Pulsed Sextupole Injection for MAX IV

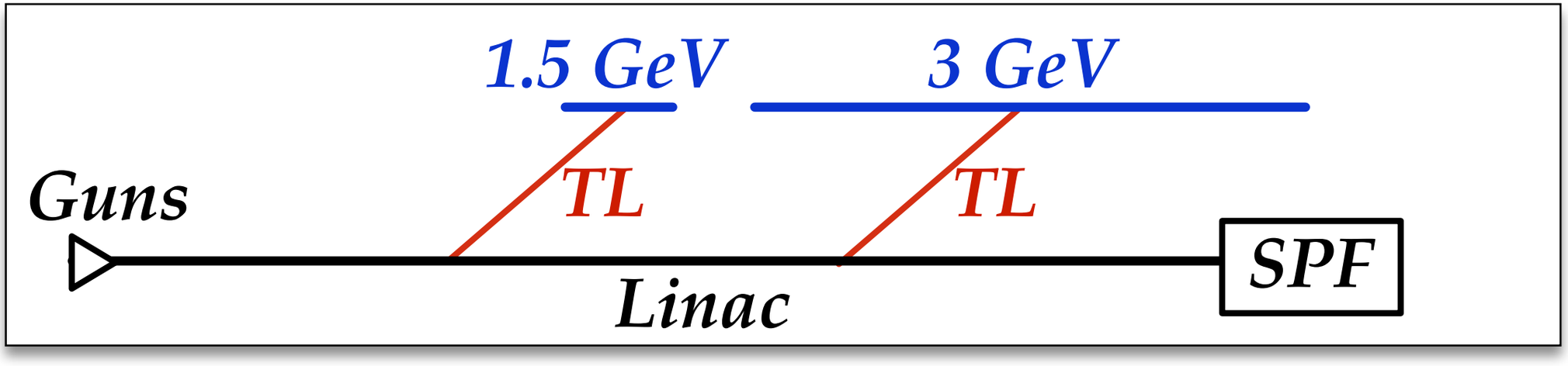
Simon C. Leemann

Workshop on Accelerator R&D for Ultimate Storage Rings, Huairou, Beijing, China, Oct 30 - Nov 1, 2012

MAX IV LABORATORY

MAX IV Injection Requirements

- Top-up injection into both MAX IV storage rings
  - –3.5 GeV linac with two extraction points
  - –two vertical (achromatic) transfer lines with two DC Lambertson septa each
  - –inject bunches with ε_n = 10 mm mrad, σ_δ = 0.1%



MAX IV Injection Requirements

- Ideally, injection should be transparent to users

  ➡tough! (~200 nm vertical stability req. in 3 GeV ring)

- Original injection scheme: local 4-kicker bump

  ➡but worried about complexity and stability

MAX IV Injection Requirements

- Ideally, injection should be transparent to users
  - ➡tough! (~200 nm vertical stability req. in 3 GeV ring)
- Original injection scheme: local 4-kicker bump
  - ➡but worried about complexity and stability
    - matching, synchronizing and aligning 4 kickers/pulsers to properly close bump
    - strong sextupoles & octupoles within bump: bump can only be properly closed for one energy and amplitude
    - 4 kickers and septum require lots of space

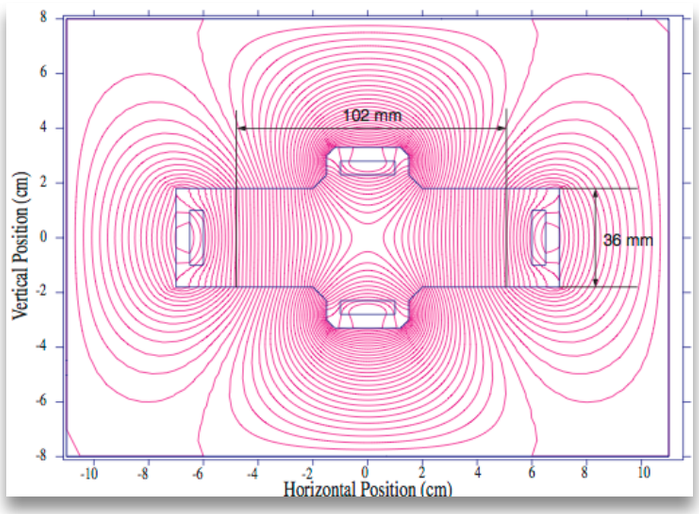
Pulsed Multipole Injection

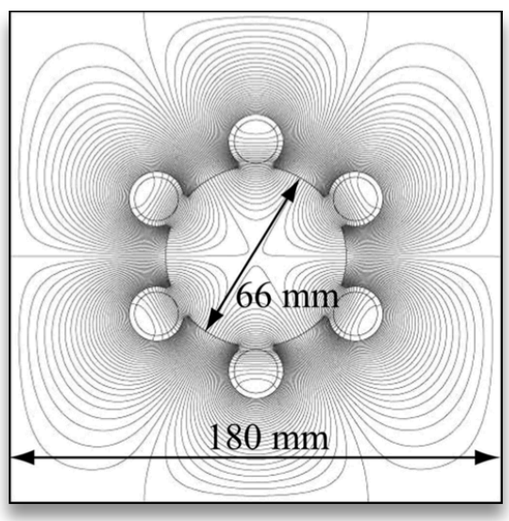
- Inspired by work at KEK on pulsed multipole injection with PQM & PSM

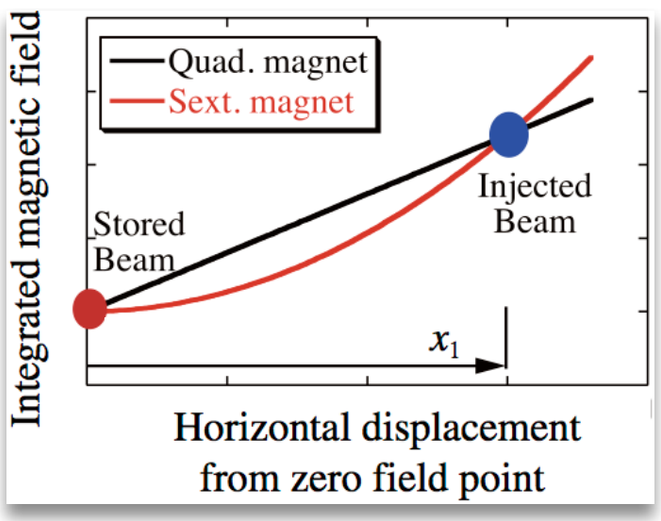
PRST-AB **10**, 123501 (2007)

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

  - –align only one magnet to stored beam
  - –synchronize only one pulser to injection
  - –minute perturbation of stored beam by PSM







Design of PSM Injection Scheme

- KEK: studied analytically (under assumption of linear optics) → ideal phase advance so that
  - –invariant of motion of injected bunch reduced to desired value

$$\frac{|x_{\mathrm{psm}}|}{\sqrt{\beta_{\mathrm{psm}}}} < A_x$$

  - –PSM strength minimized

$$(b_3 L) = \frac{\theta_{\mathrm{psm}}}{{x_{\mathrm{psm}}}^2}$$

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

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

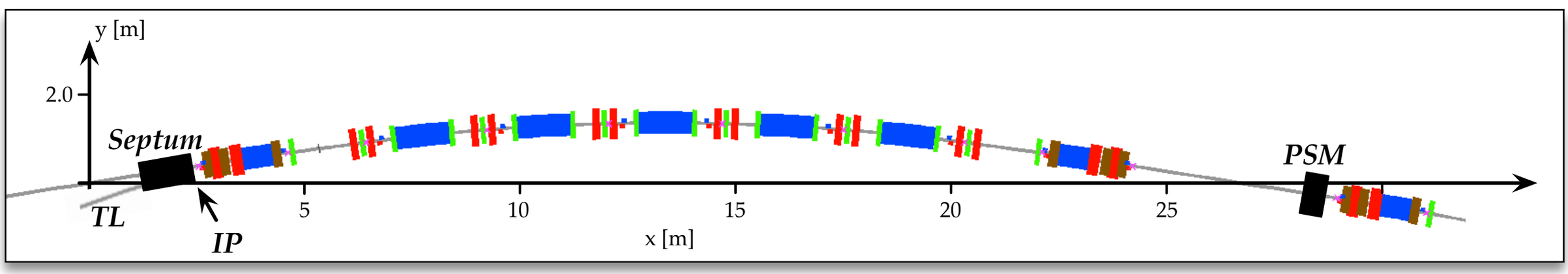
- In MAX IV storage rings strong nonlinearities require deriving exact solution from tracking studies (Tracy-3 and DIMAD)

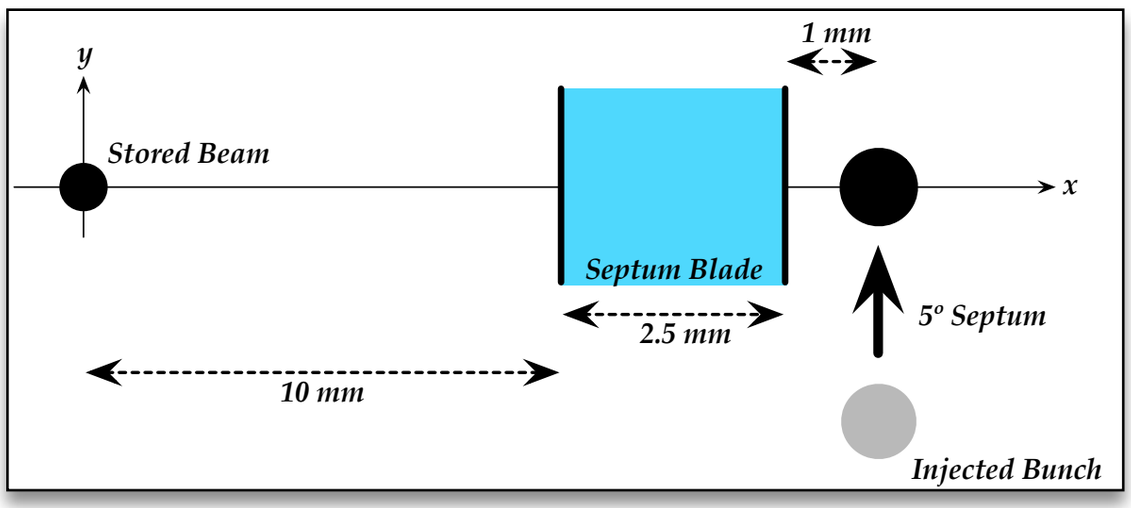
PAC'**11**, THP214, p.2522

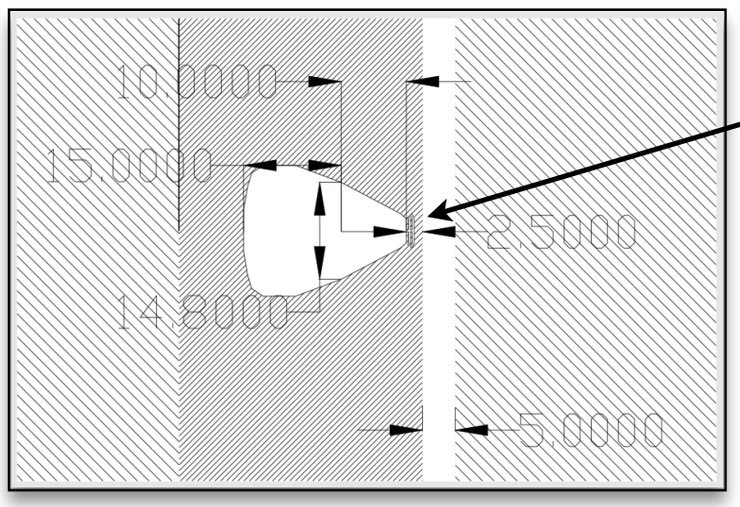
PRST-AB **15**, 050705 (2012)

PSM Injection for the 3 GeV Ring

- Injection geometry & septum







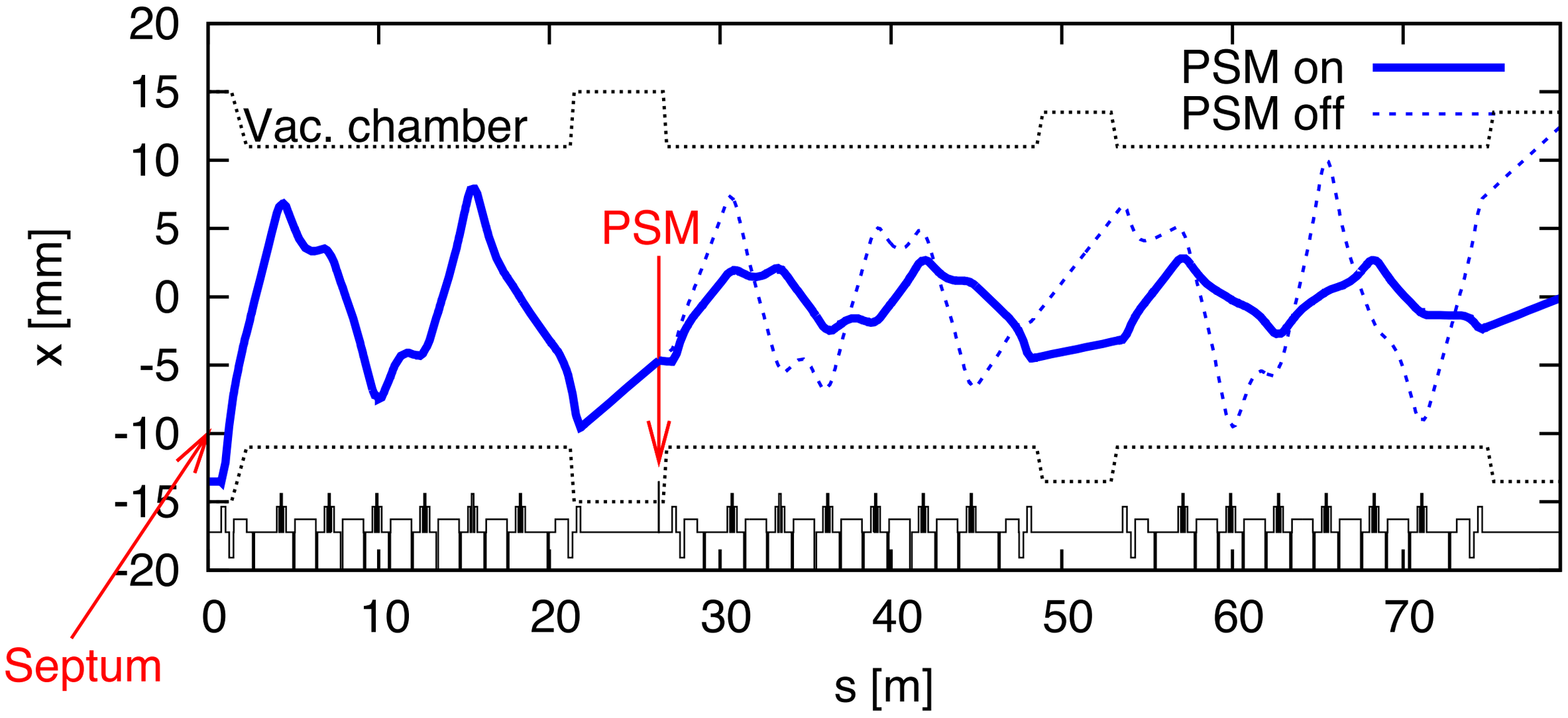
septum nose with filter

NIM-A **490**, 592, 2002

NIM-A **547**, 686, 2005

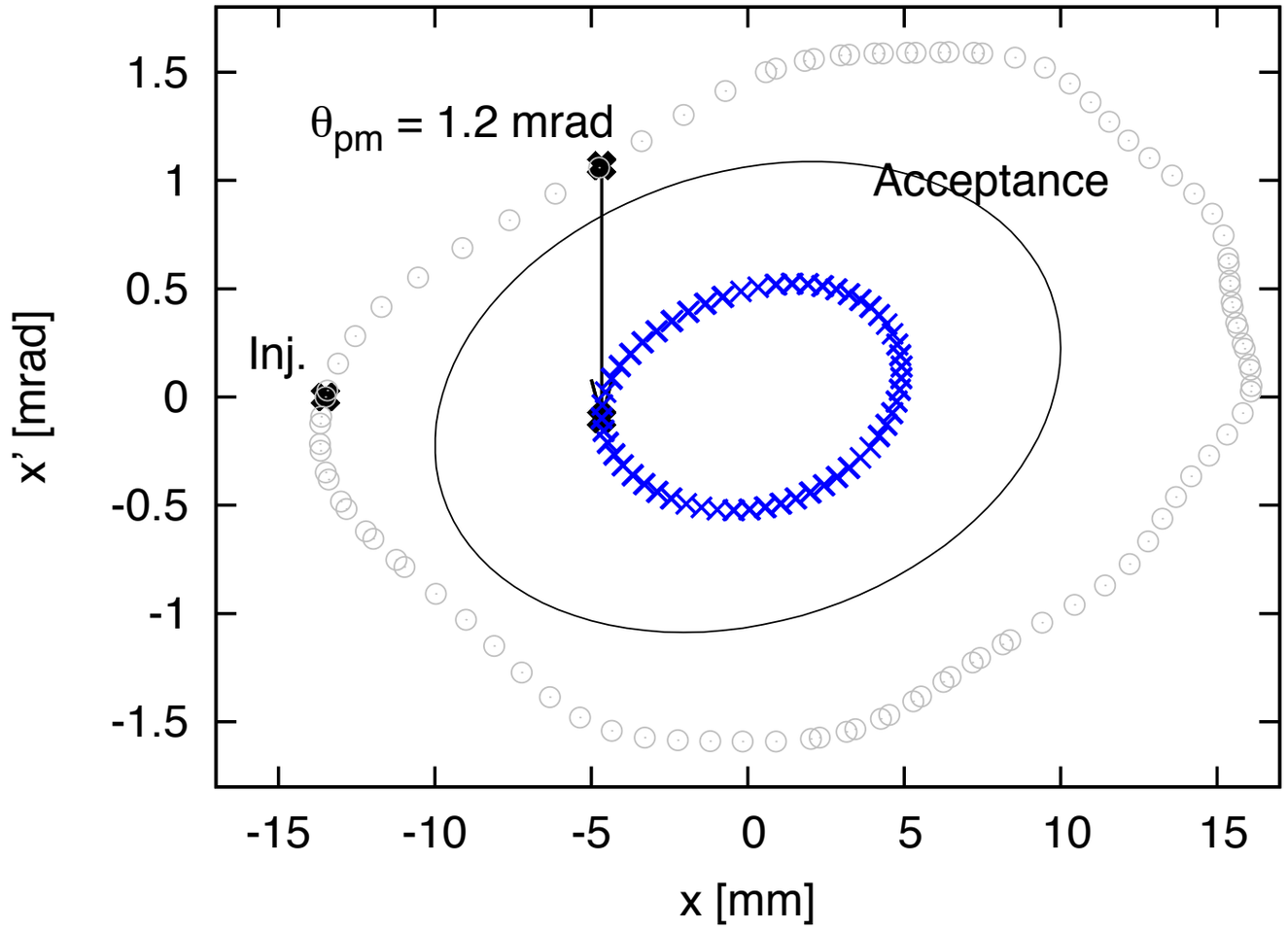
PSM Injection for the 3 GeV Ring

- Injection orbit



PSM Injection for the 3 GeV Ring

- Injection & capture in phase space

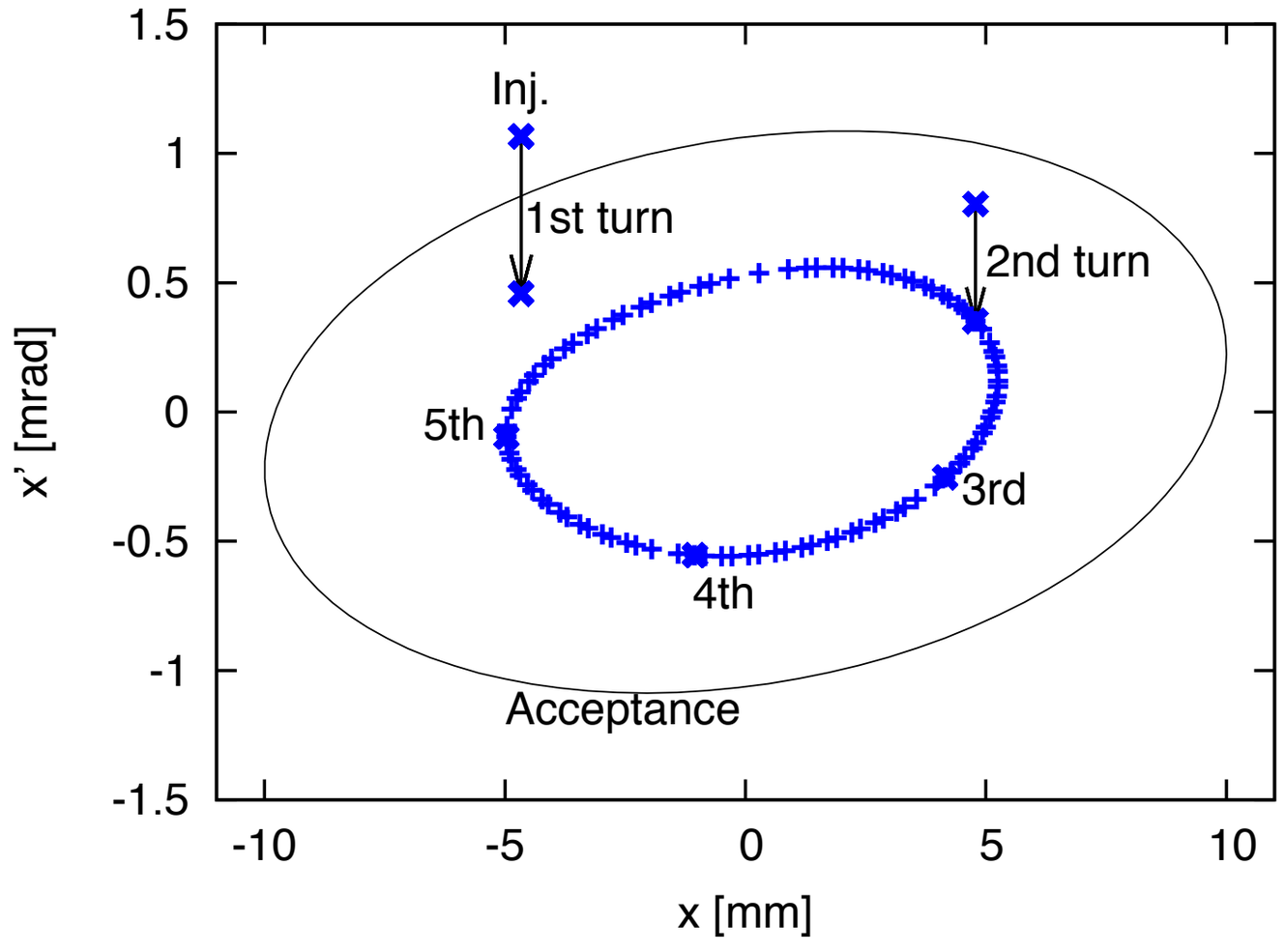


- ~1.2 mrad to minimize reduced invariant

- ~0.8 mrad sufficient for capture within (design) acceptance

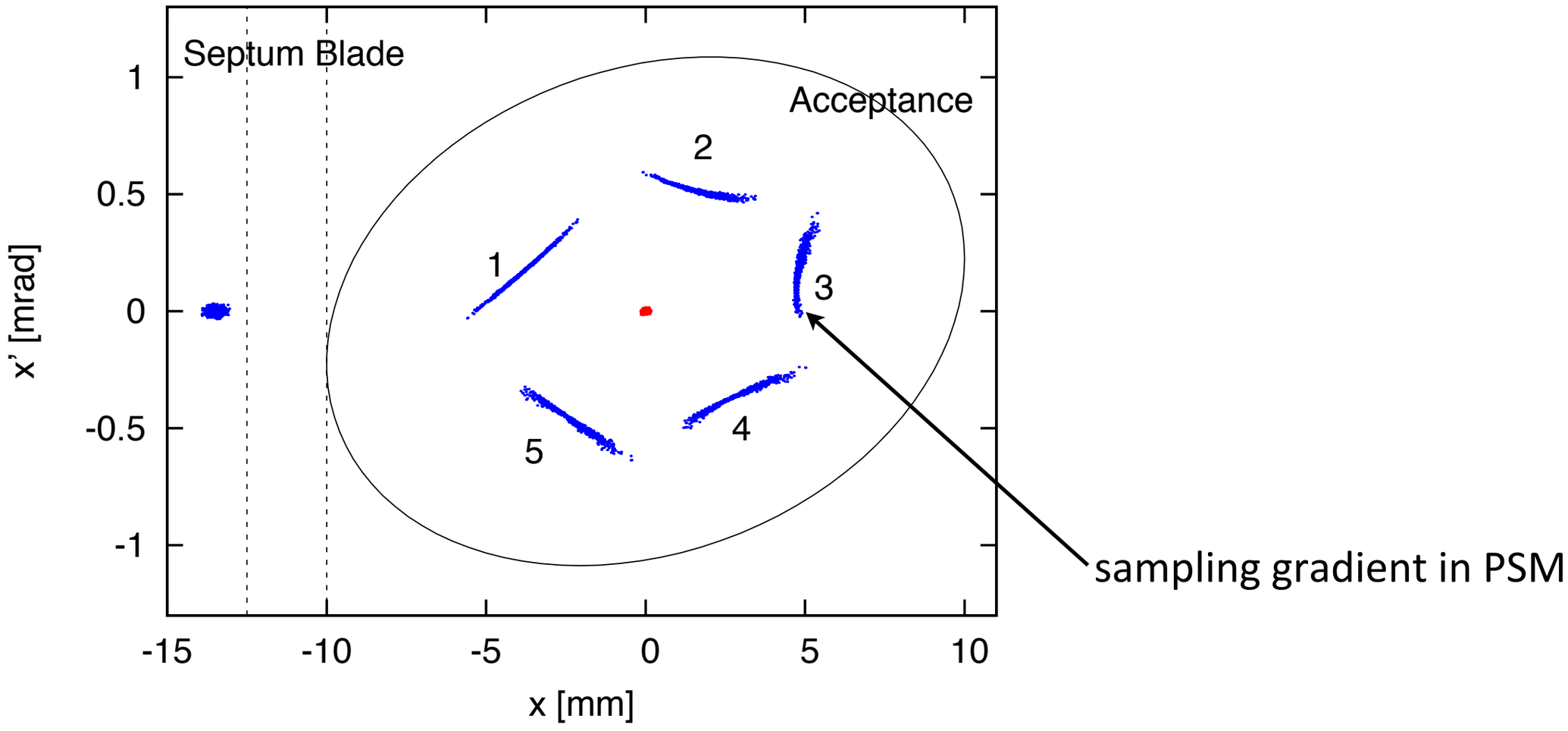
PSM Injection for the 3 GeV Ring

- Two-turn option → increase pulse duration and/or reduce required PSM strength



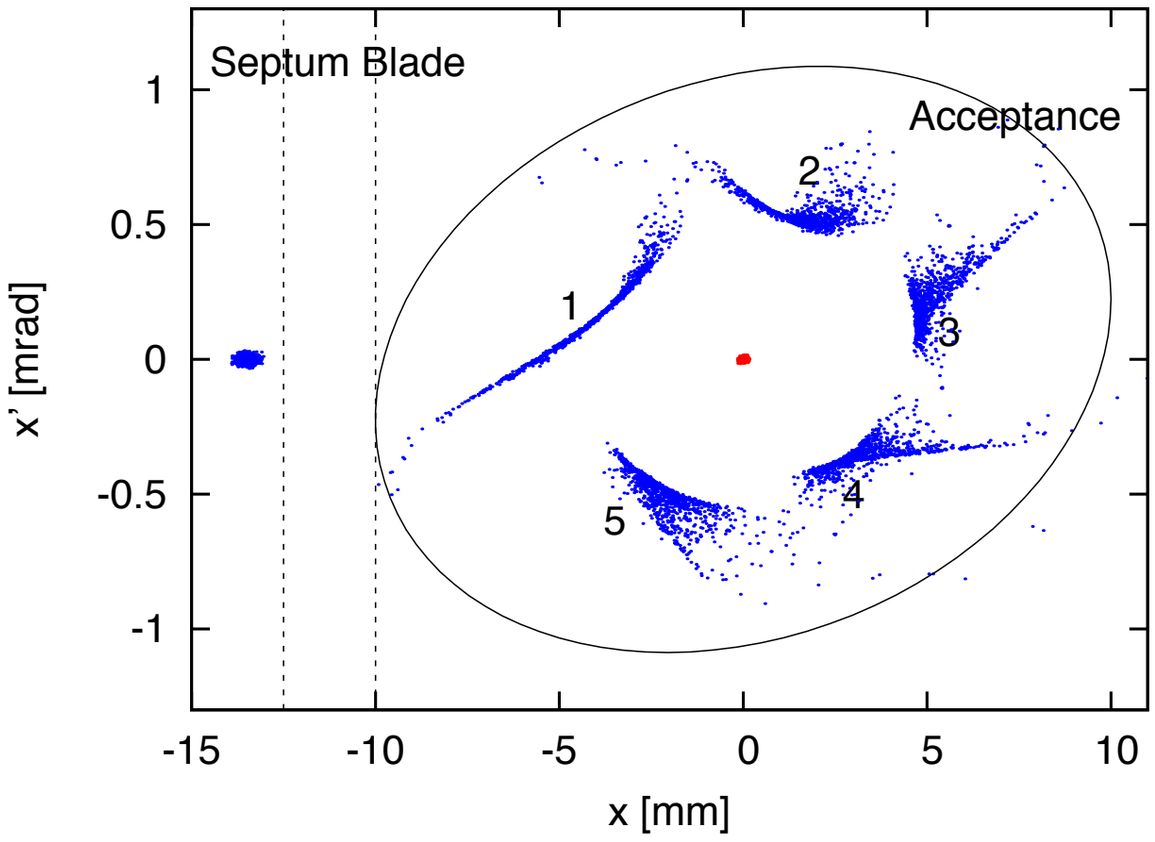
Injection & Capture Efficiency

- Design injection ensures high efficiency

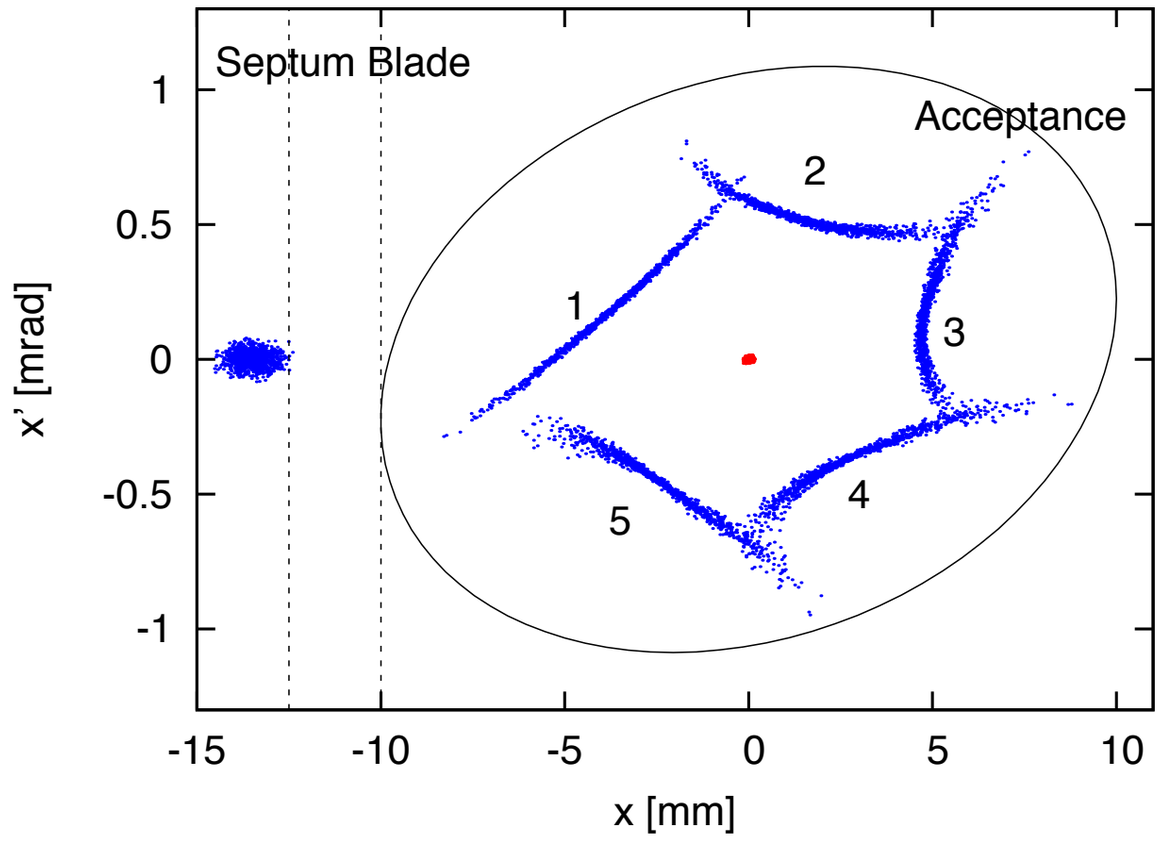


Injection & Capture Efficiency

- Design includes significant margin for error



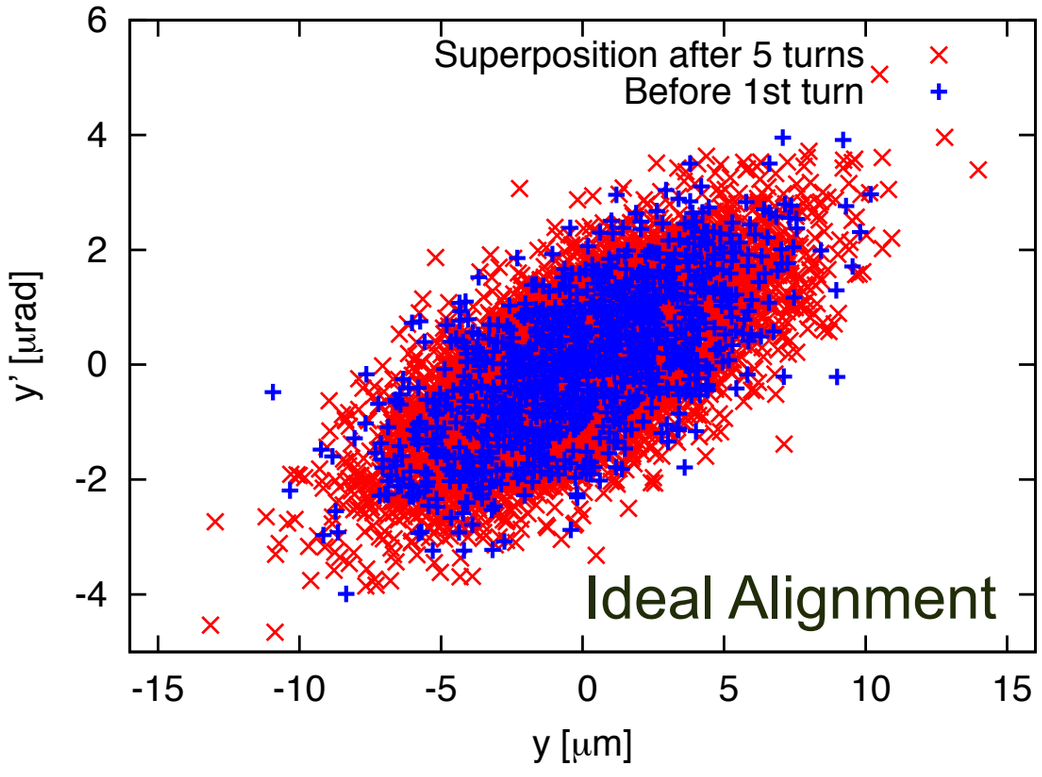
$\sigma_\delta \rightarrow 8\times\sigma_\delta$

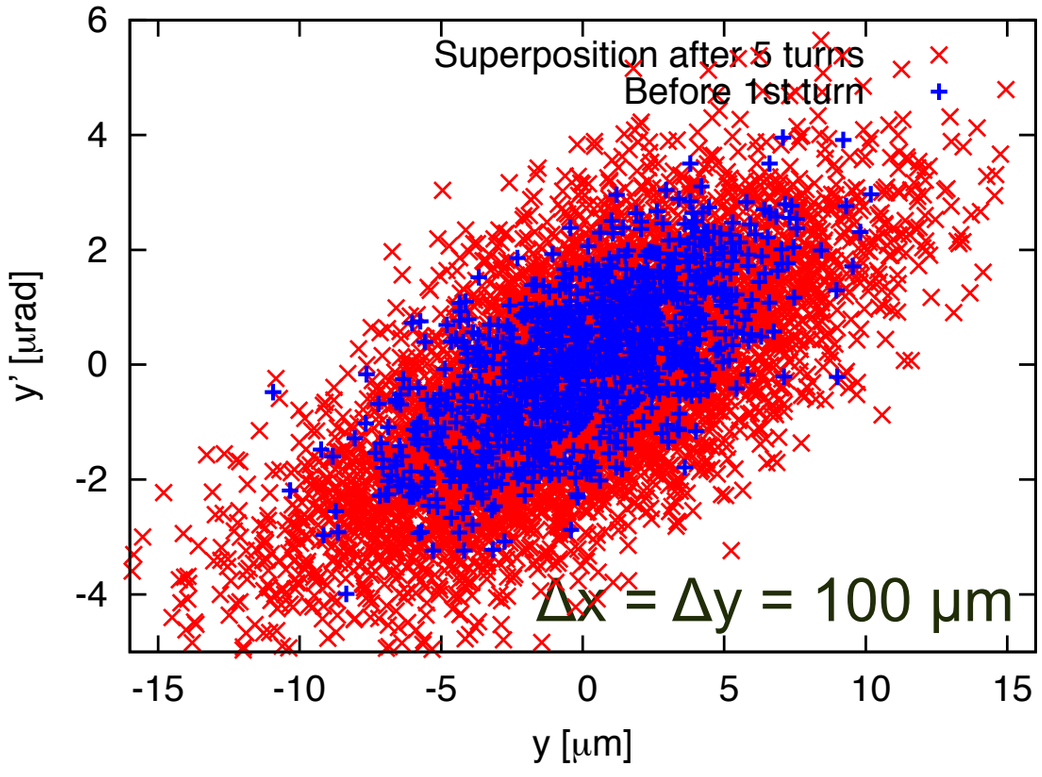


$\varepsilon_n \rightarrow 6\times\varepsilon_n$

Requirements & Tolerances

- If PSM properly aligned effect on stored beam is indeed negligible, but tolerances are tight





Requirements & Tolerances

- Alignment & residual field tolerances

3 GeV, H residual dipole field	< 1 μT m
3 GeV, V residual dipole field	< 5 μT m
3 GeV, H misalignment	< 96 μm
3 GeV, V misalignment	< 10 μm
3 GeV, H angular acceptance at IP	± 0.1 mrad
1.5 GeV, H residual dipole field	< 1.5 μT m
1.5 GeV, V residual dipole field	< 15 μT m
1.5 GeV, H misalignment	< 202 μm
1.5 GeV, V misalignment	< 10 μm
1.5 GeV, H angular acceptance at IP	± 0.2 mrad

Limit perturbations to stored beam

Accurate V alignment

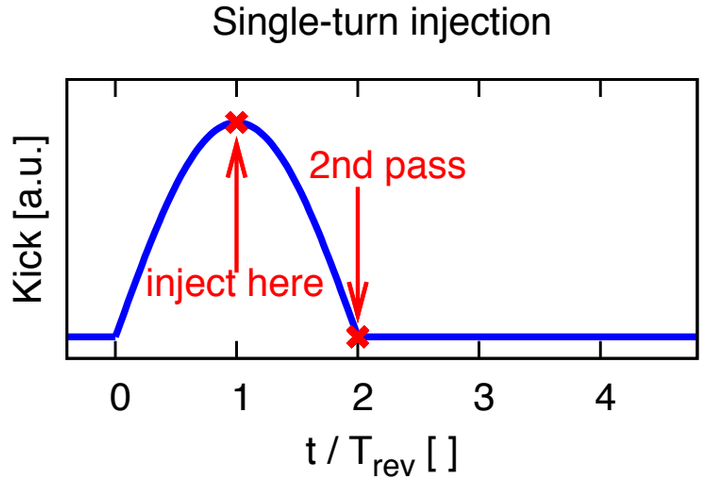
rely on OFB & beam-based (re-)alignment (→ girder design!)

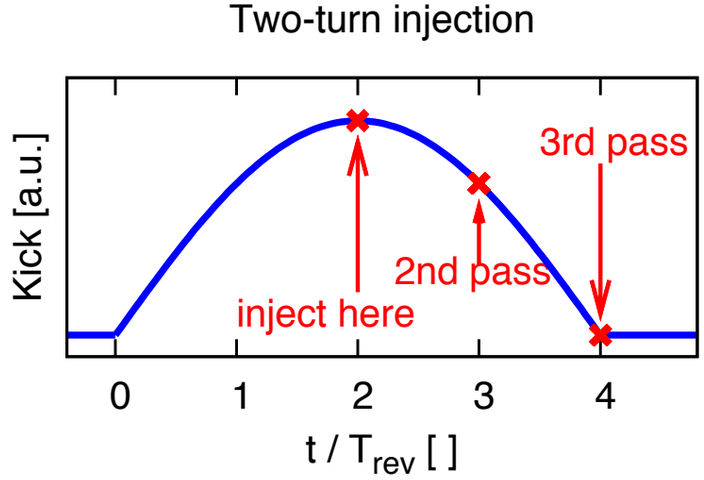
Requirements & Tolerances

- PSM requirements

	B'' [T/m^2]	L [m]	τ [μs]
3 GeV PSM, nominal	3575	0.3	< 3.5
Reduced kick	2420	0.3	< 3.5
Two-turn injection	1867	0.3	< 7
1.5 GeV PSM, nominal	1847	0.4	< 0.64
Reduced kick	665	0.4	< 0.64
Two-turn injection	1847	0.4	< 1.28
Two-turn, reduced kick	1475	0.4	< 1.28

very short pulse

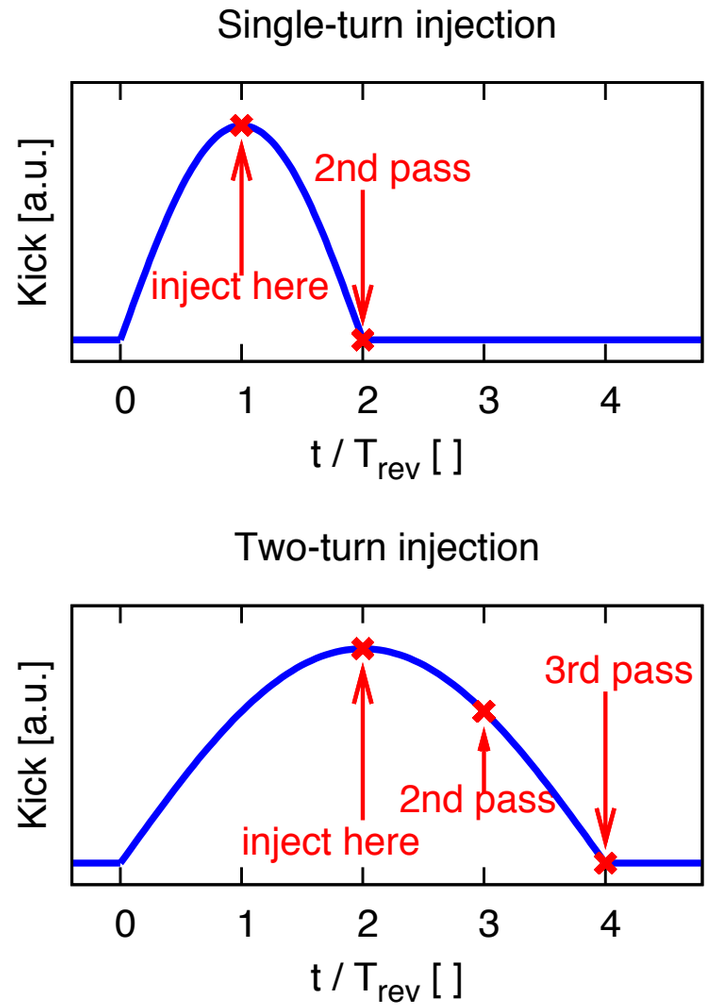




Requirements & Tolerances

- Pulser and timing issues

	3 GeV PSM	1.5 GeV PSM
Pulse length, nominal	< 3.5 μs	< 640 ns
Pulse length, two-turn injection	< 7 μs	< 1.28 μs
Fall time	< 1.8 μs	< 320 ns
Amplitude jitter	±0.1%	
Long-time amplitude drift	< 1%	
Maximum repetition rate	10 Hz	

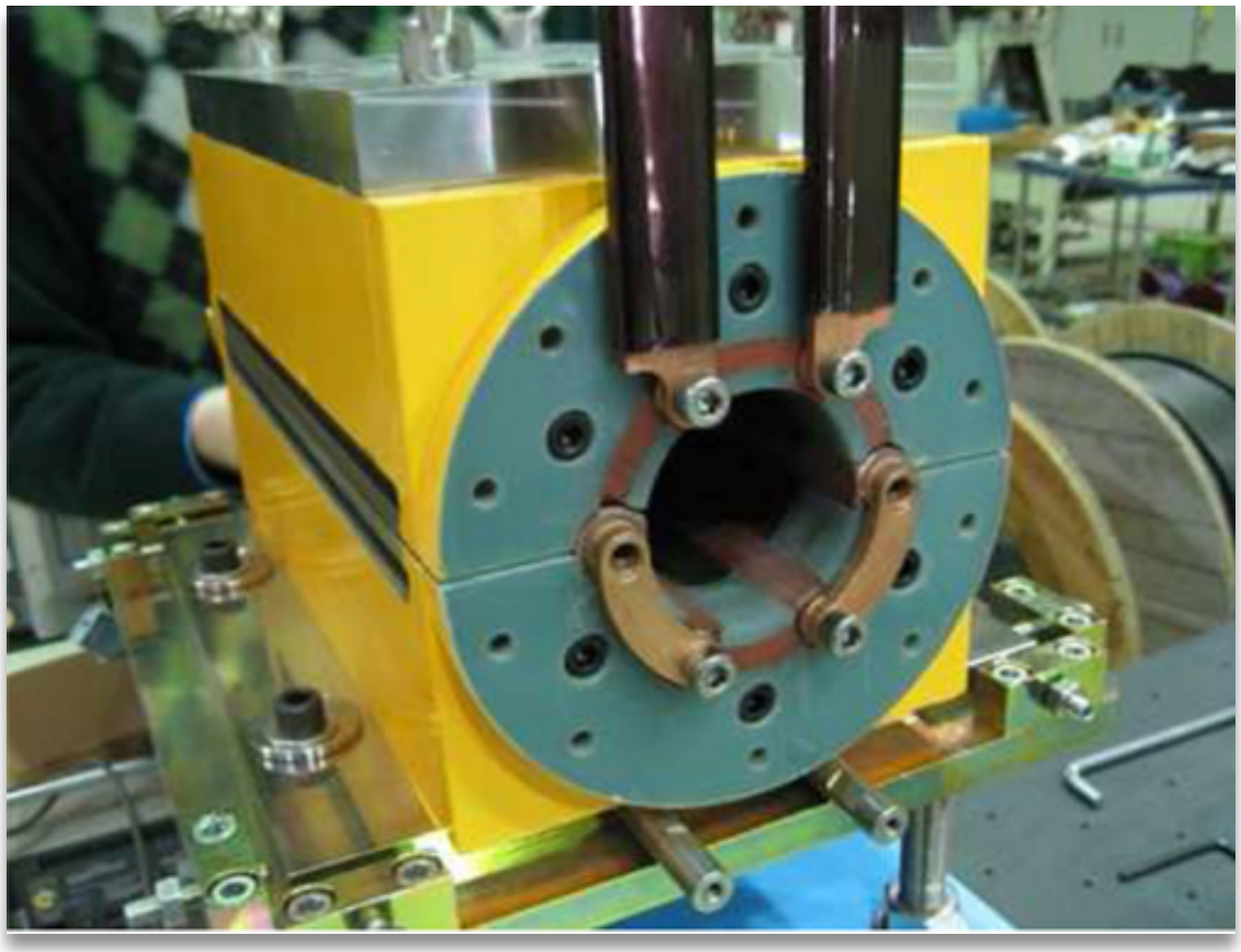


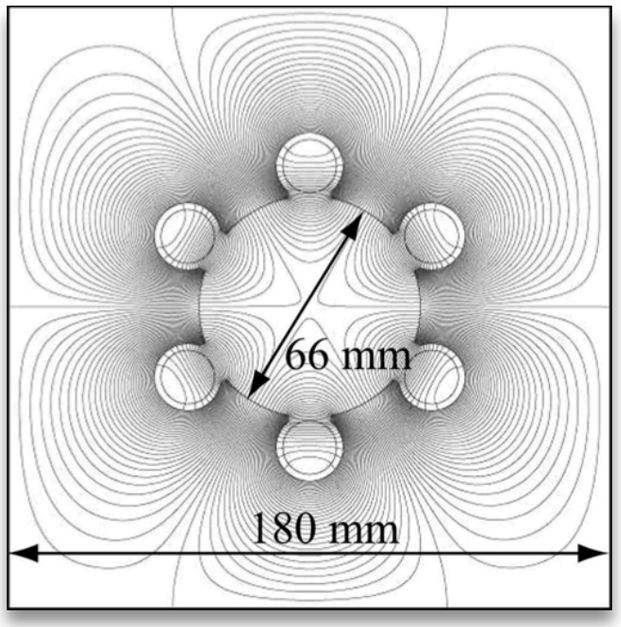
Limited energy acceptance at injection → limited phase acceptance → 3 linac bunches (3 GHz) can be injected into 1 storage ring bucket (100 MHz)

→ Maximum train for injection: 10 × 3 × 100 pC at 10 Hz (3 GeV ring: Q_{tot} = 881 nC)

Technical Design Issues

- KEK designed PSM with 66 mm bore





~1.4 mrad at 15 mm

~0.2 T pole-tip field

3000 A peak current
~19 J stored energy

→ ~34 kV for 1.2 µs pulse

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

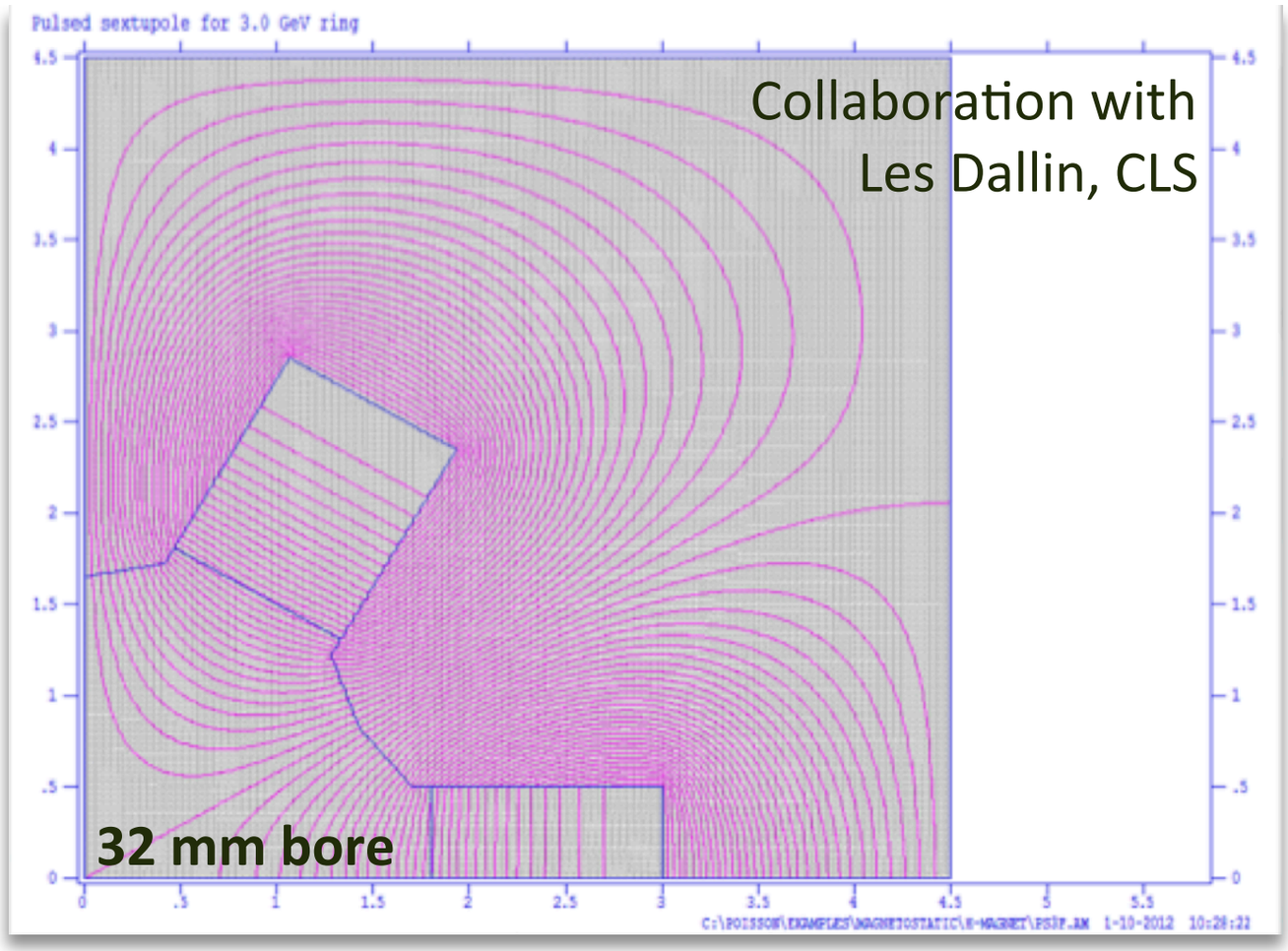
Technical Design Issues

- Short pulses @ MAX IV → need to reduce stored energy → reduce cross section

~1.2 mrad at 4.7 mm

~0.5 T pole-tip field

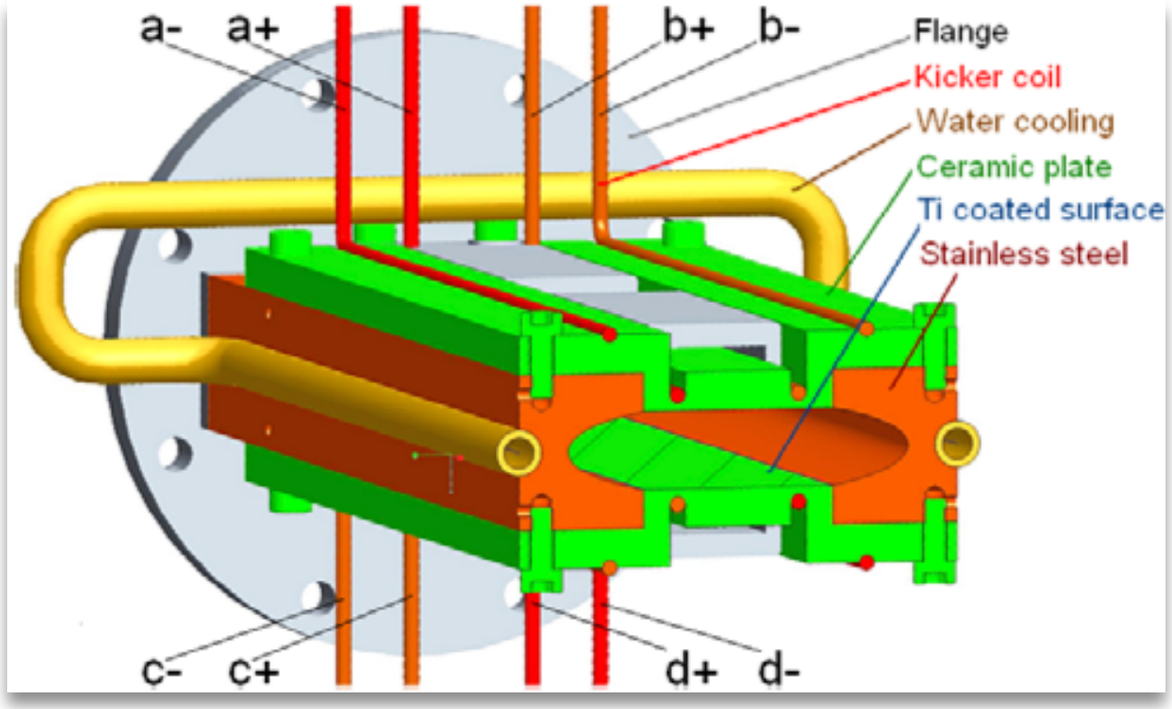
2171 A / 4342 A peak current
~21 J stored energy
→ ~16 kV / 8 kV for 3.5 µs pulse

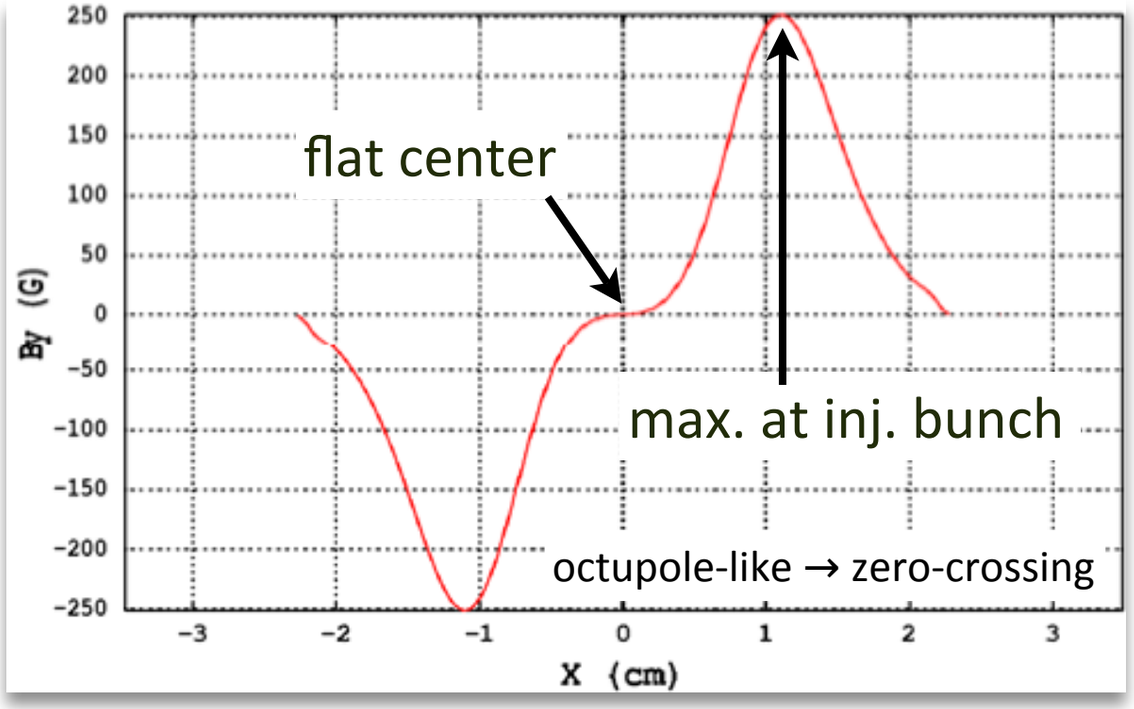


Technical Design Issues

- Alternative: nonlinear kicker magnet design recently developed for BESSY II
  - ➡Olaf Dressler's presentation

IPAC'11, THPO024, p.3394

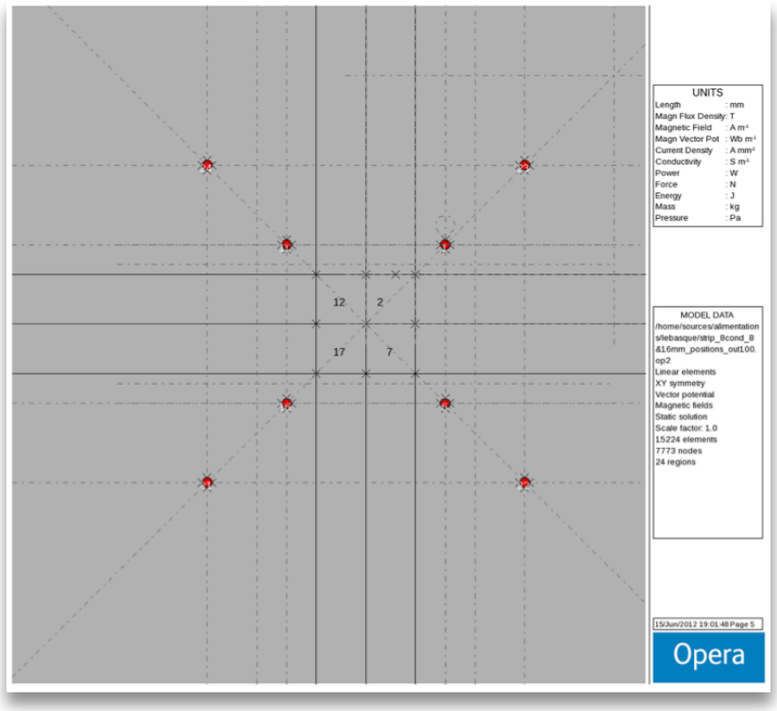


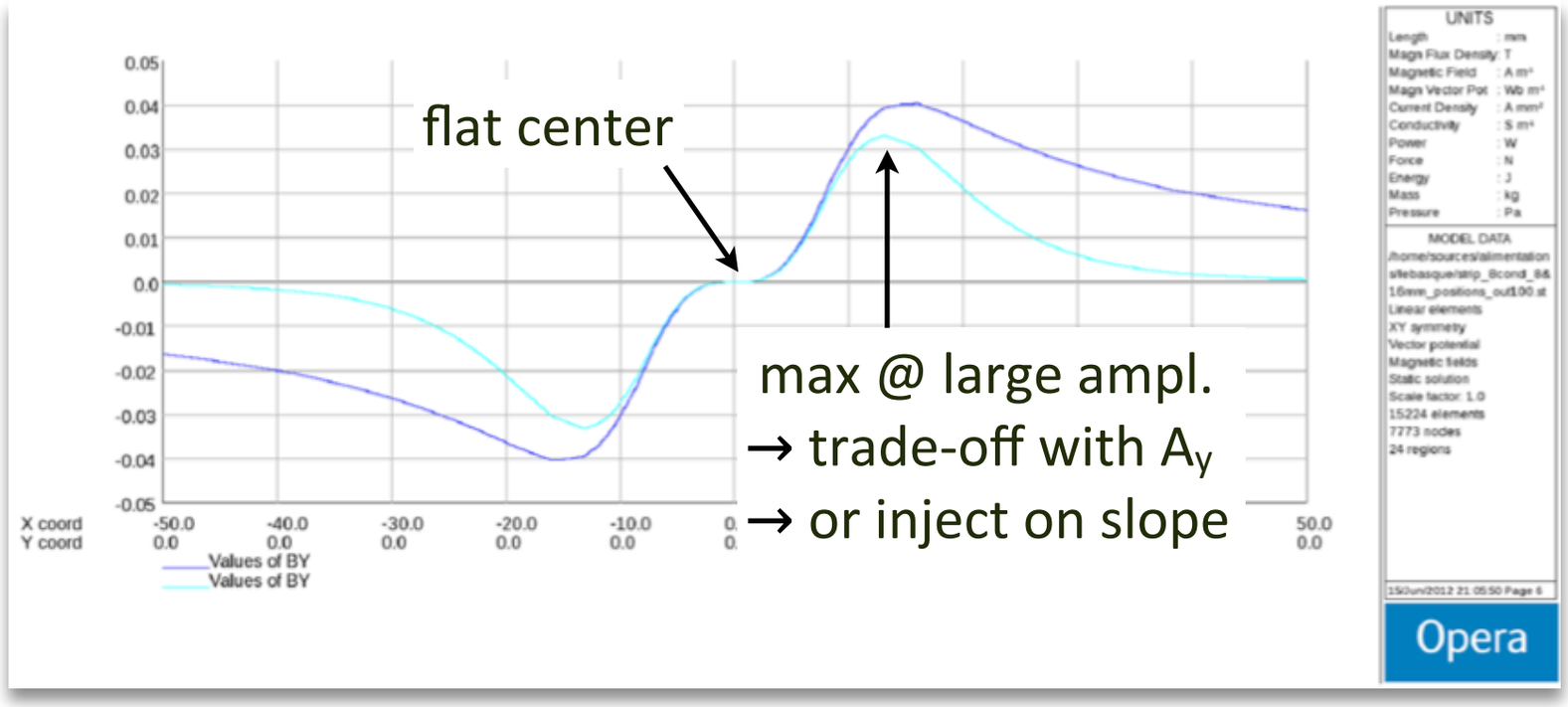


Technical Design Issues

- Entered collaboration with SOLEIL
  - –adapting BESSY II design to MAX IV requirements
  - –comparing with “conventional” PSM design

P. Lebasque, SOLEIL





Outlook

- Confident we will find a technical solution for a pulsed multipole magnet in both MAX IV rings
  - fall-backs: two-turn injection, reduced kick

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  - –fall-backs: two-turn injection, reduced kick

➡MAX IV rings will not use 4-kicker bump injection

➡Only one dipole kicker will be installed per ring
  - –simple injection during early commissioning
  - –later: serves as horizontal pinger magnet

NIM-A **693**, 117, 2012