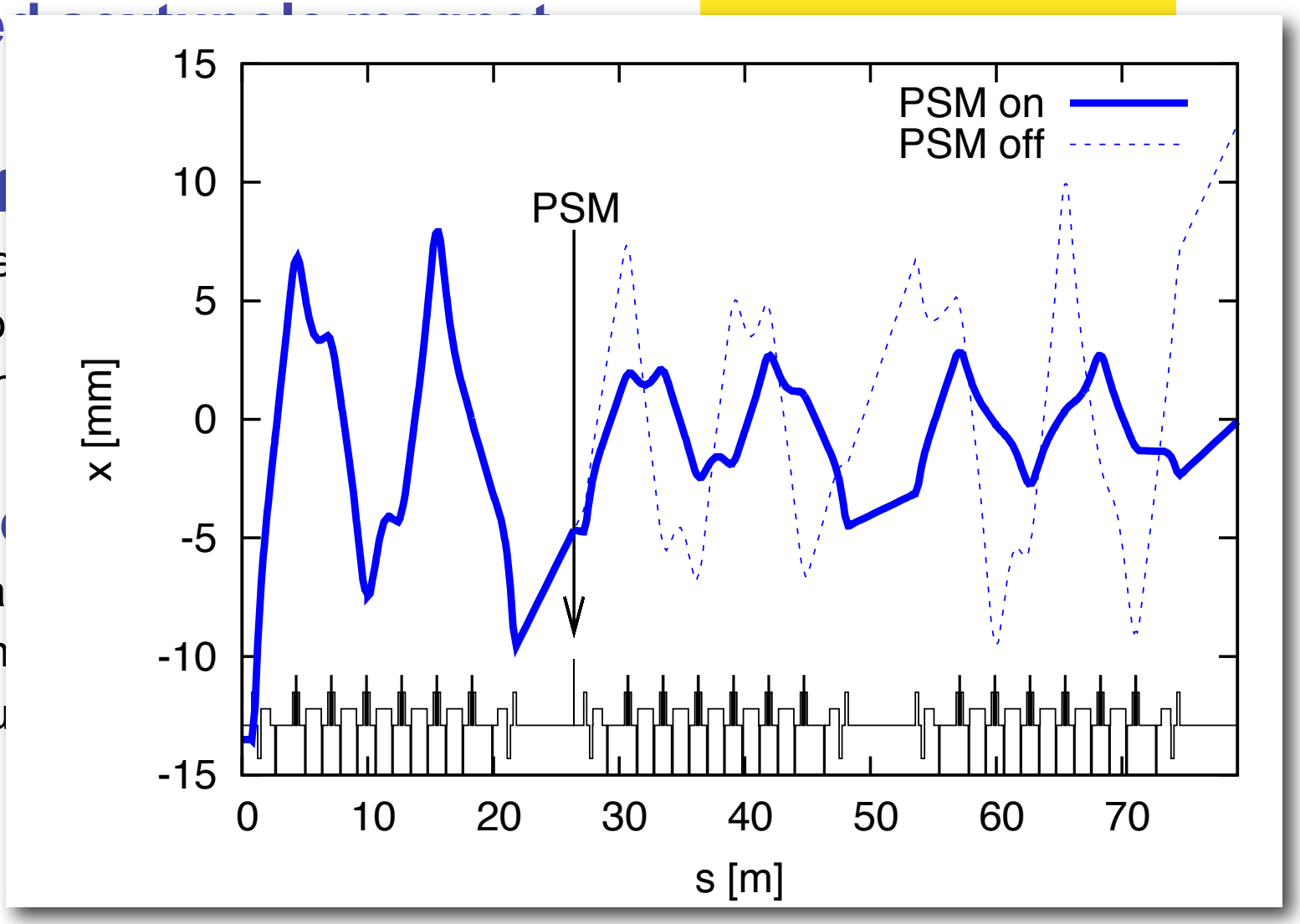

Injection

- **Proposed solution is:**
  - Compatible with DA results
  - Compatible with thermionic gun, offers substantial margins (ε, σ_δ, optics)

Injection

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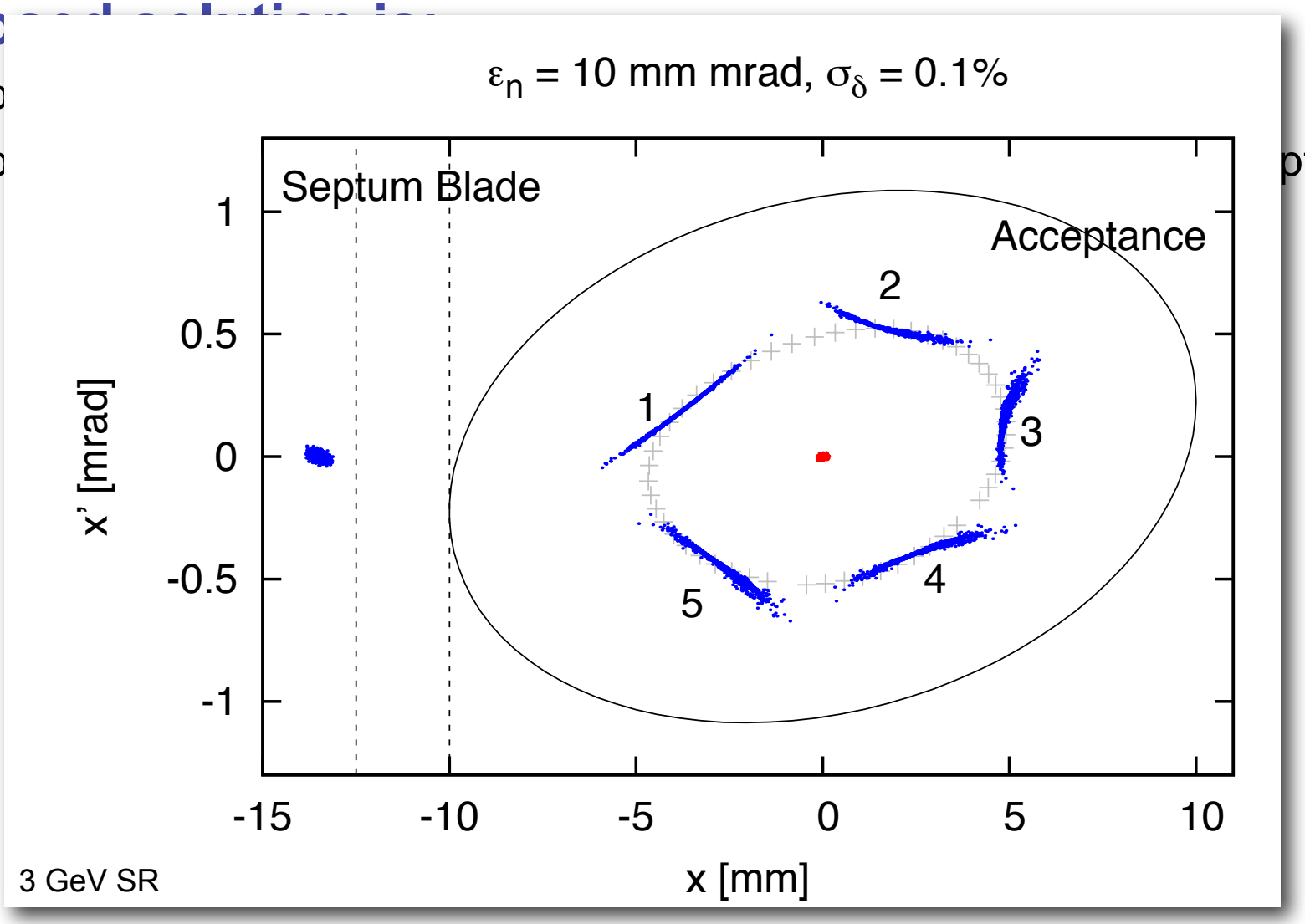
  - Co ptics)



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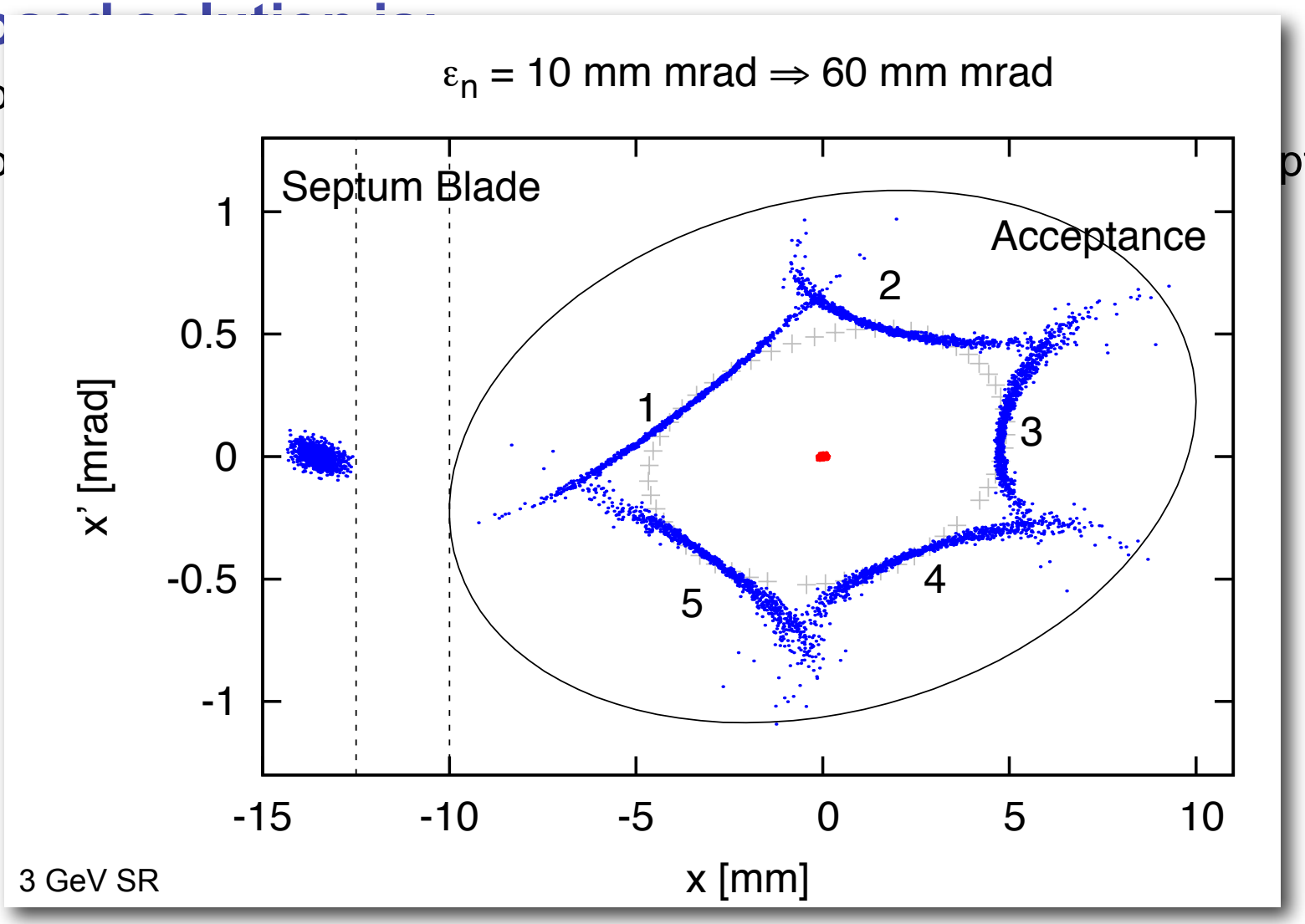

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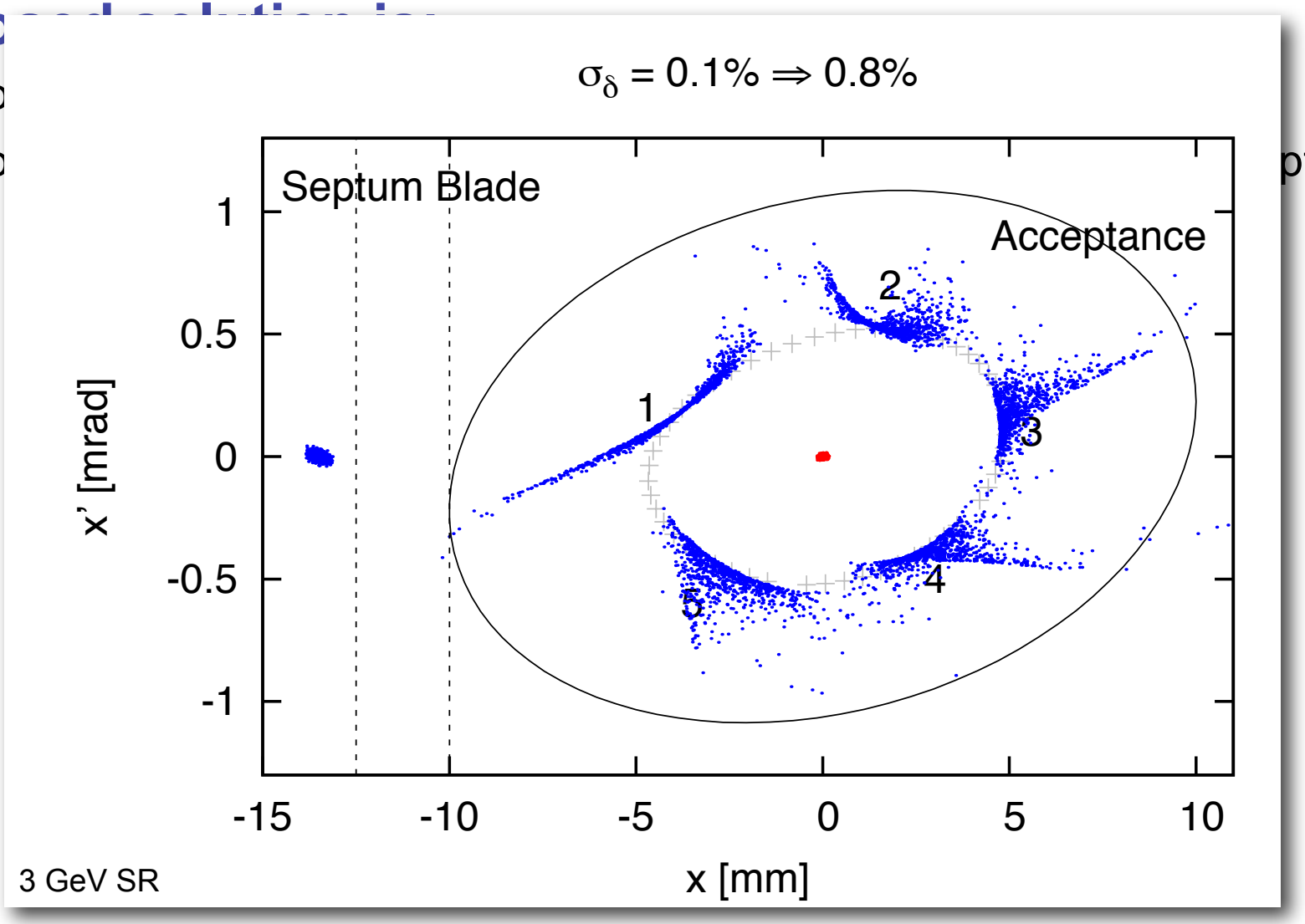

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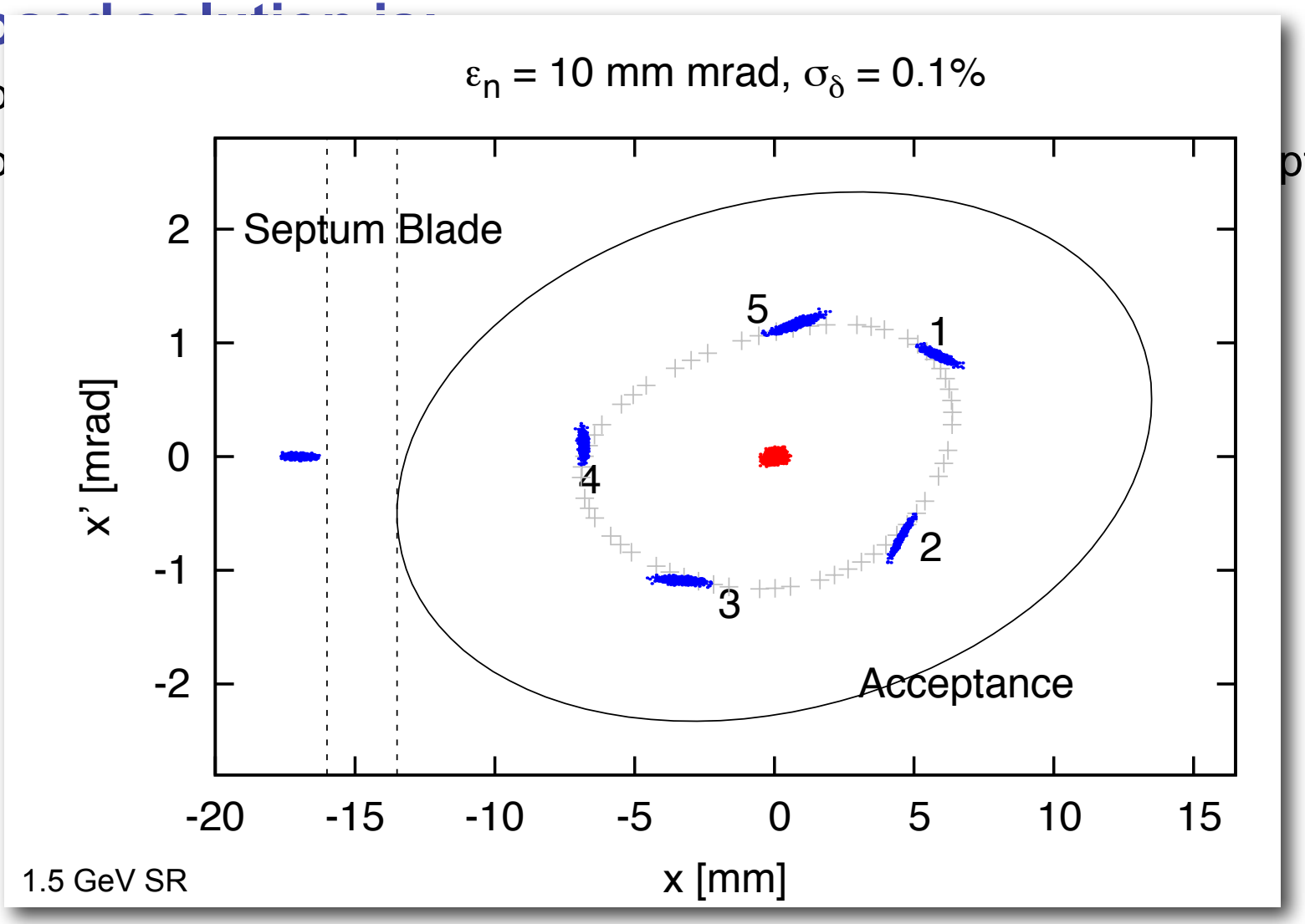

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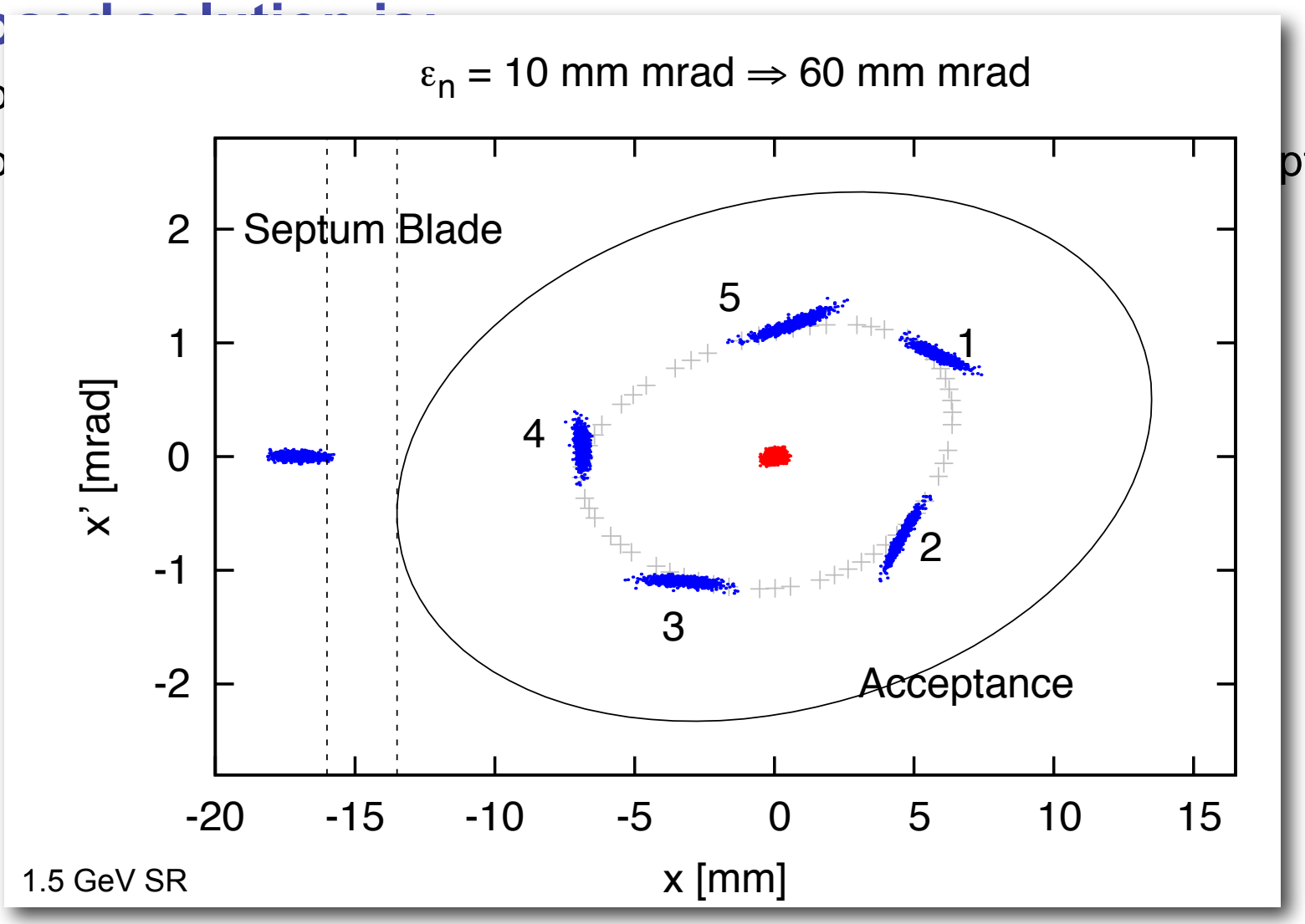

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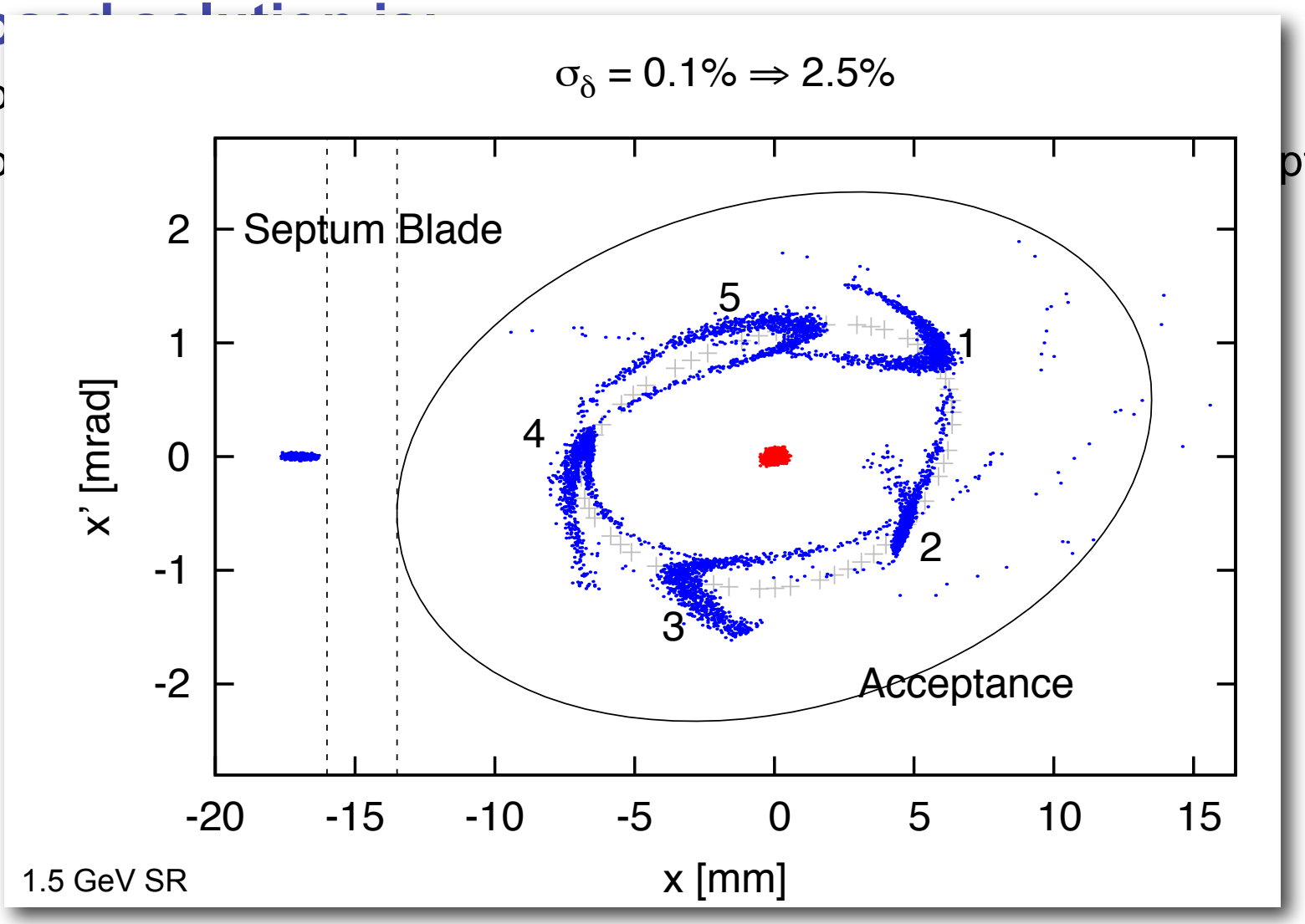

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- **Proposed solution is:**
  - Compatible with DA results
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  - Comparable with PSM demonstrated at KEK (scale field strength)
  - Demanding in terms of pulse duration (1.5 GeV ring)

- **Possible improvements:**
  - Bringing blade closer to stored beam → unfavorable trade-off
  - Bringing injected bunches closer to blade? (presently: 6.6 σ_x)
  - Thinner blade? NIM-A **490**, 592 (2002) NIM-A **547**, 686 (2005)

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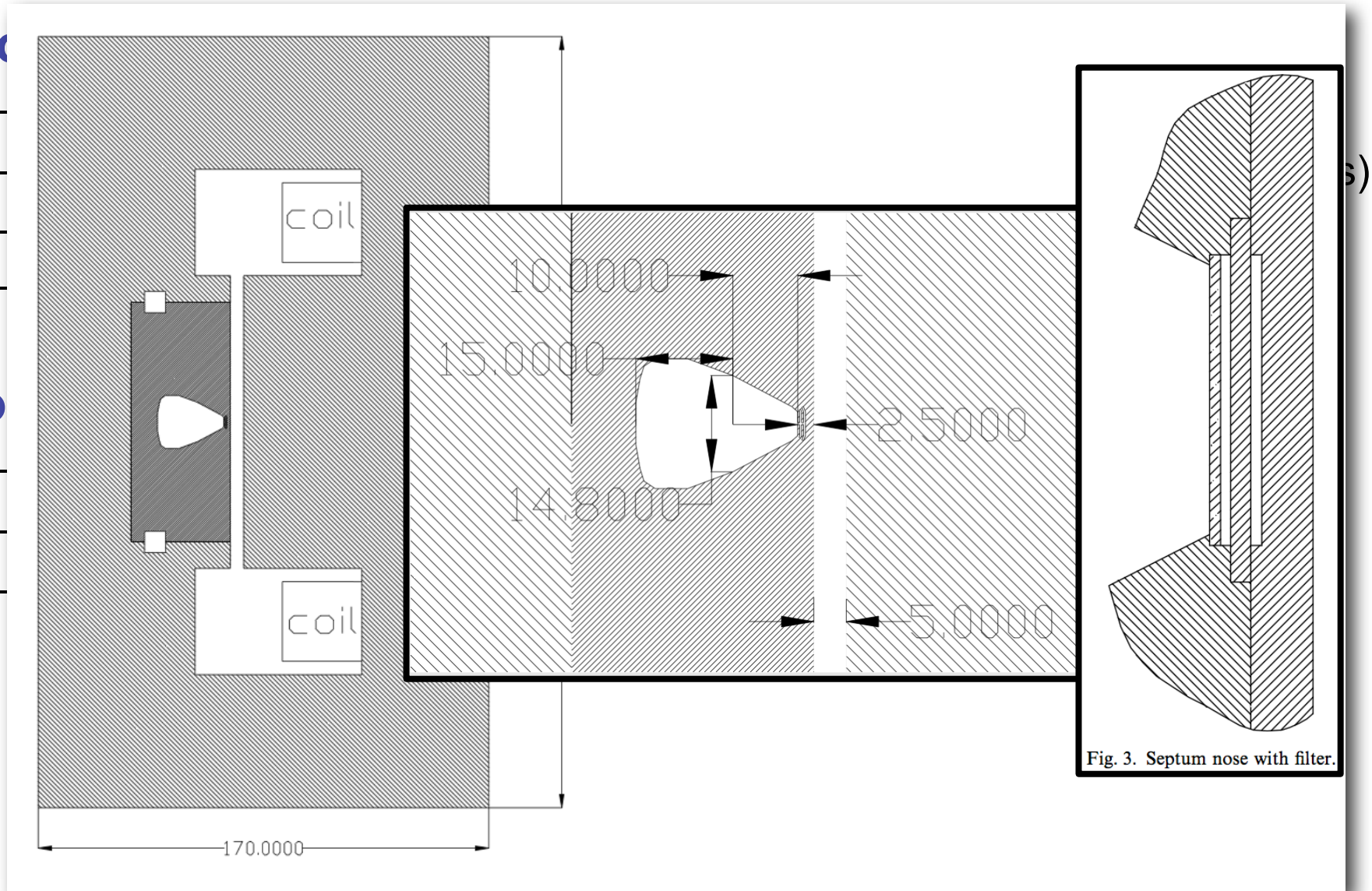

Fig. 3. Septum nose with filter.

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  - Two-turn injection → solution for 1.5 GeV ring with 1.3 µs pulse

Injection

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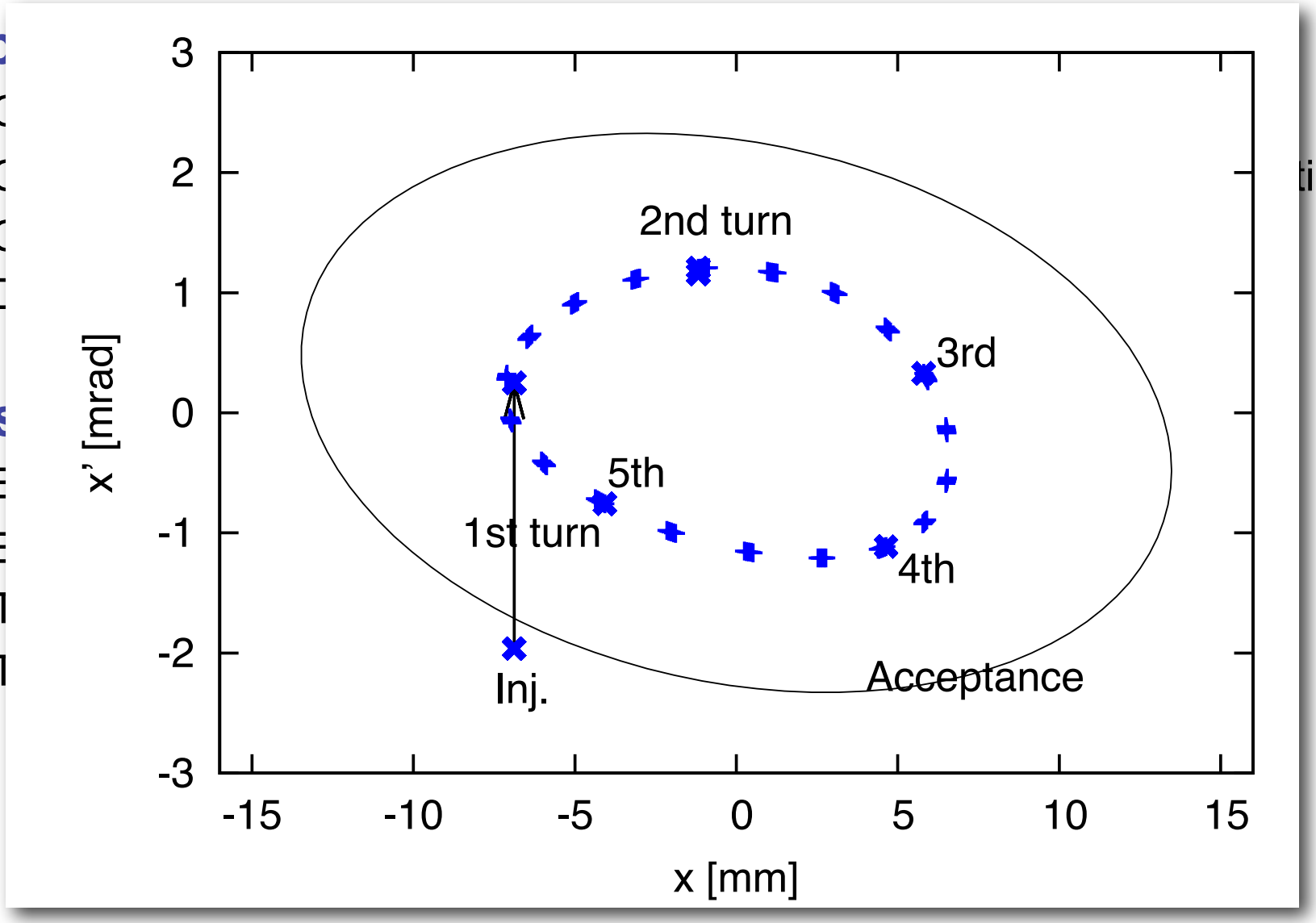

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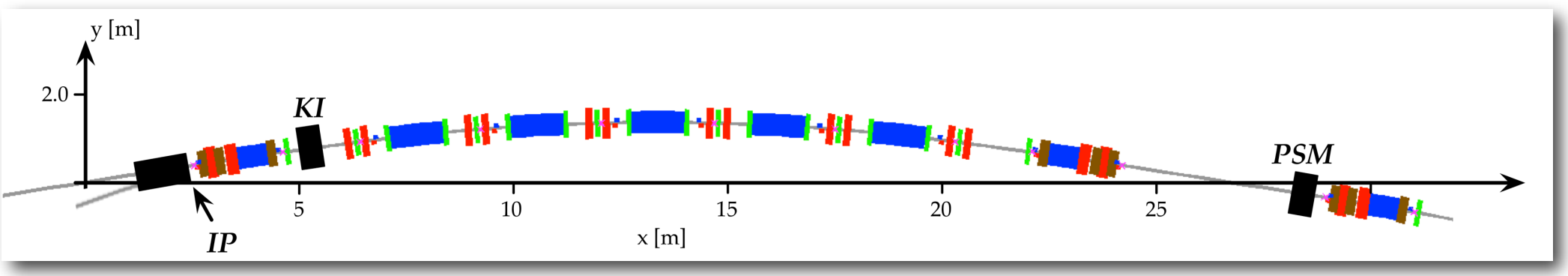
Injection

- **Fallback for commissioning: dipole kicker**
  - Installed close to septum
  - Minimum reduced invariant achieved with 3.4 mrad
  - Capture above ~1.4 mrad
  - Stored beam tolerates up to ~3 mrad
  - ➡ Allows some accumulation

IPAC'11, THPC059



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