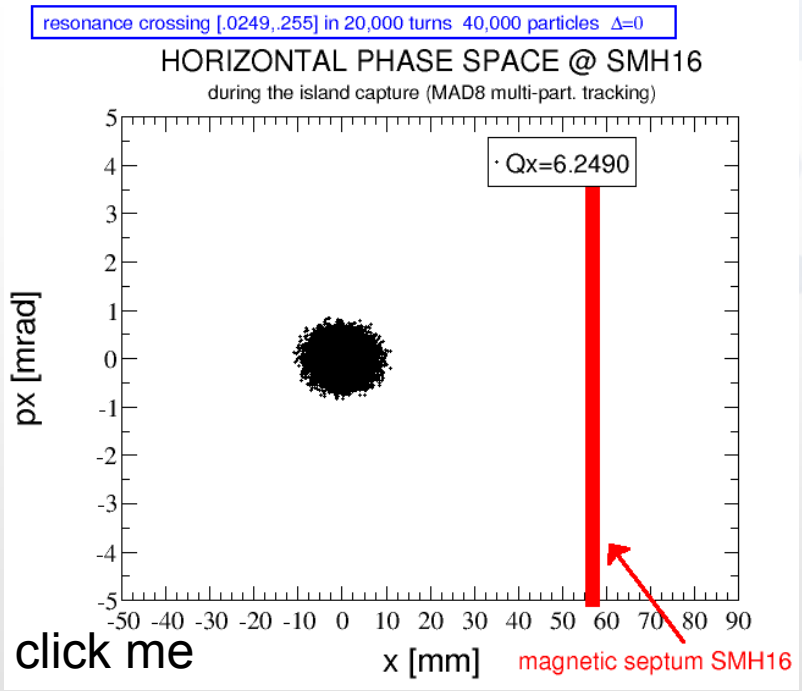
Can we inject or extract a beam without magnetic septa?

Andrea Franchi (ESRF)
Massimo Giovannozzi (CERN)

AOC workshop, CERN, 5-6 January 2015

On-axis inj/ext without septum magnets



Multi-Turn Extraction @ CERN PS

- ¼ horizontal resonance crossed
- beam split into 4 islands + core
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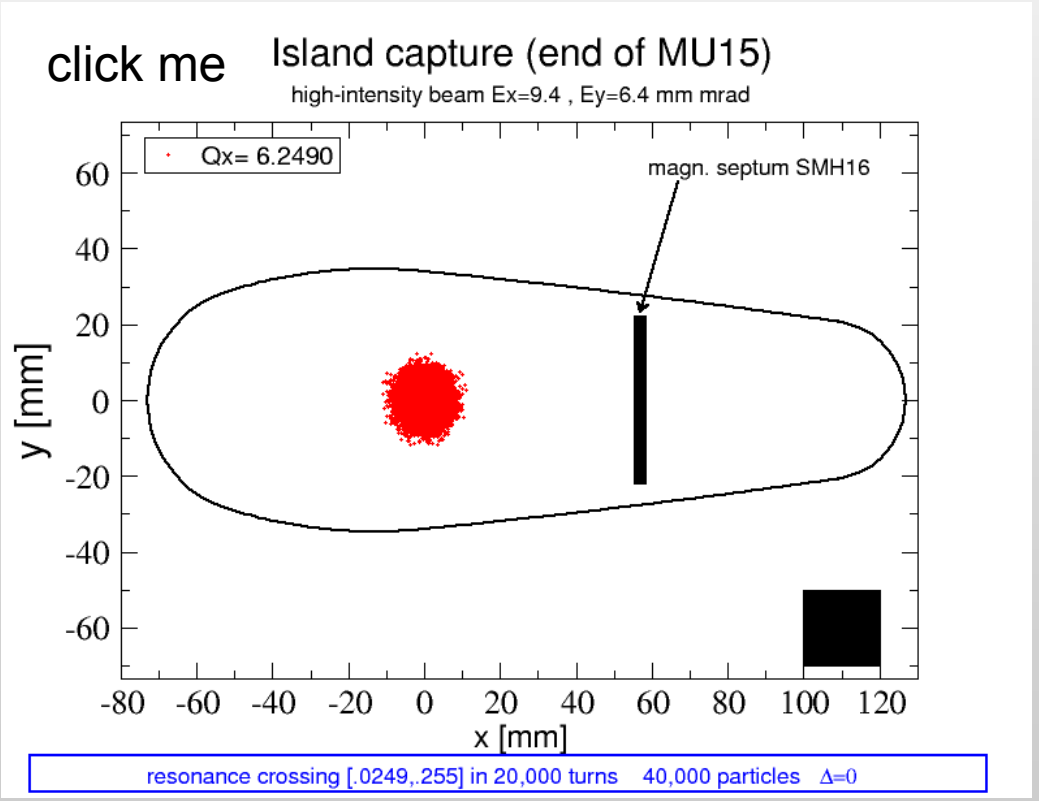

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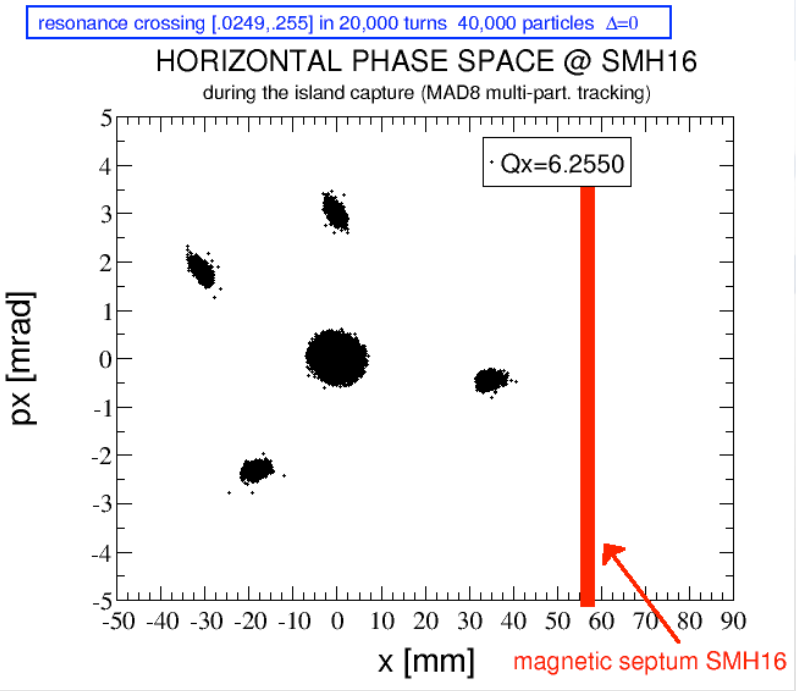

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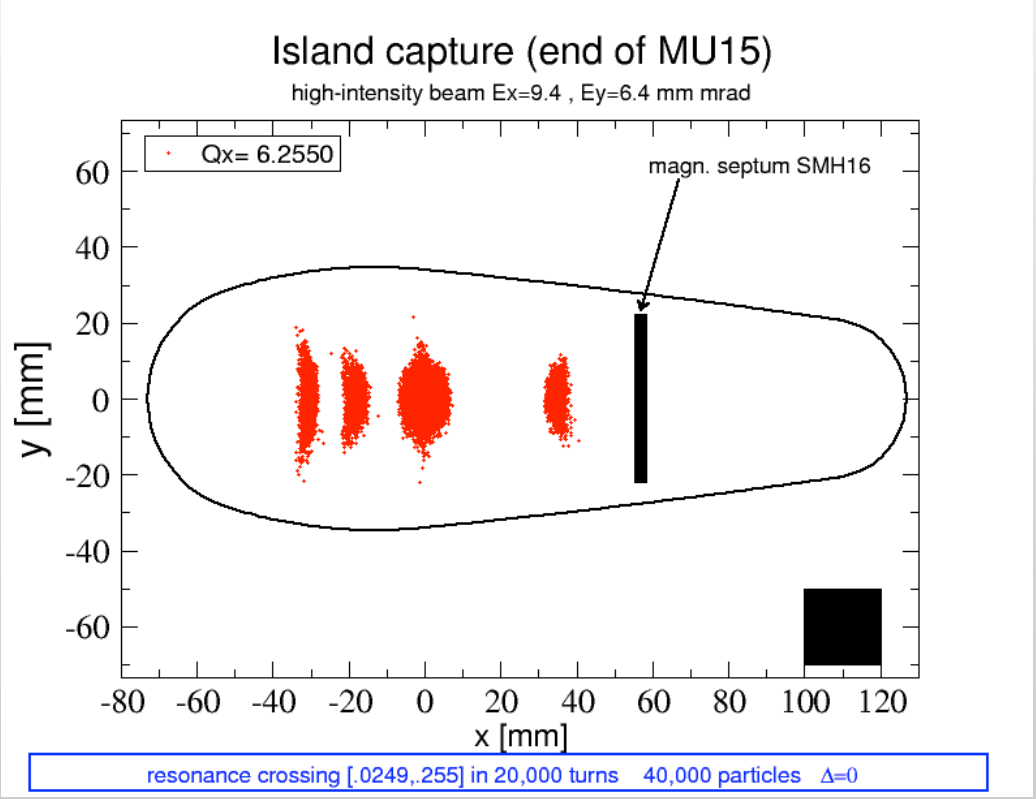

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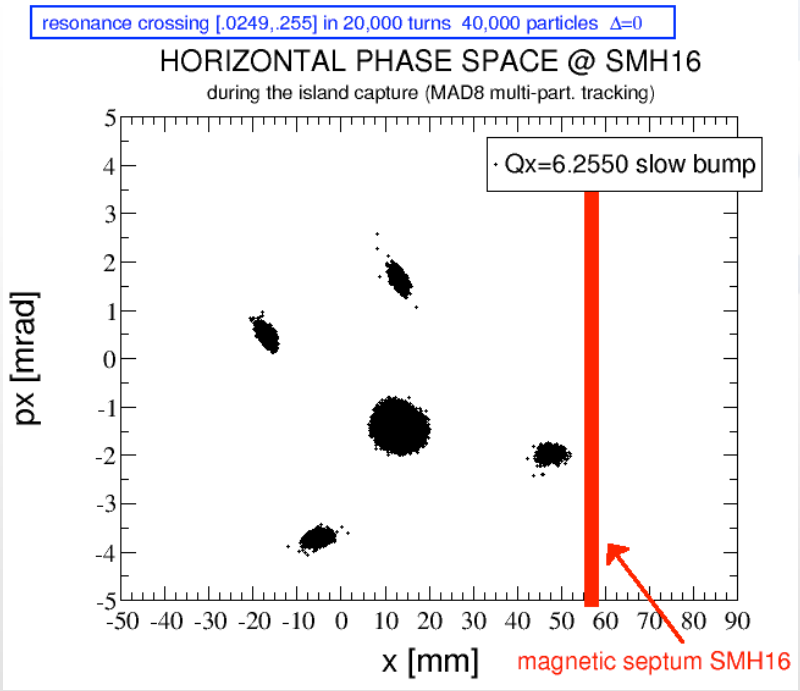

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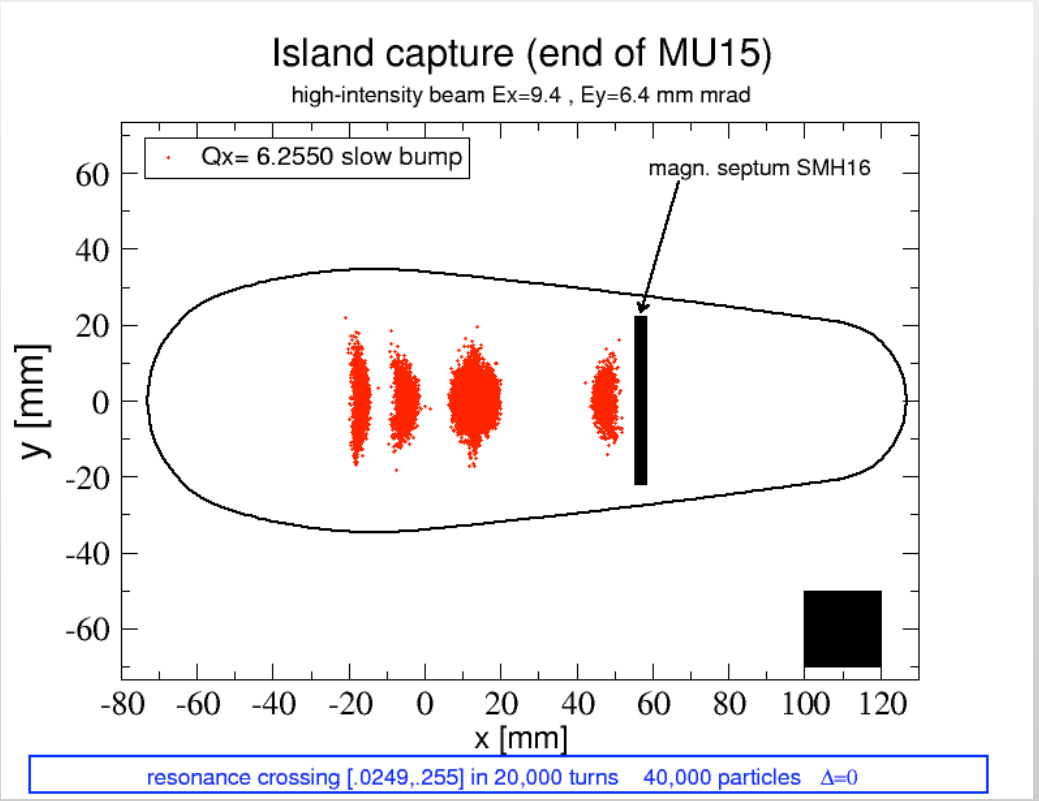

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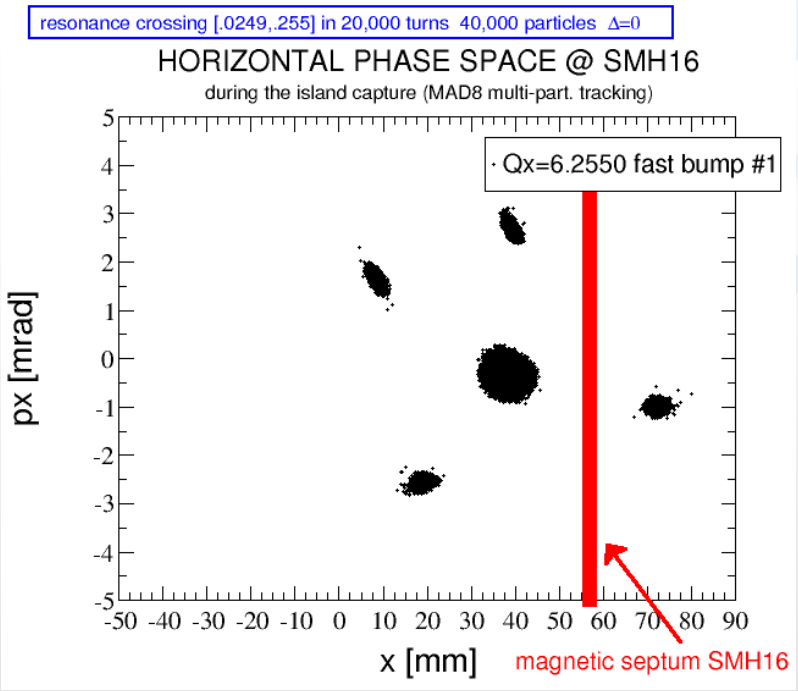

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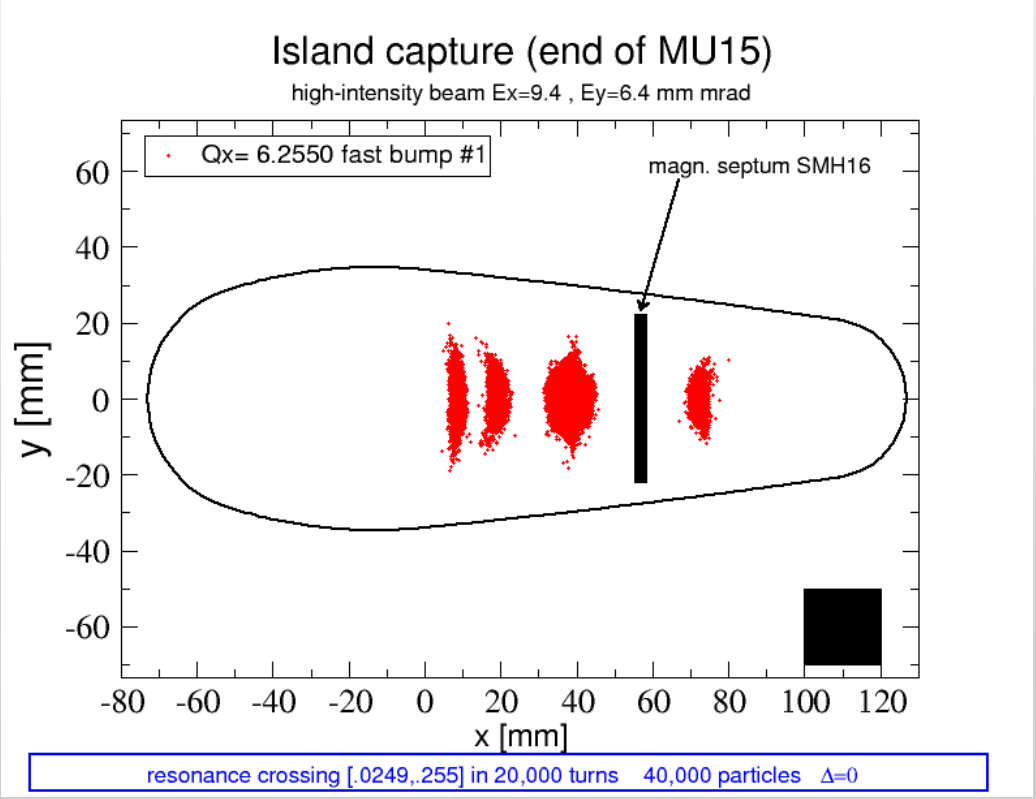

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Extraction: magnetic septum
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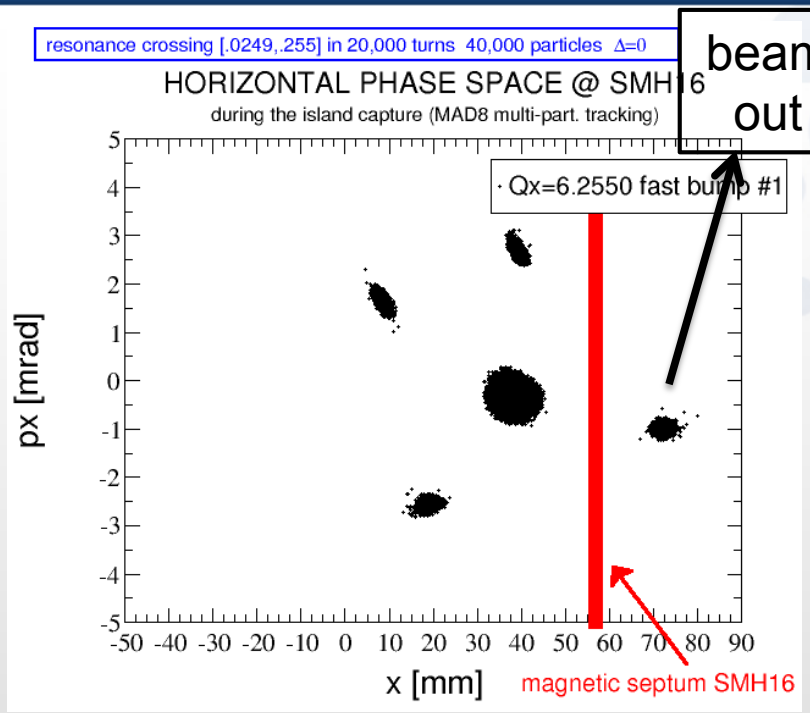

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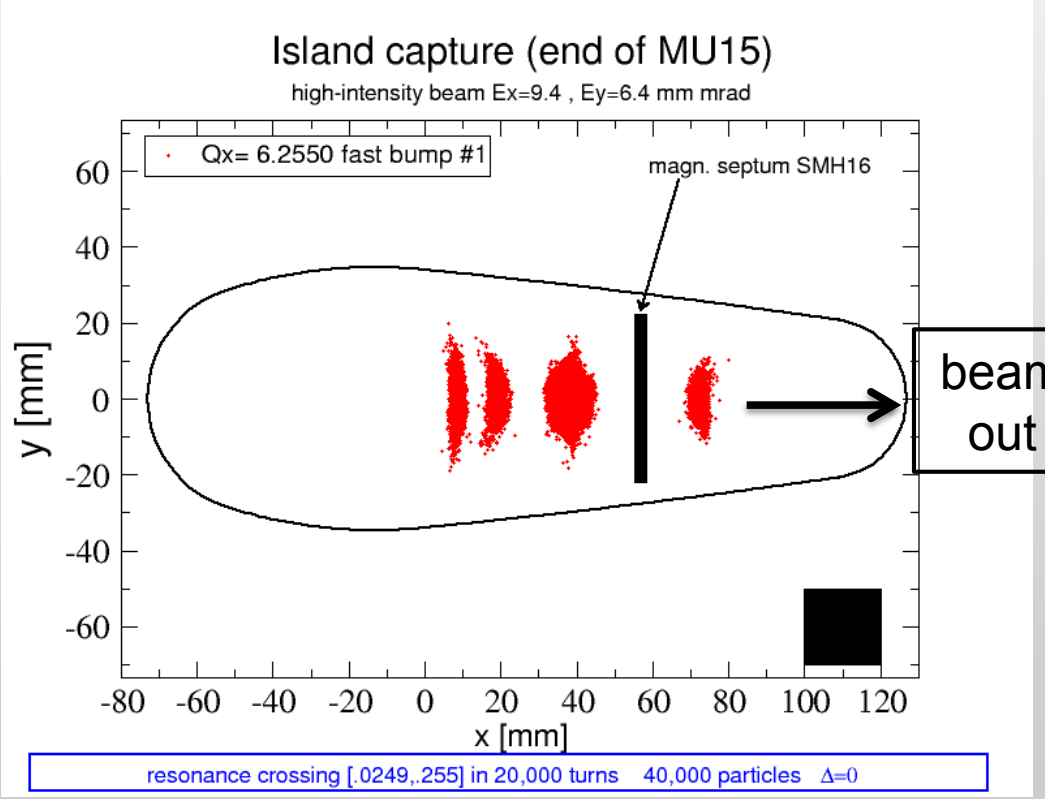

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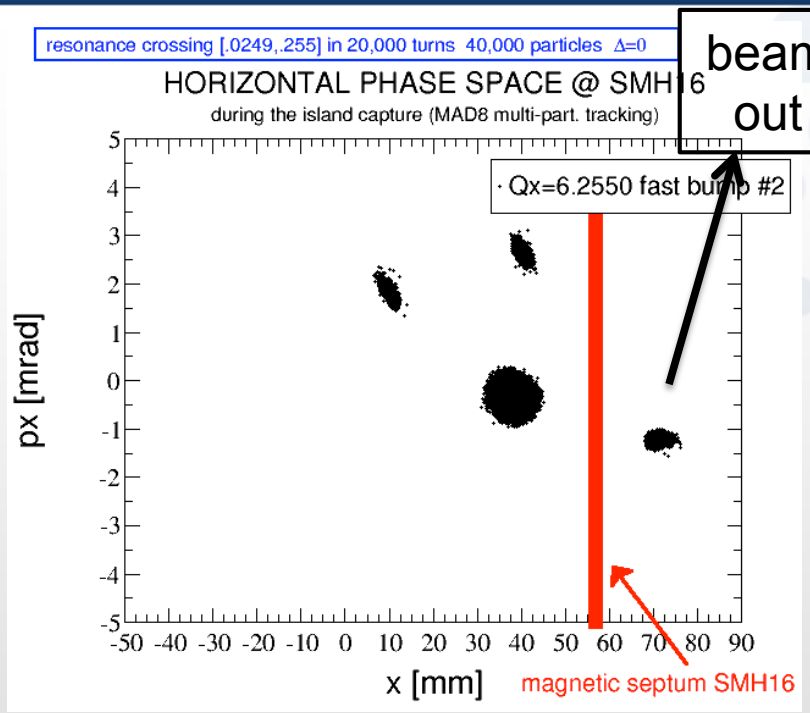

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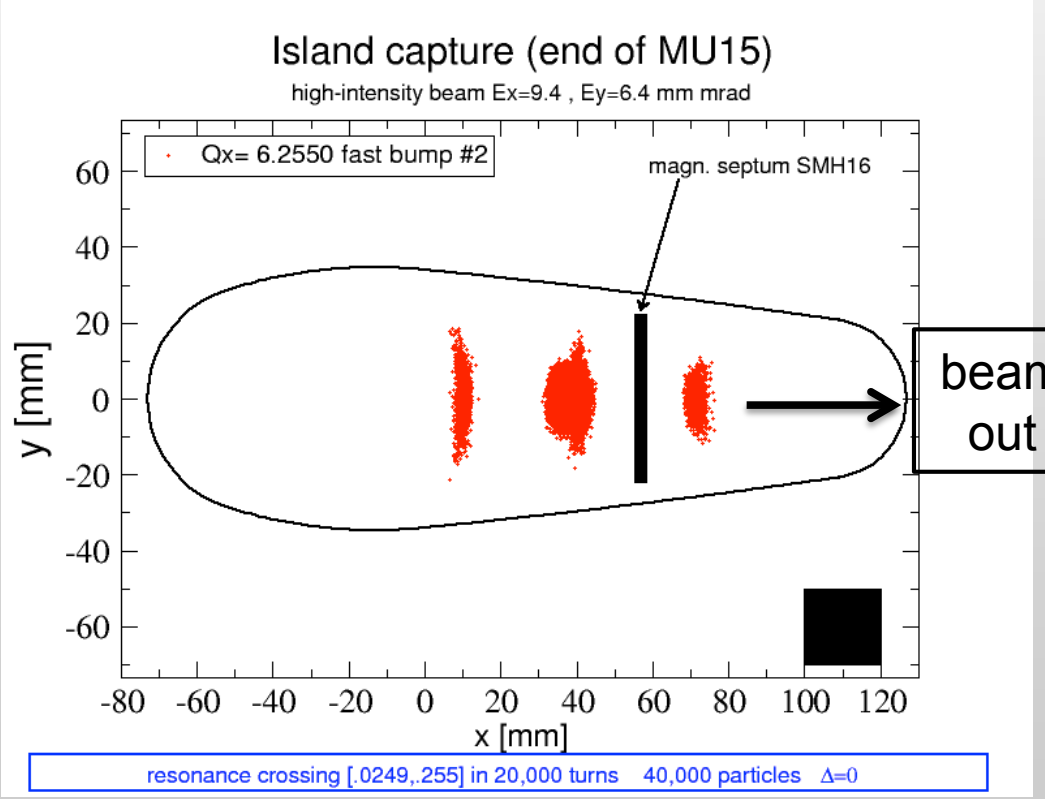

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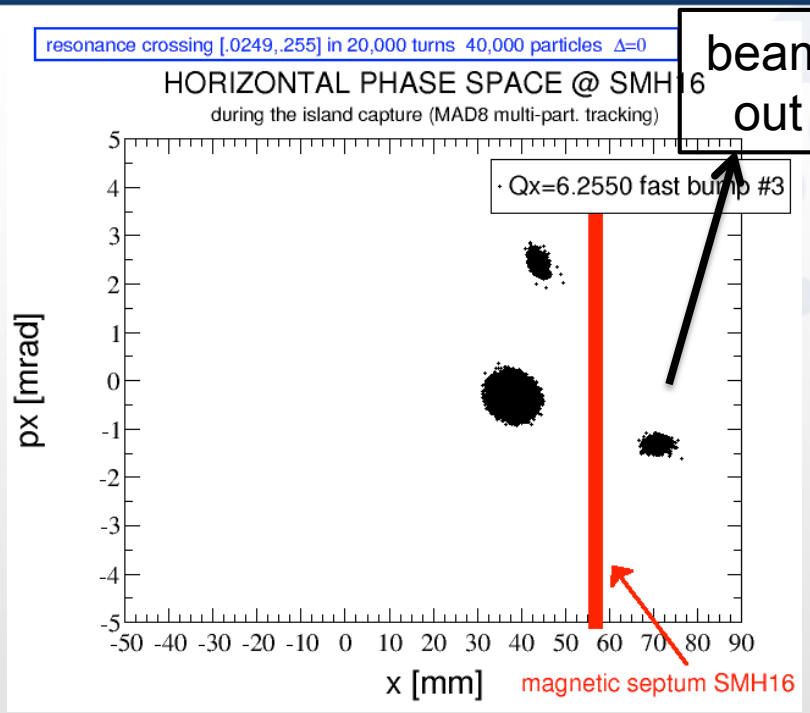

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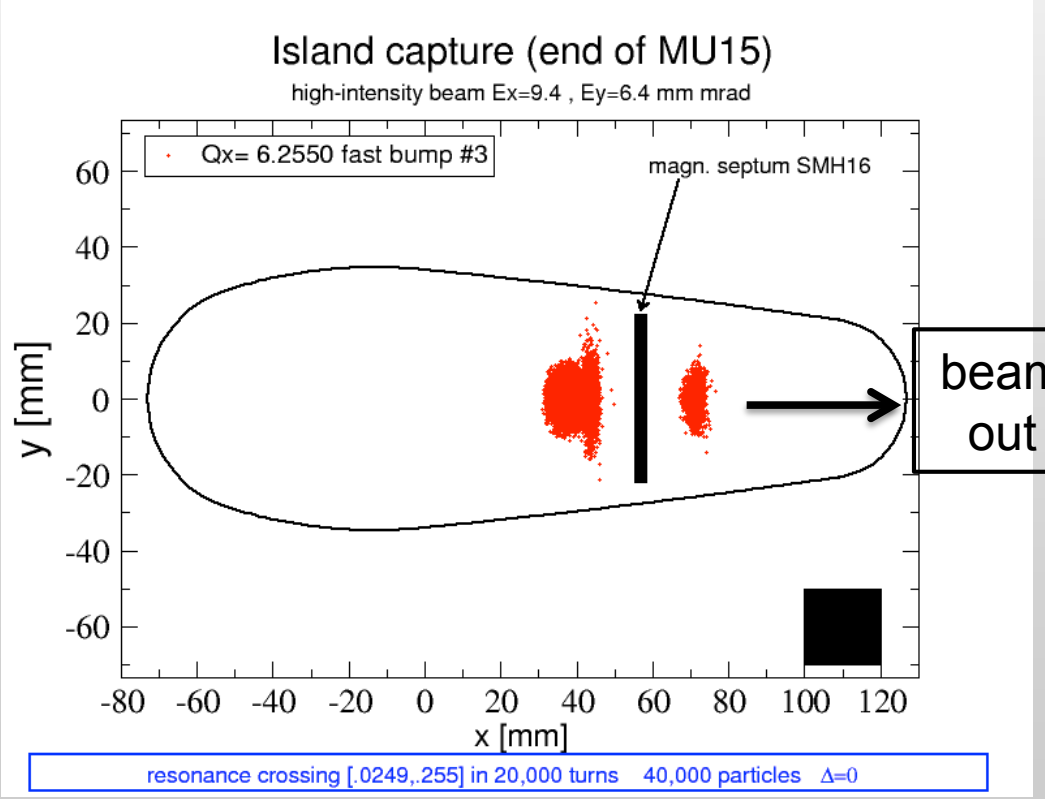

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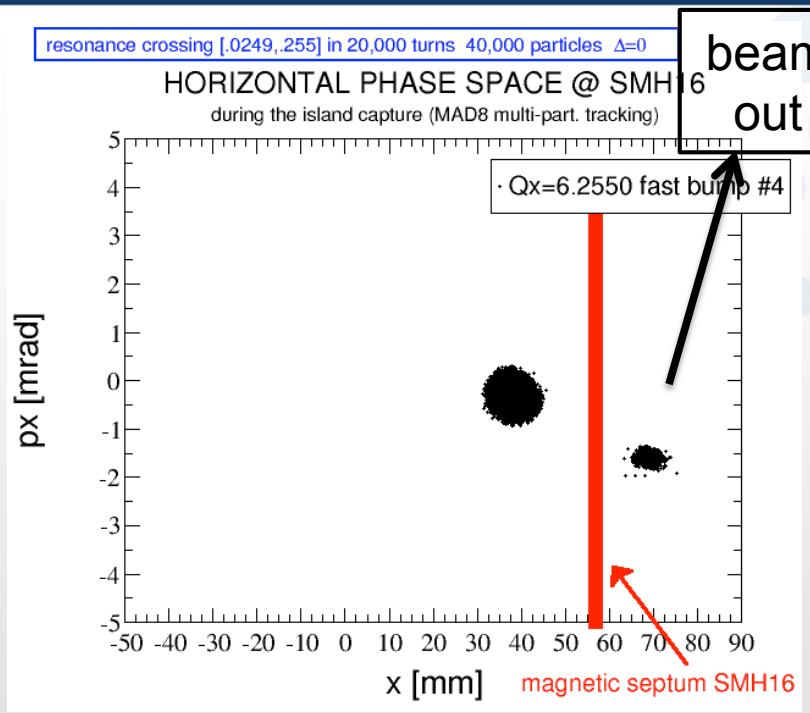

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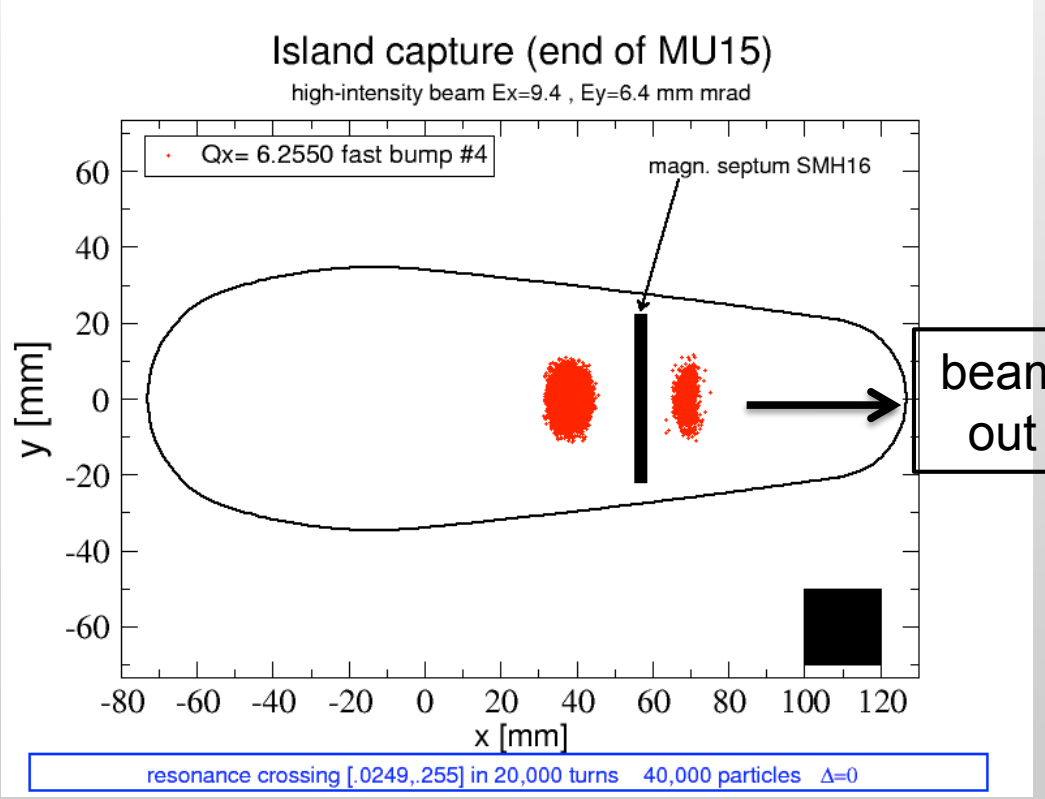

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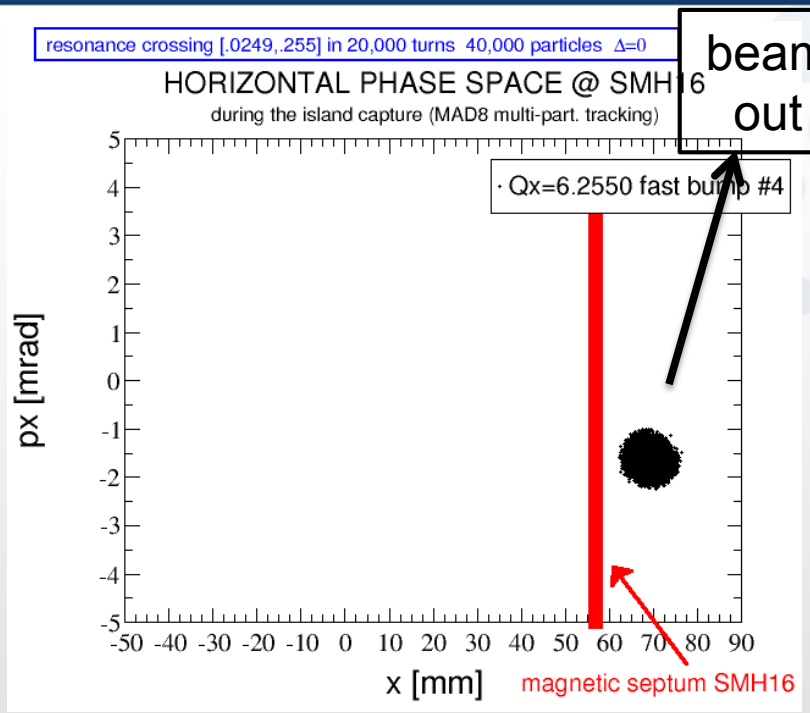

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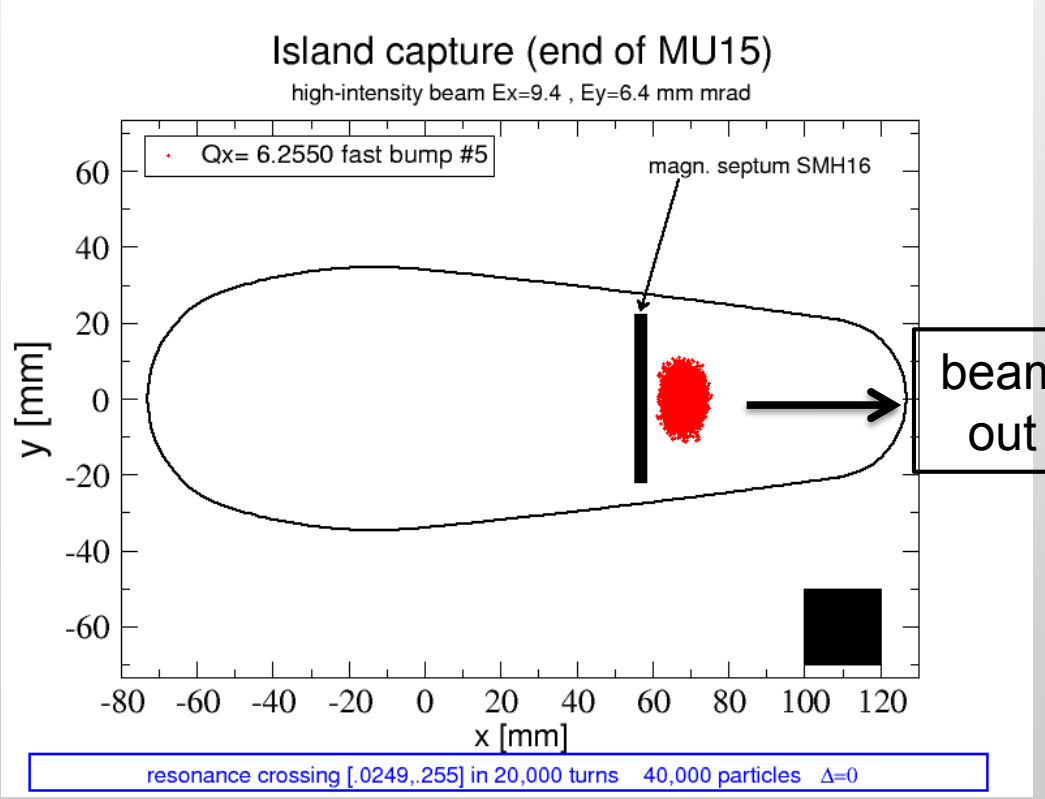

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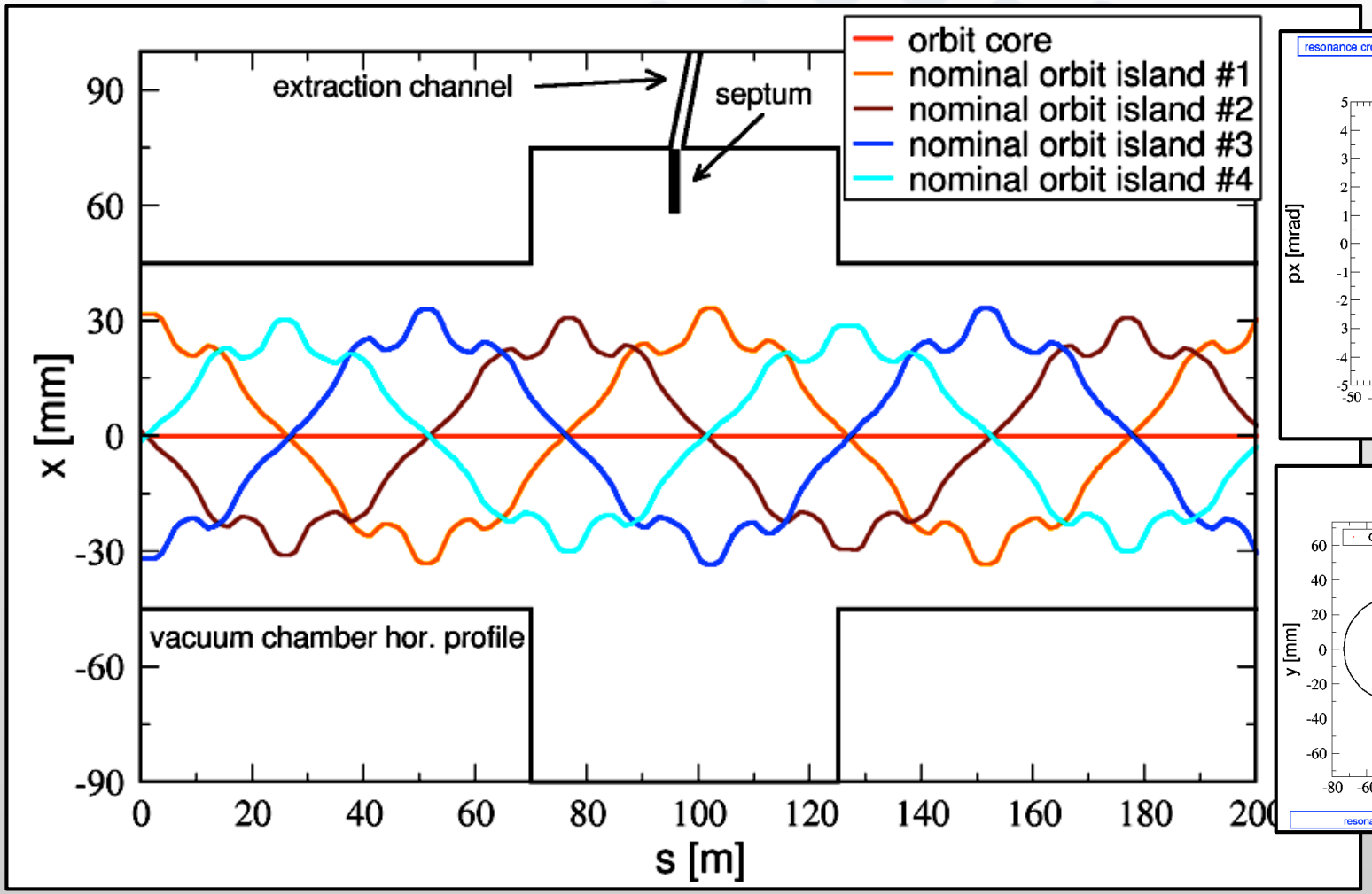
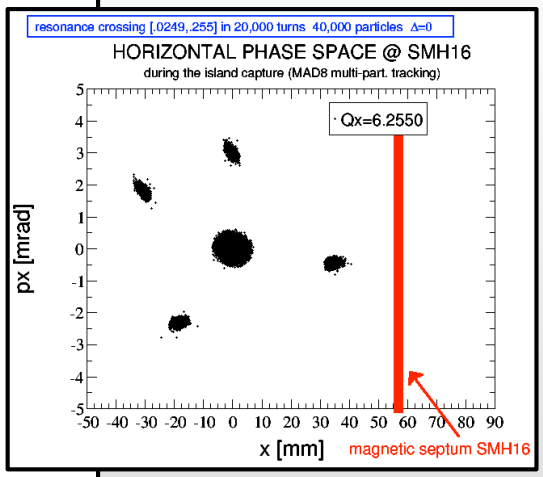
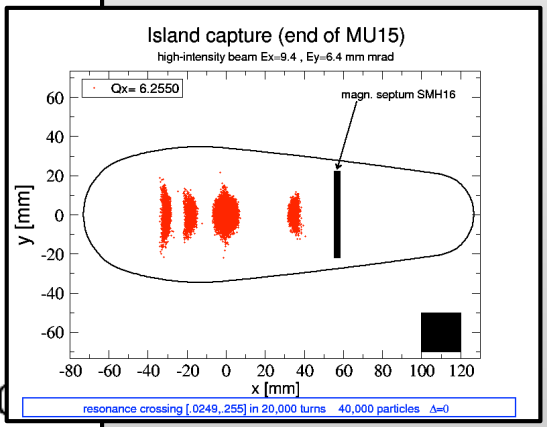
On-axis inj/ext without septum magnets

Multi-Turn Extraction @ CERN PS : split beam prior orbit bump

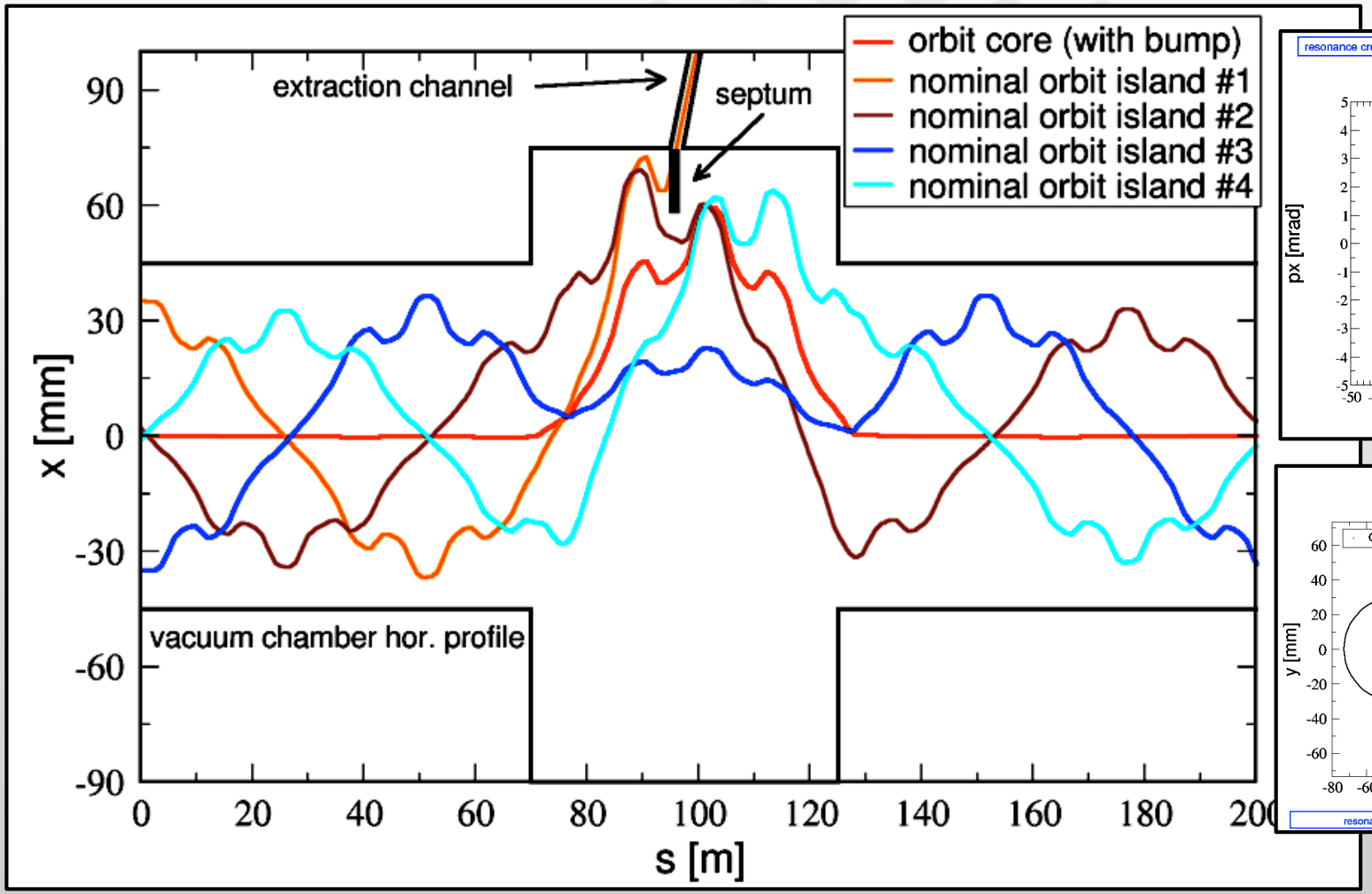


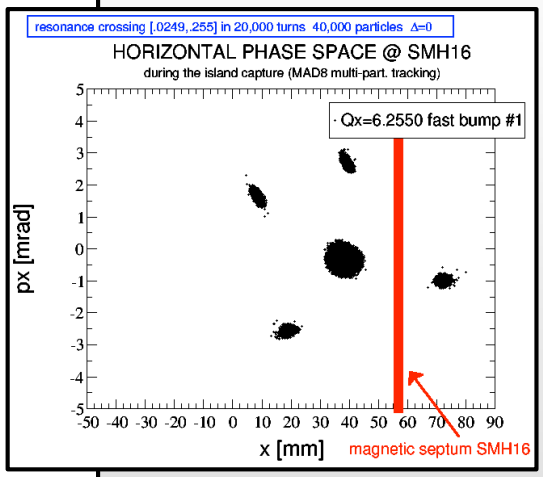


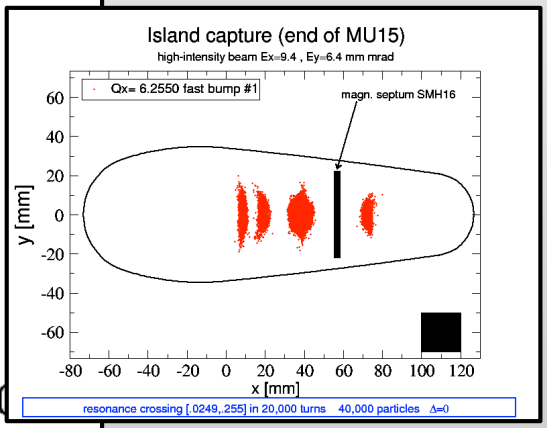


On-axis inj/ext without septum magnets

Multi-Turn Extraction @ CERN PS : split beam with orbit bump

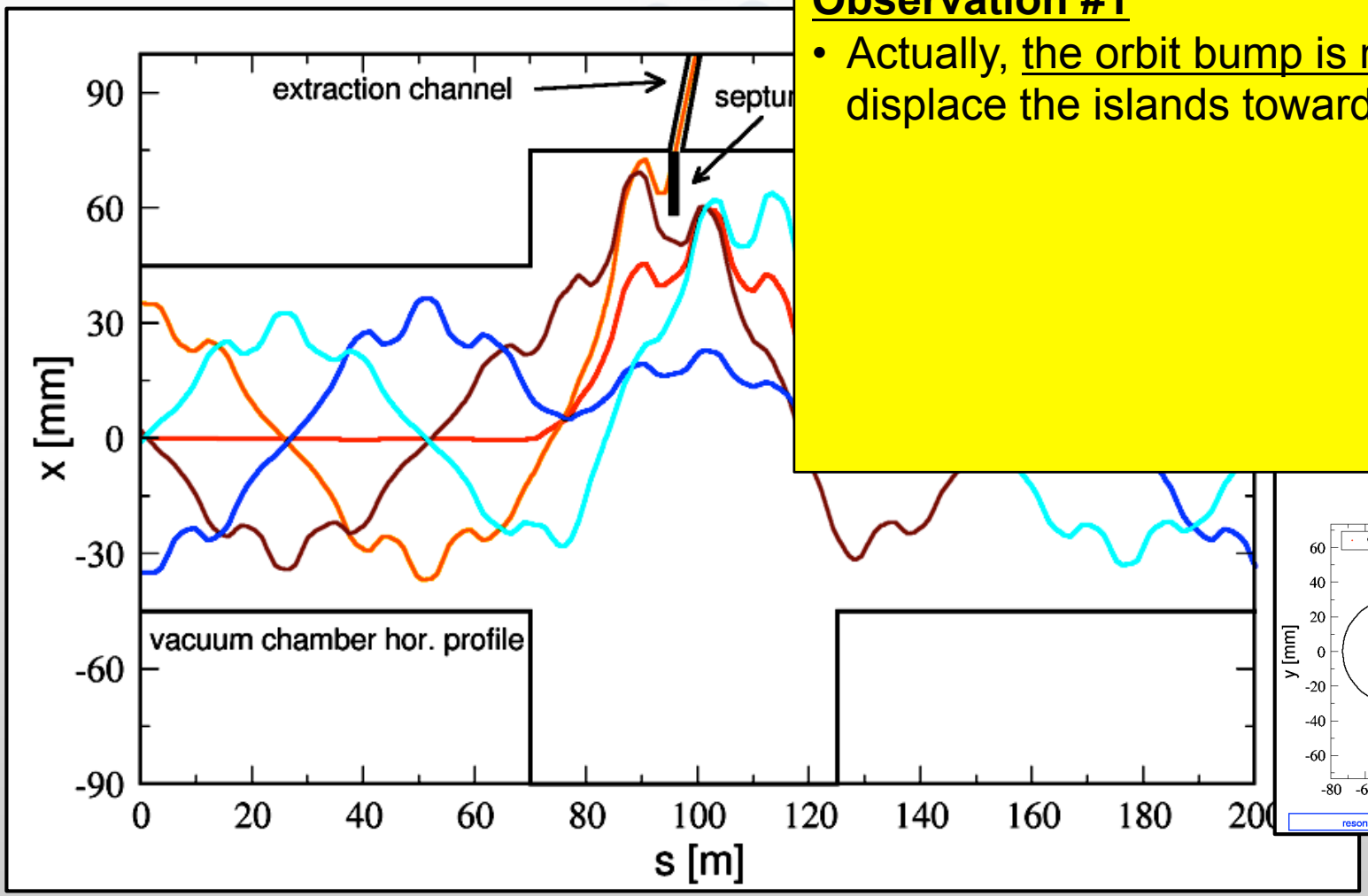






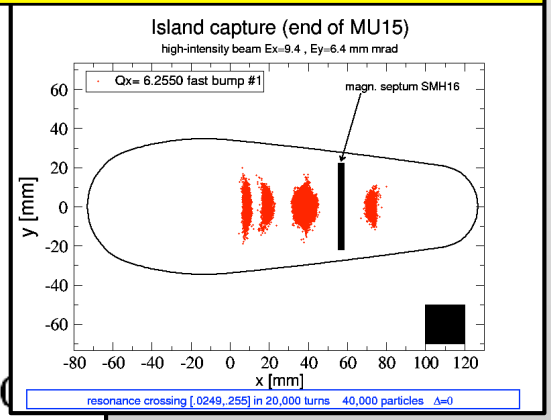
On-axis inj/ext without septum magnets

MTE : some observations



Observation #1

- Actually, the orbit bump is not needed to displace the islands towards the septum.



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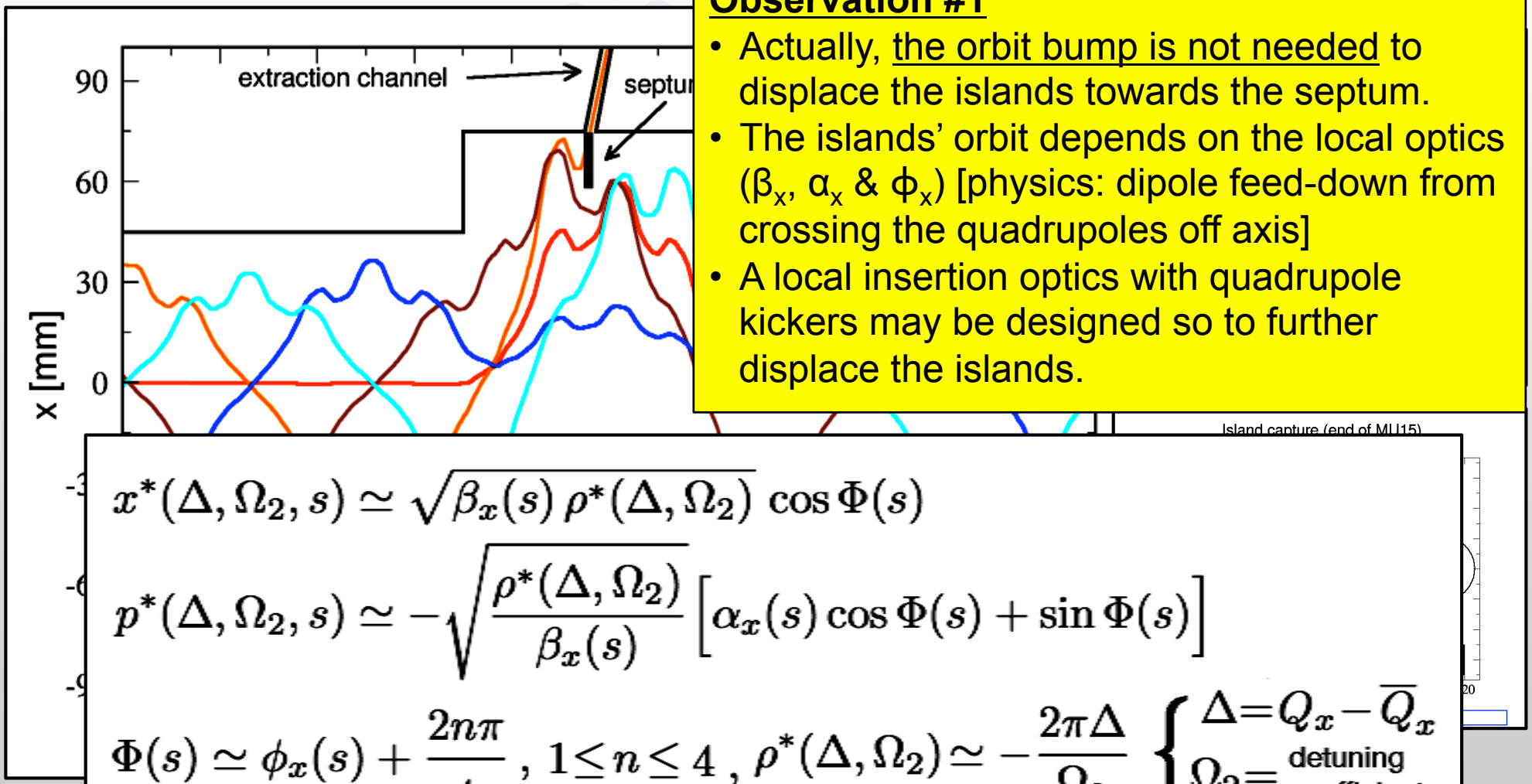

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- Actually, the orbit bump is not needed to displace the islands towards the septum.
- The islands' orbit depends on the local optics (β_x, α_x & ϕ_x) [physics: dipole feed-down from crossing the quadrupoles off axis]
- A local insertion optics with quadrupole kickers may be designed so to further displace the islands.

$$x^*(\Delta,\Omega_2,s) \simeq \sqrt{\beta_x(s)\,\rho^*(\Delta,\Omega_2)}\,\cos\Phi(s)$$

$$p^*(\Delta,\Omega_2,s) \simeq -\sqrt{\frac{\rho^*(\Delta,\Omega_2)}{\beta_x(s)}}\left[\alpha_x(s)\cos\Phi(s)+\sin\Phi(s)\right]$$

$$\Phi(s) \simeq \phi_x(s)+\frac{2n\pi}{4},\ 1\le n\le 4\,,\ \rho^*(\Delta,\Omega_2)\simeq -\frac{2\pi\Delta}{\Omega_2}$$

$\Delta = Q_x - \overline{Q}_x$

$\Omega_2 =$ detuning coefficient

On-axis inj/ext without septum magnets

MTE : some observations

Observation #2

- The insertion optics may be designed so to have x*≈70 mm and p_x^* ≈10 mrad (via β_x, α_x & ϕ_x) at the the extraction channel
- Need no magnetic septum, just of a physical septum at larger distance (i.e. larger beam stay clear)

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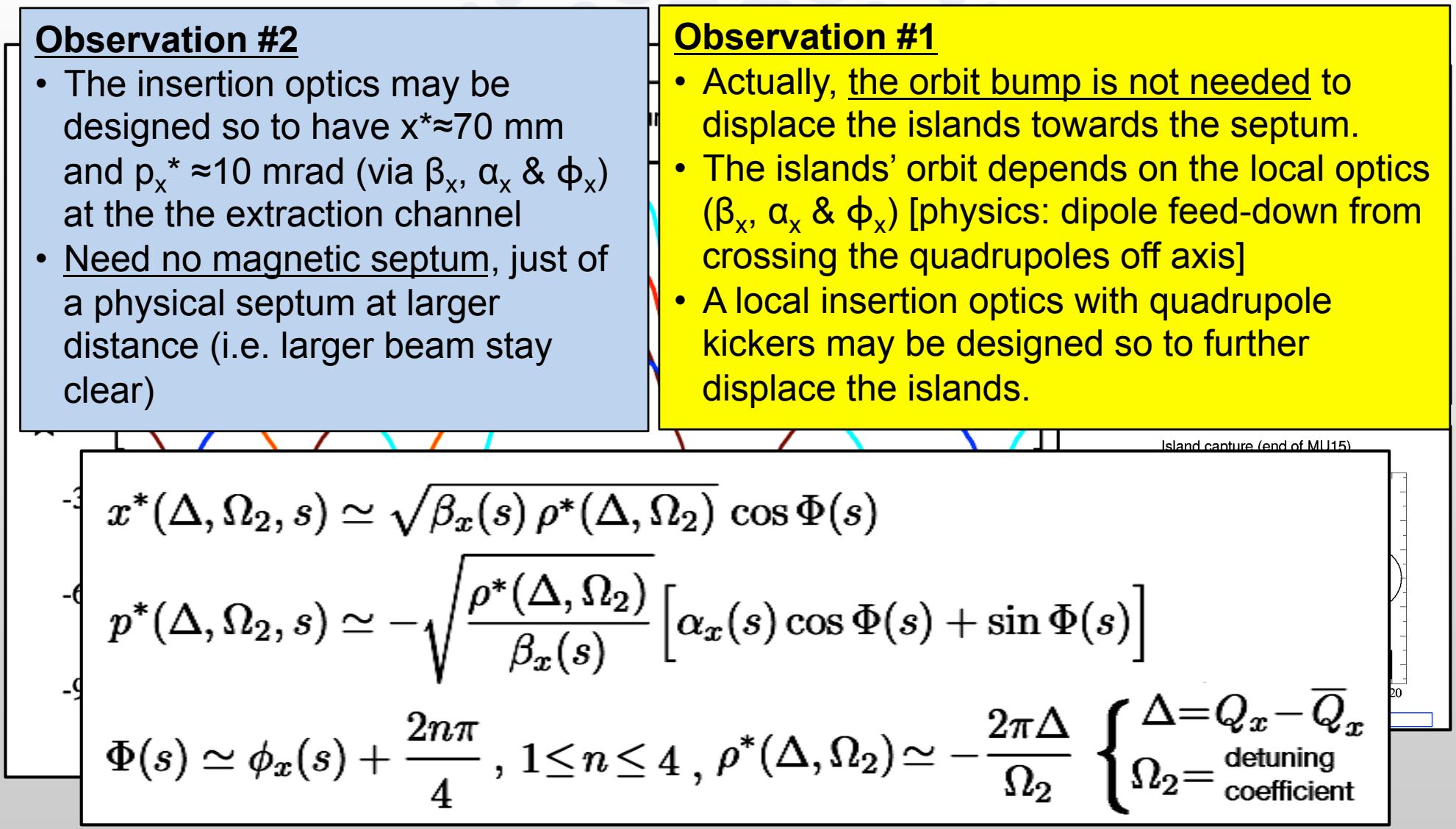

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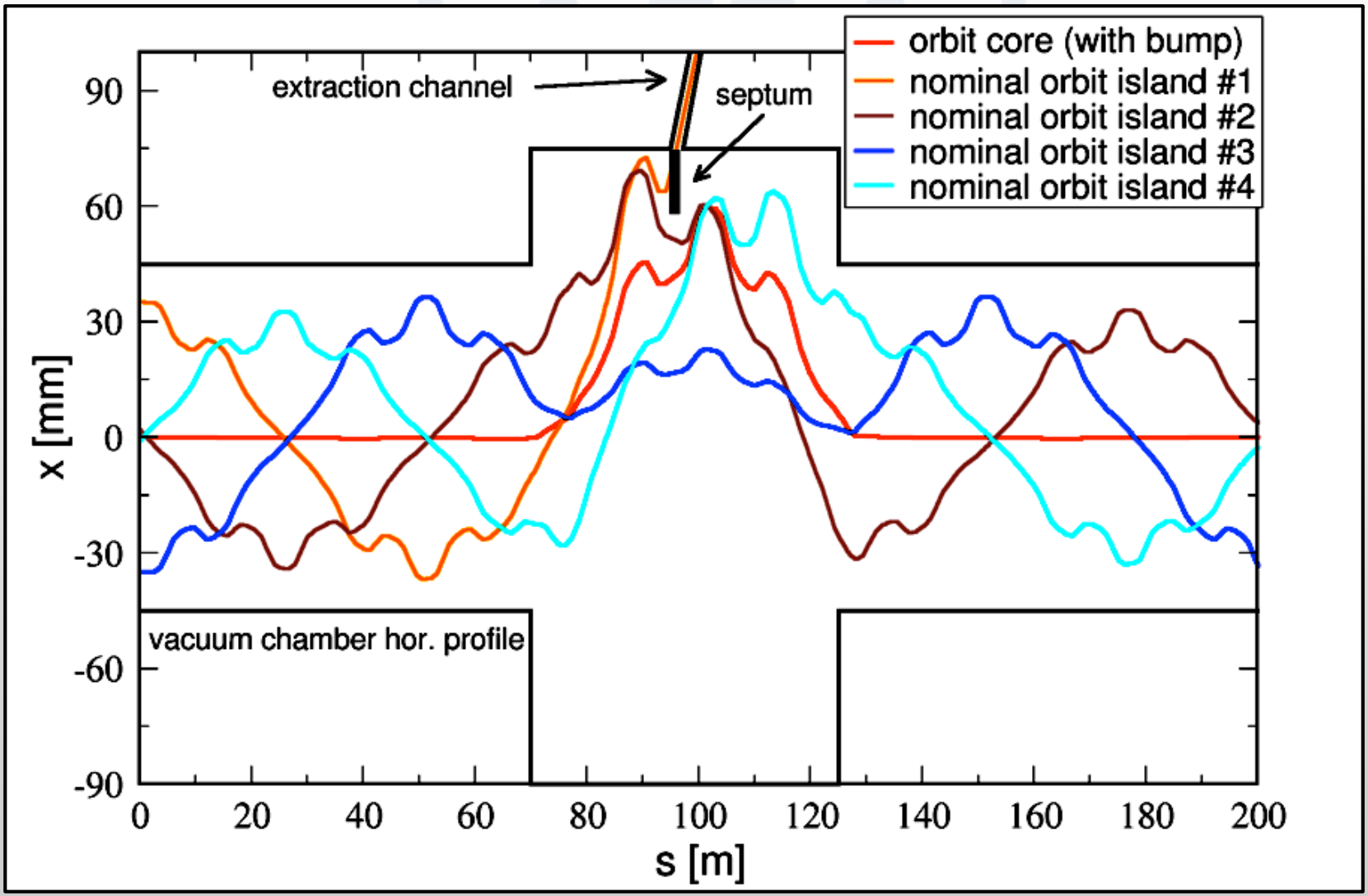
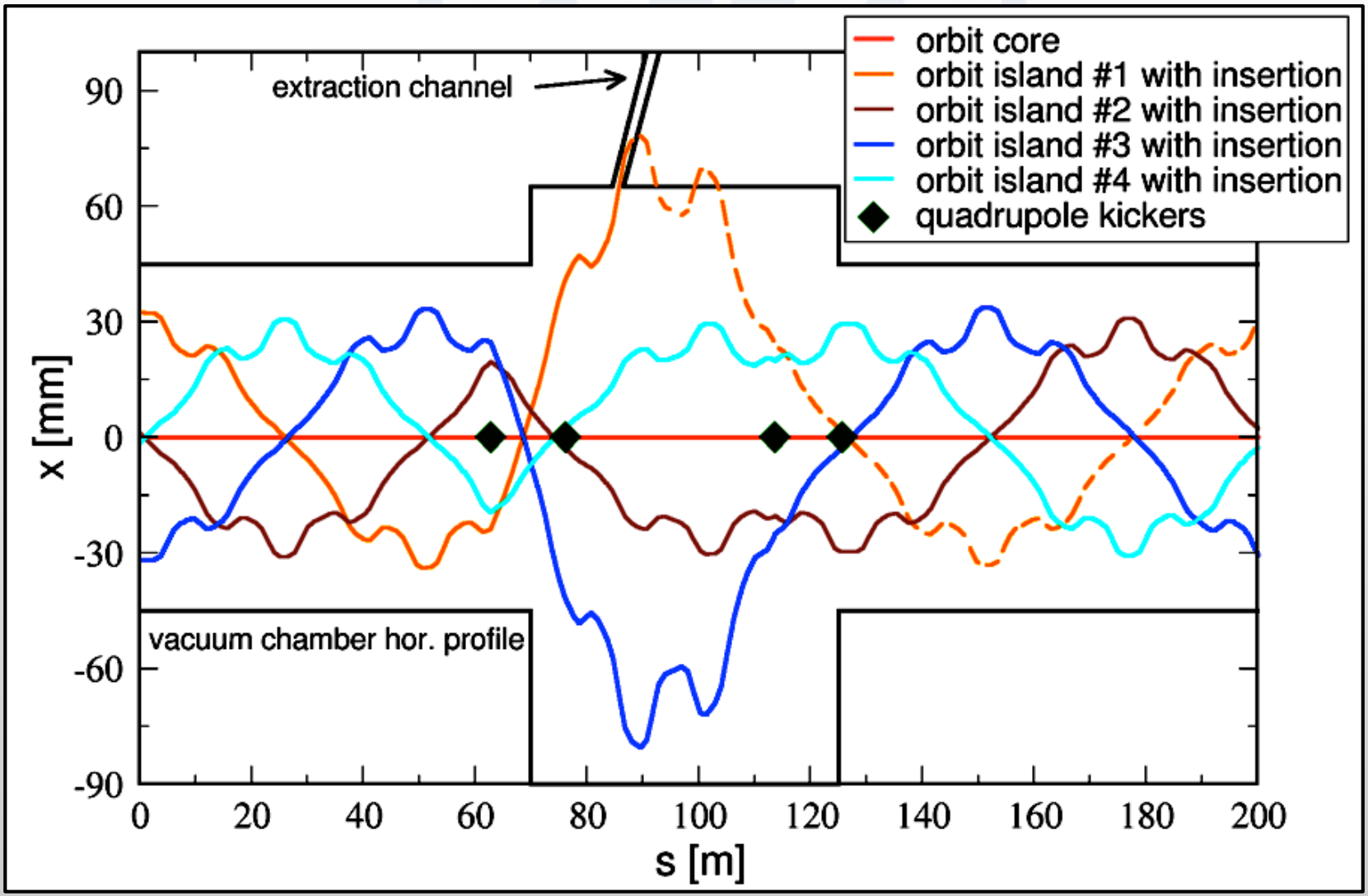
MTE: islands' extraction with orbit bump & septum magnets



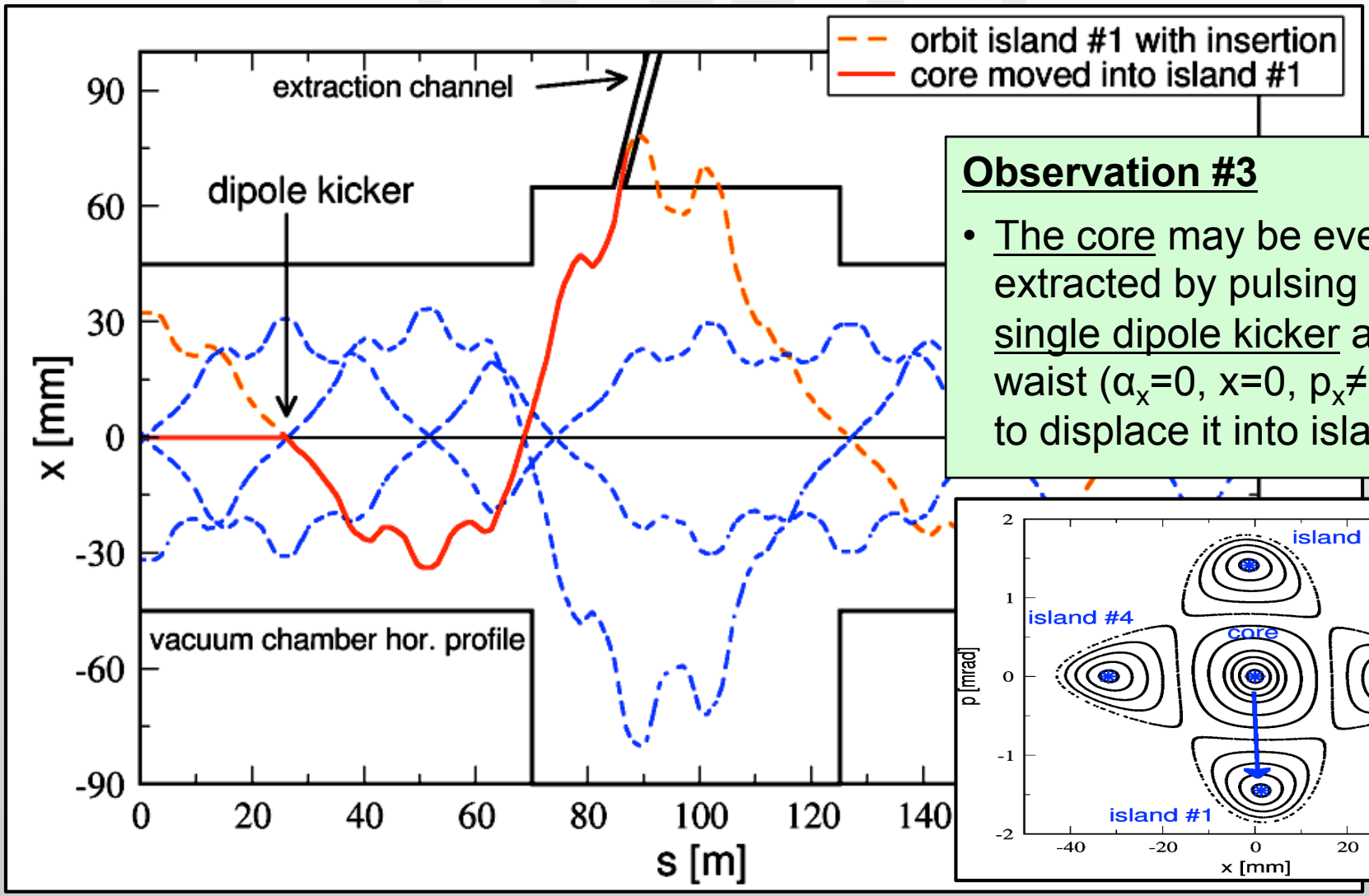
On-axis inj/ext without septum magnets

MTE: islands' extraction with neither orbit bump nor septum magnets



On-axis inj/ext without septum magnets

MTE : core extraction with a single dipole kicker



Observation #3

- The core may be eventually extracted by pulsing a single dipole kicker at a waist (α_x=0, x=0, $p_x \neq 0$) so to displace it into island #1

On-axis inj/ext without septum magnets

MTE : core extraction with a single dipole kicker

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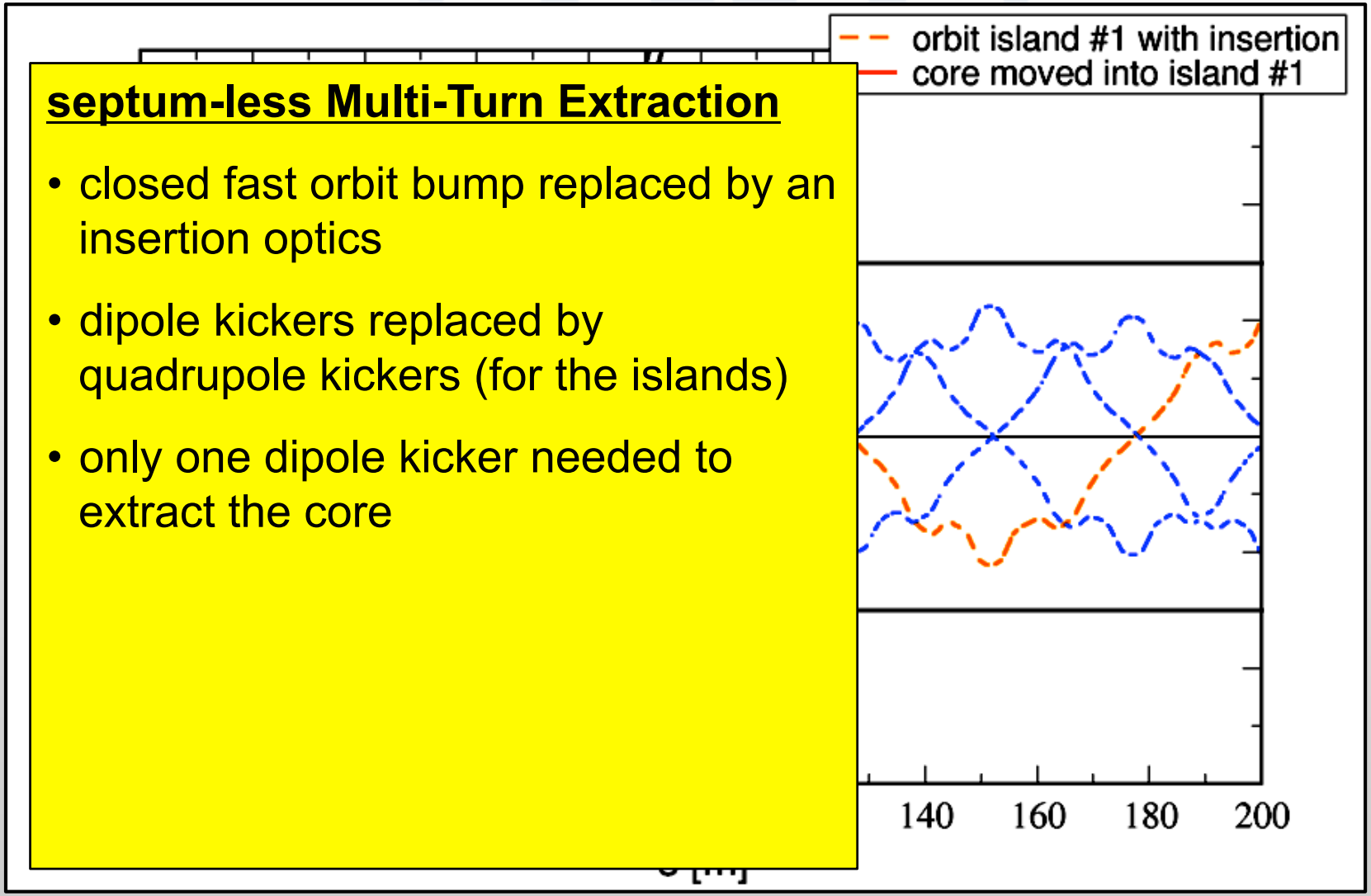

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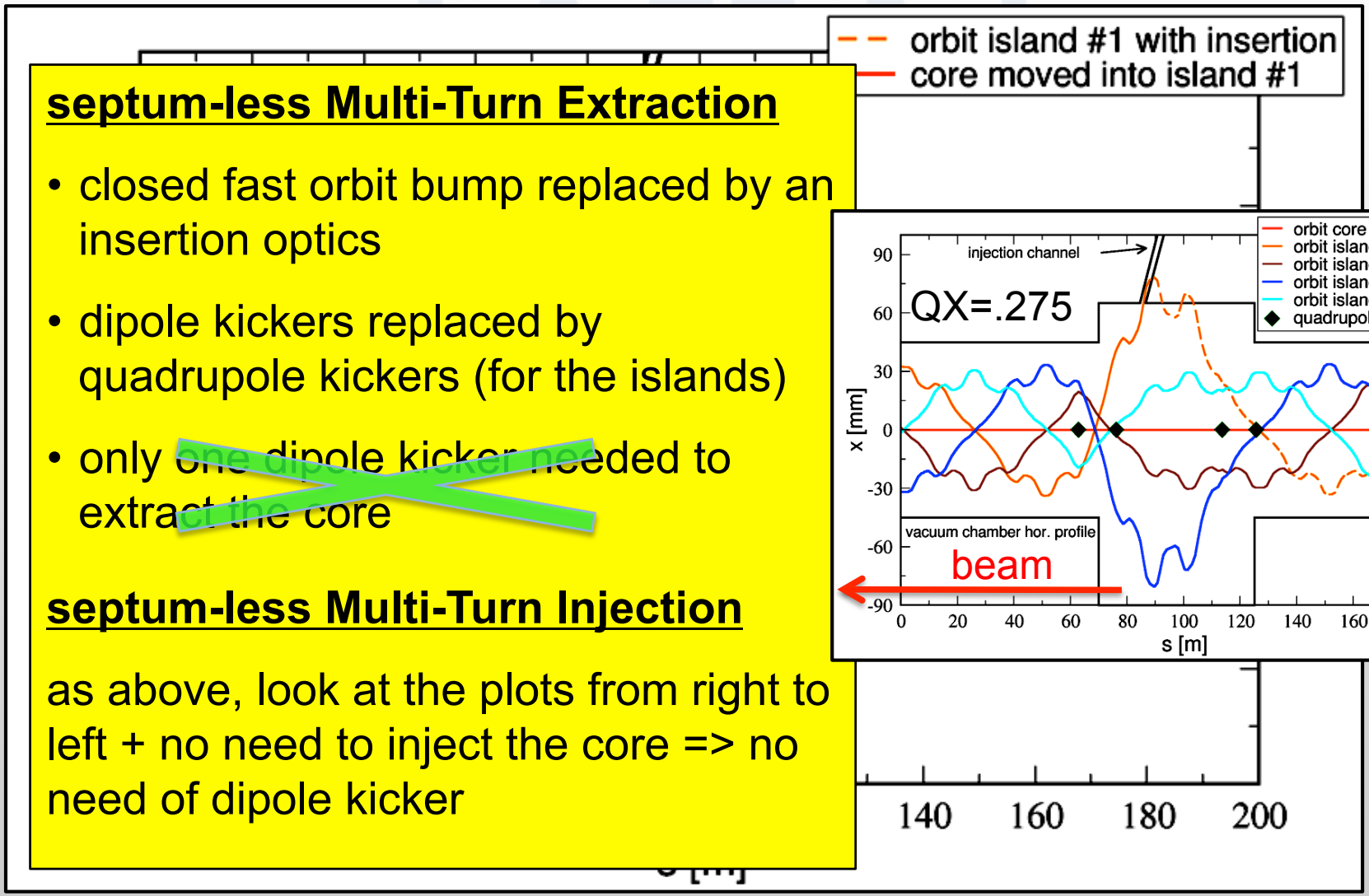

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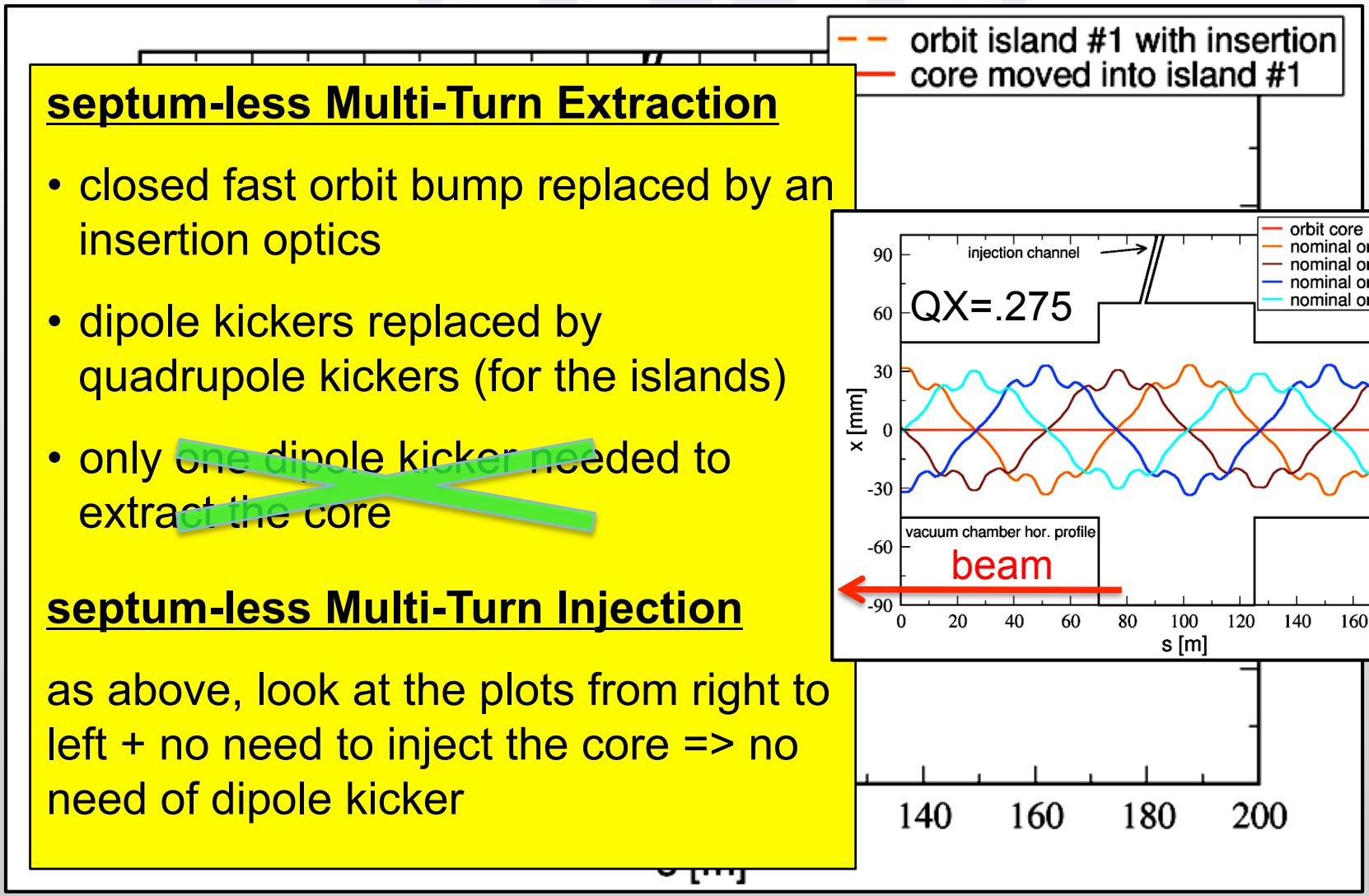

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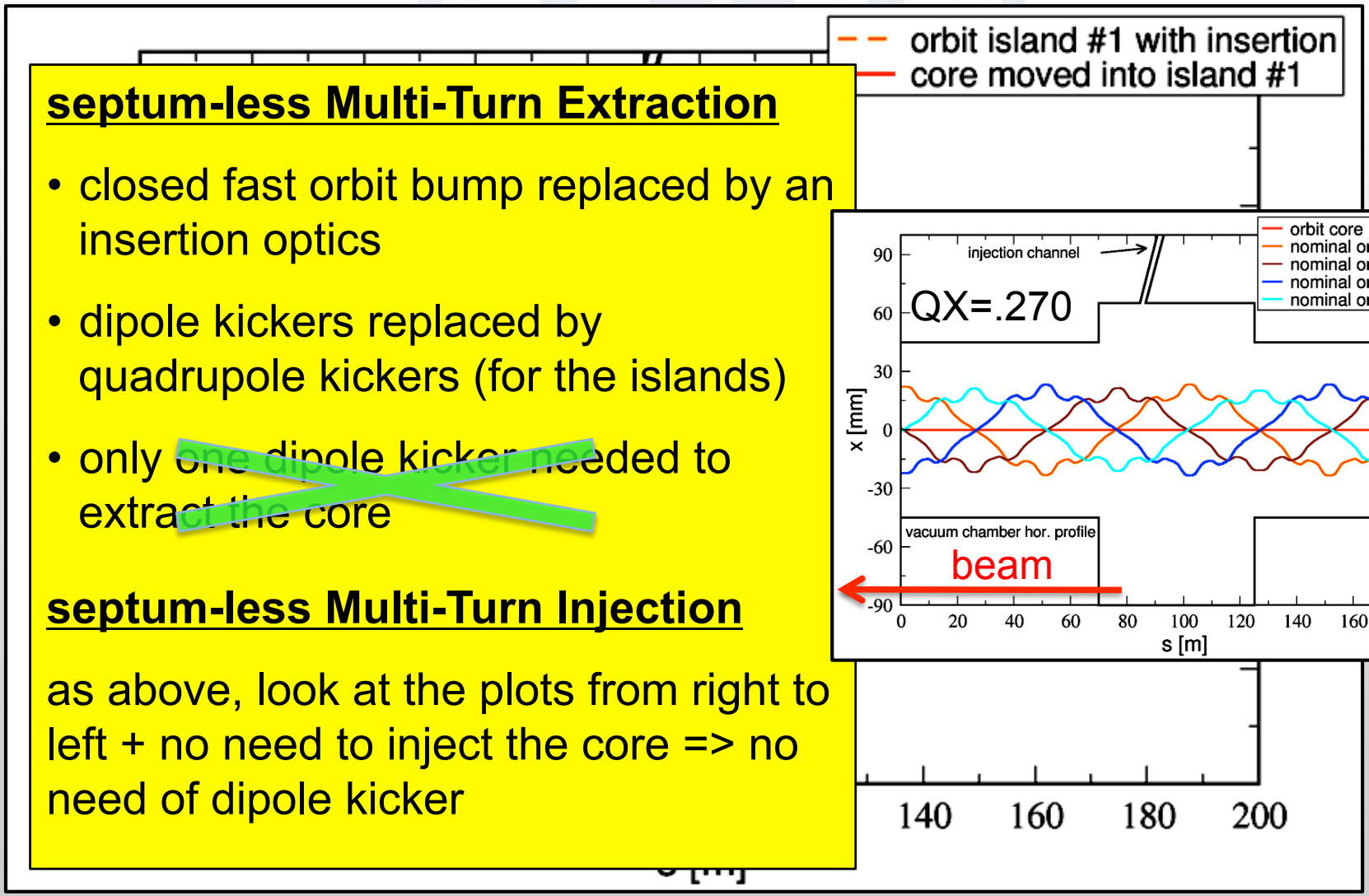

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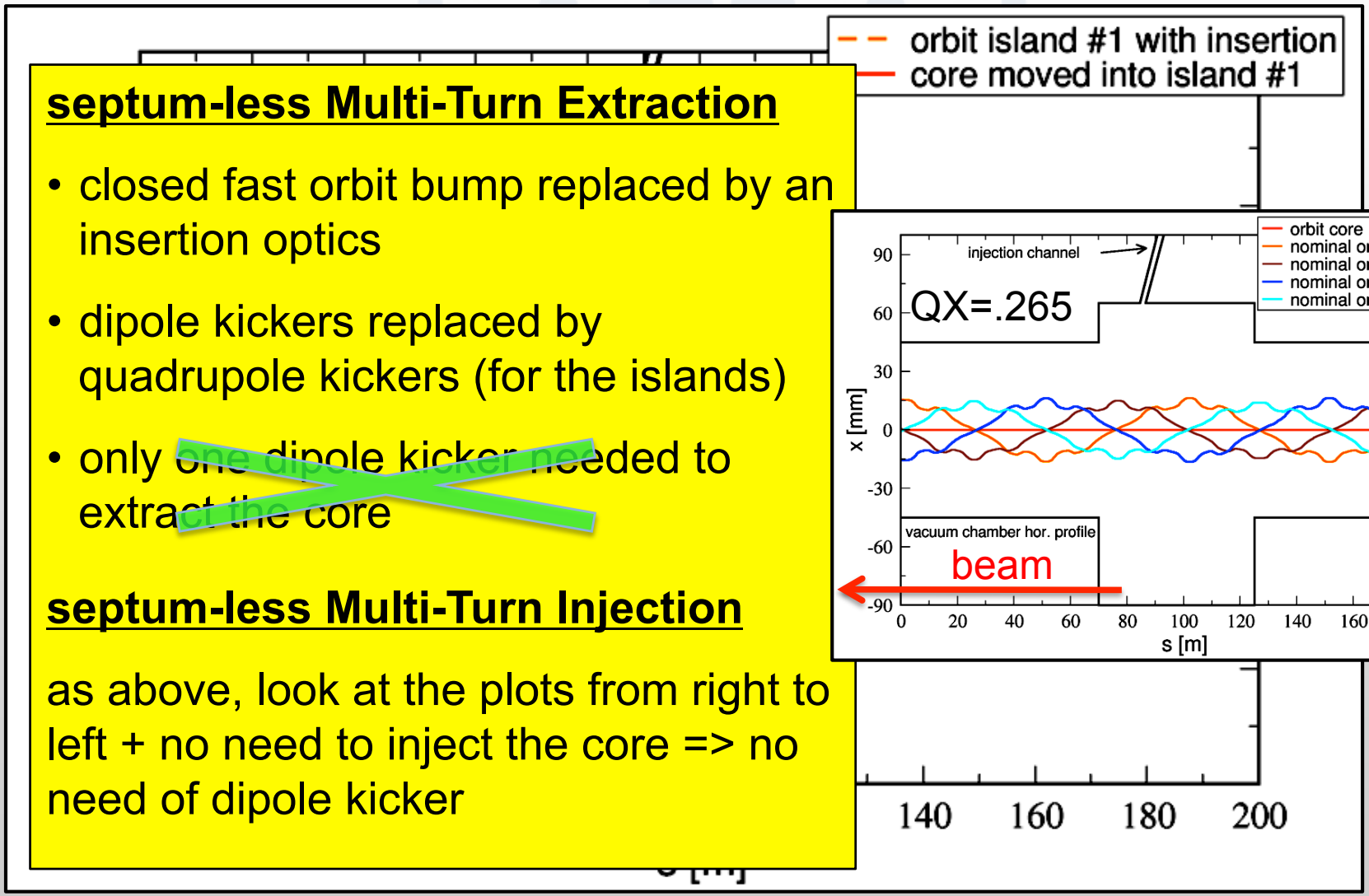

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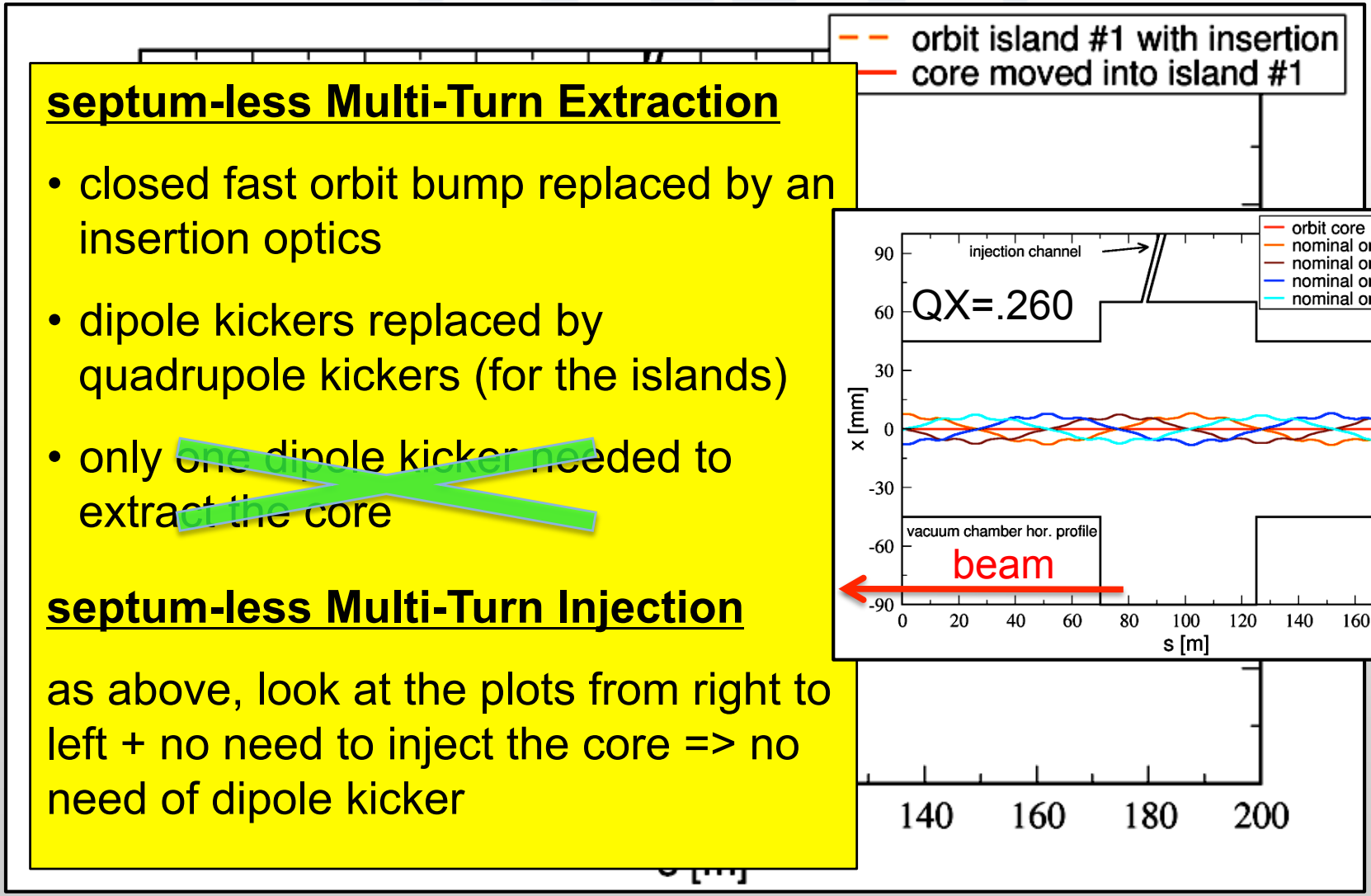

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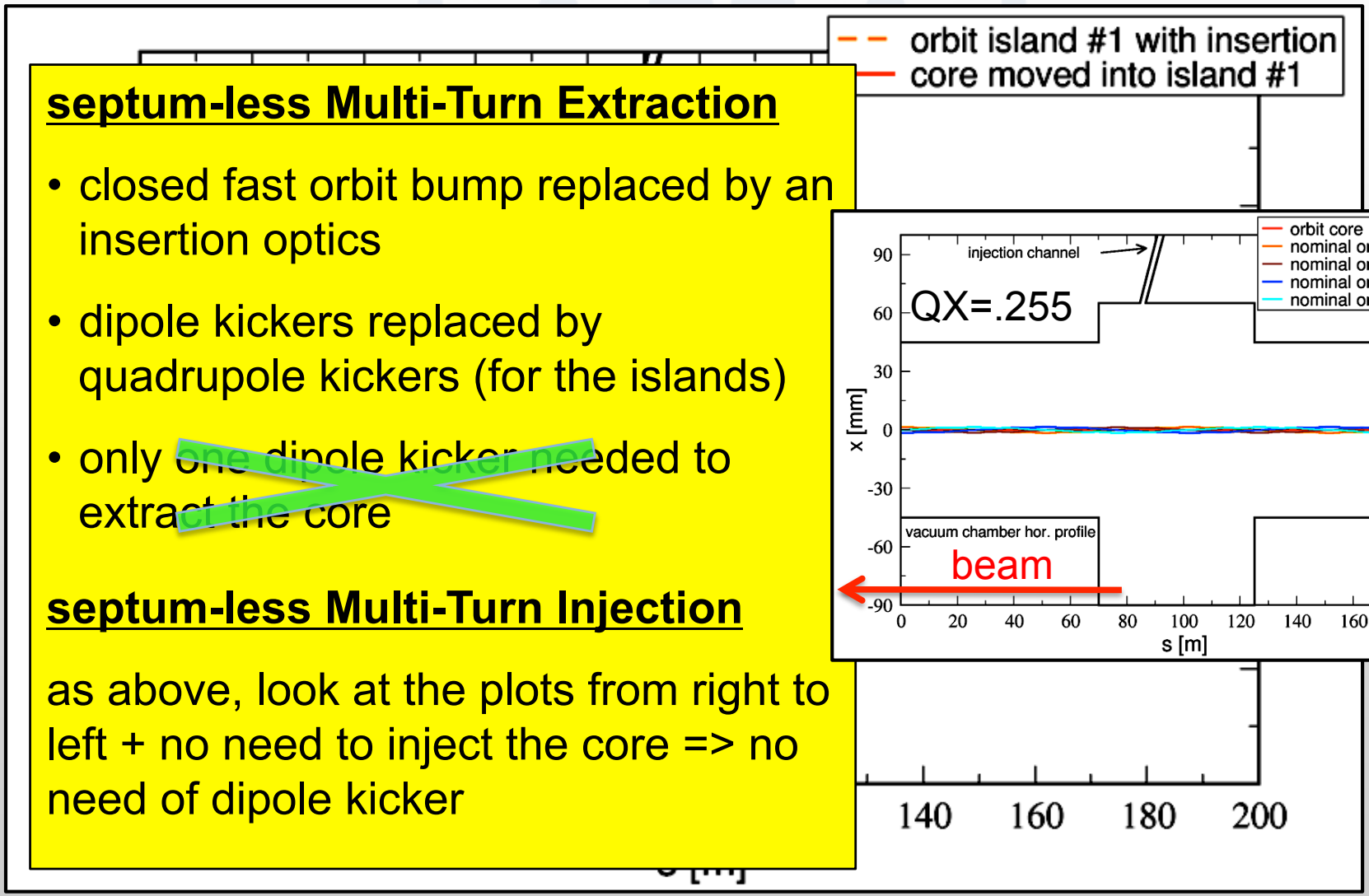

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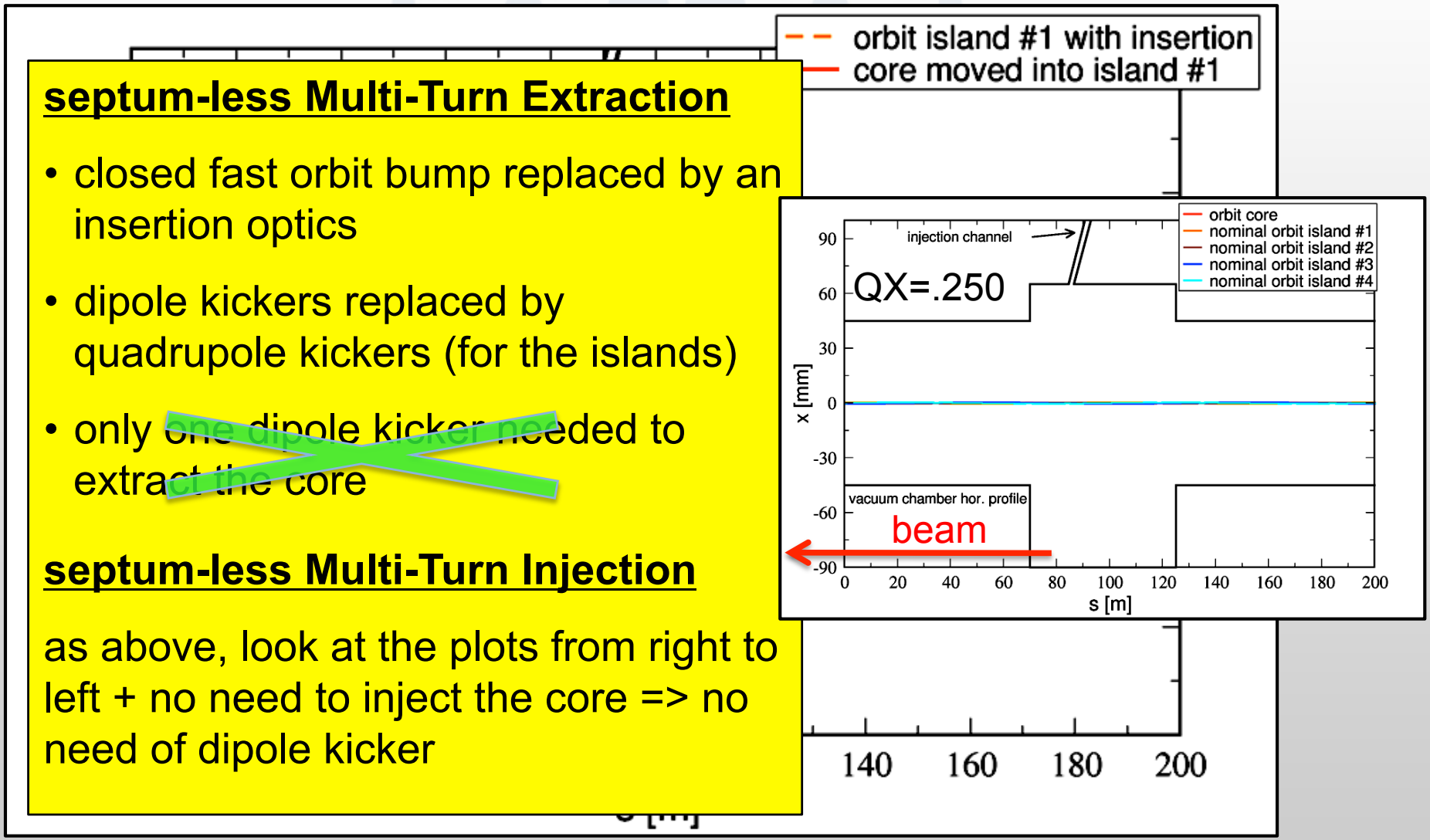


On-axis inj/ext without septum magnets

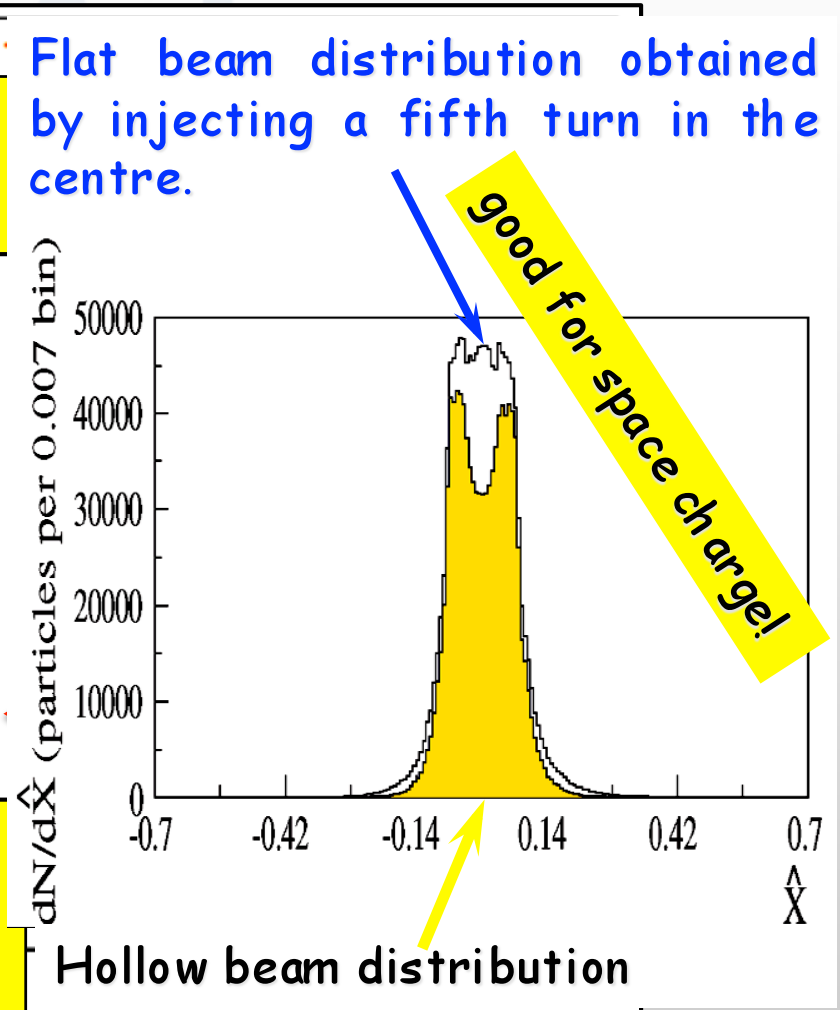
MTE : core extraction with a single dipole kicker

septum-less Multi-Turn Extraction

- closed fast orbit bump replaced by an insertion optics
- dipole kickers replaced by quadrupole kickers (for the islands)
- only ~~one dipole kicker needed~~ to extract the core

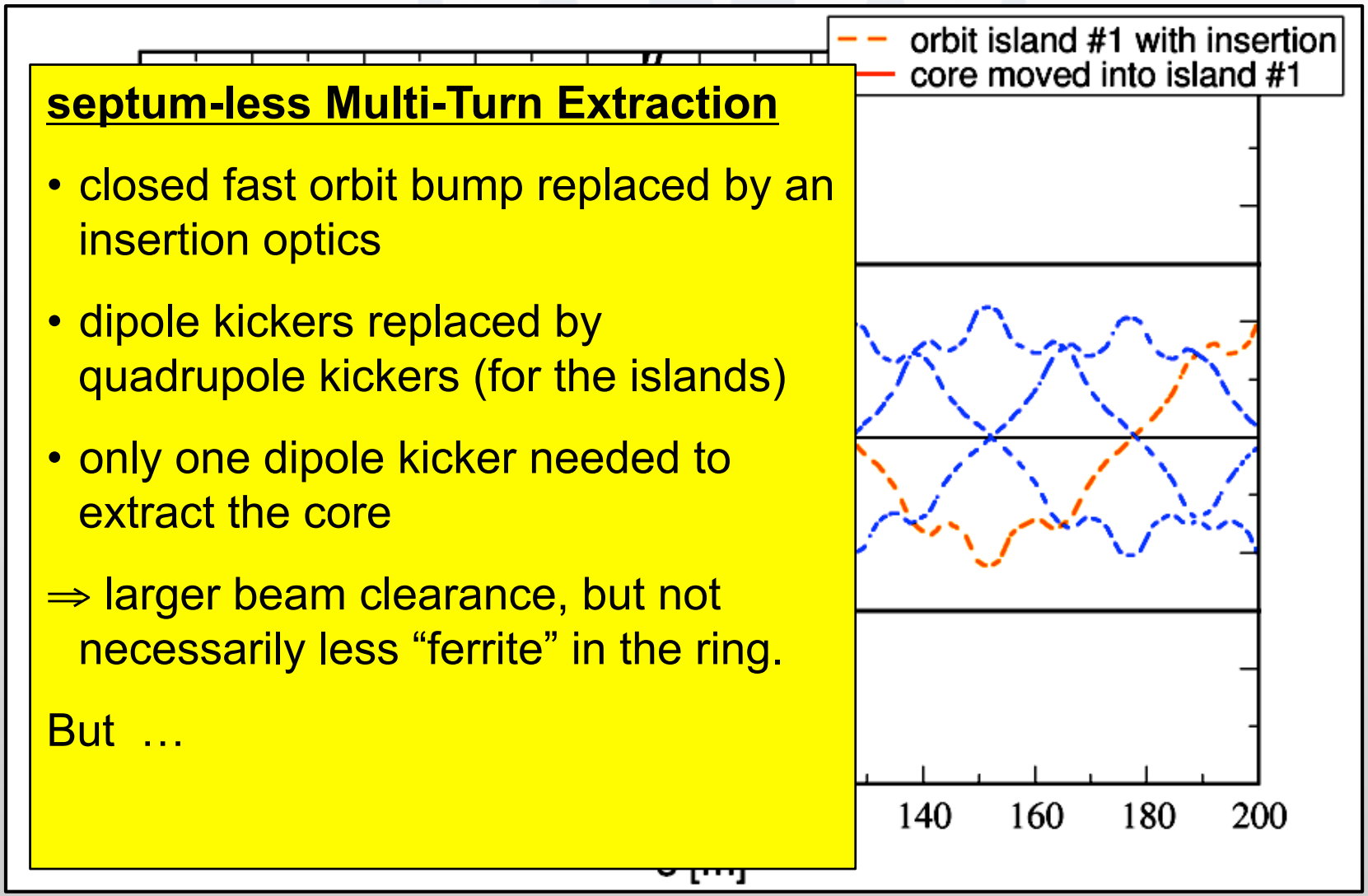
septum-less Multi-Turn Injection

as above, look at the plots from right to left + no need to inject the core => no need of dipole kicker



On-axis inj/ext without septum magnets

MTE : core extraction with a single dipole kicker



septum-less Multi-Turn Extraction

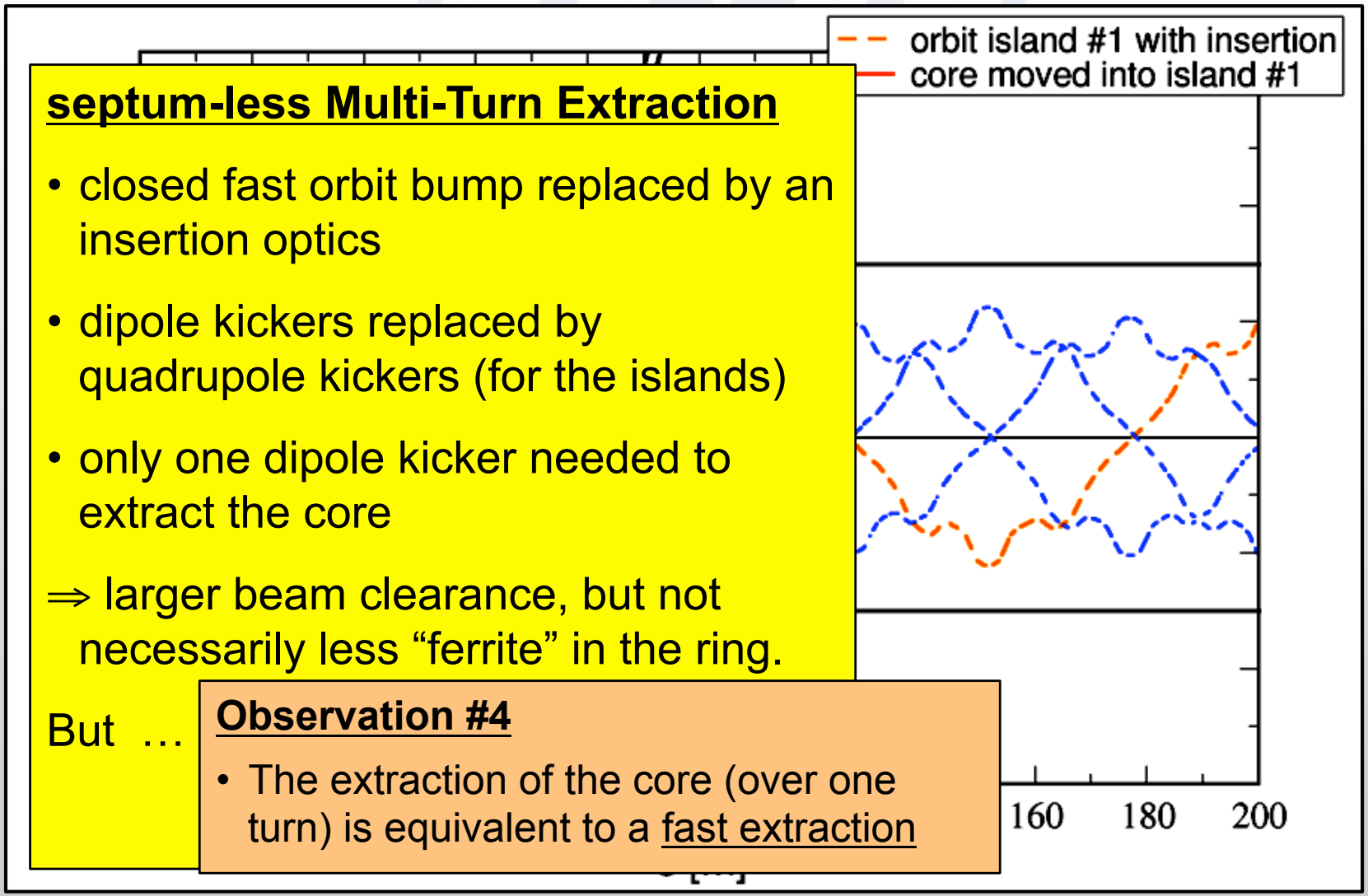
- closed fast orbit bump replaced by an insertion optics
- dipole kickers replaced by quadrupole kickers (for the islands)
- only one dipole kicker needed to extract the core

⇒ larger beam clearance, but not necessarily less “ferrite” in the ring.

But …

On-axis inj/ext without septum magnets

MTE : core extraction with a single dipole kicker



septum-less Multi-Turn Extraction

- closed fast orbit bump replaced by an insertion optics
- dipole kickers replaced by quadrupole kickers (for the islands)
- only one dipole kicker needed to extract the core

⇒ larger beam clearance, but not necessarily less “ferrite” in the ring.

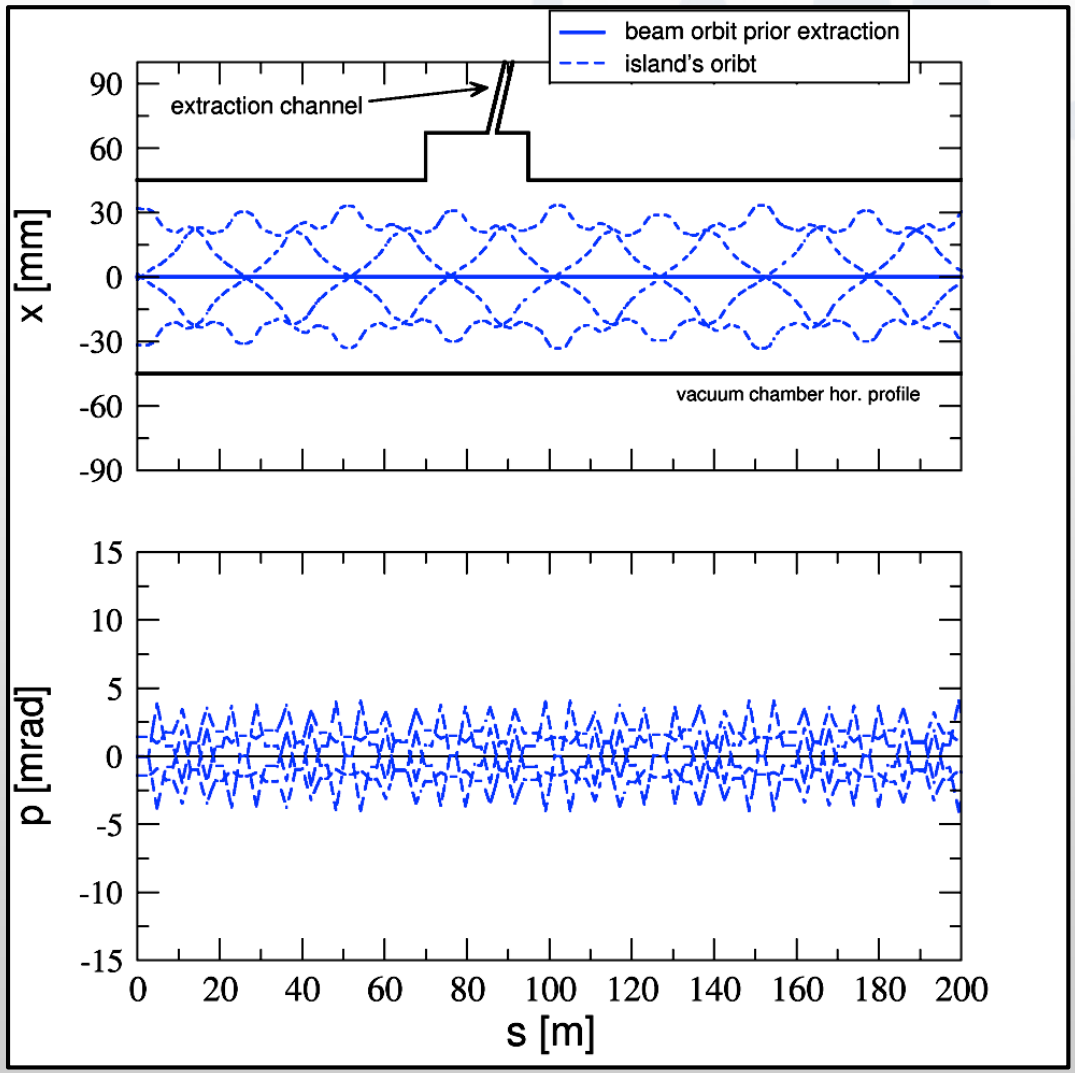
But …

Observation #4

- The extraction of the core (over one turn) is equivalent to a fast extraction

On-axis inj/ext without septum magnets

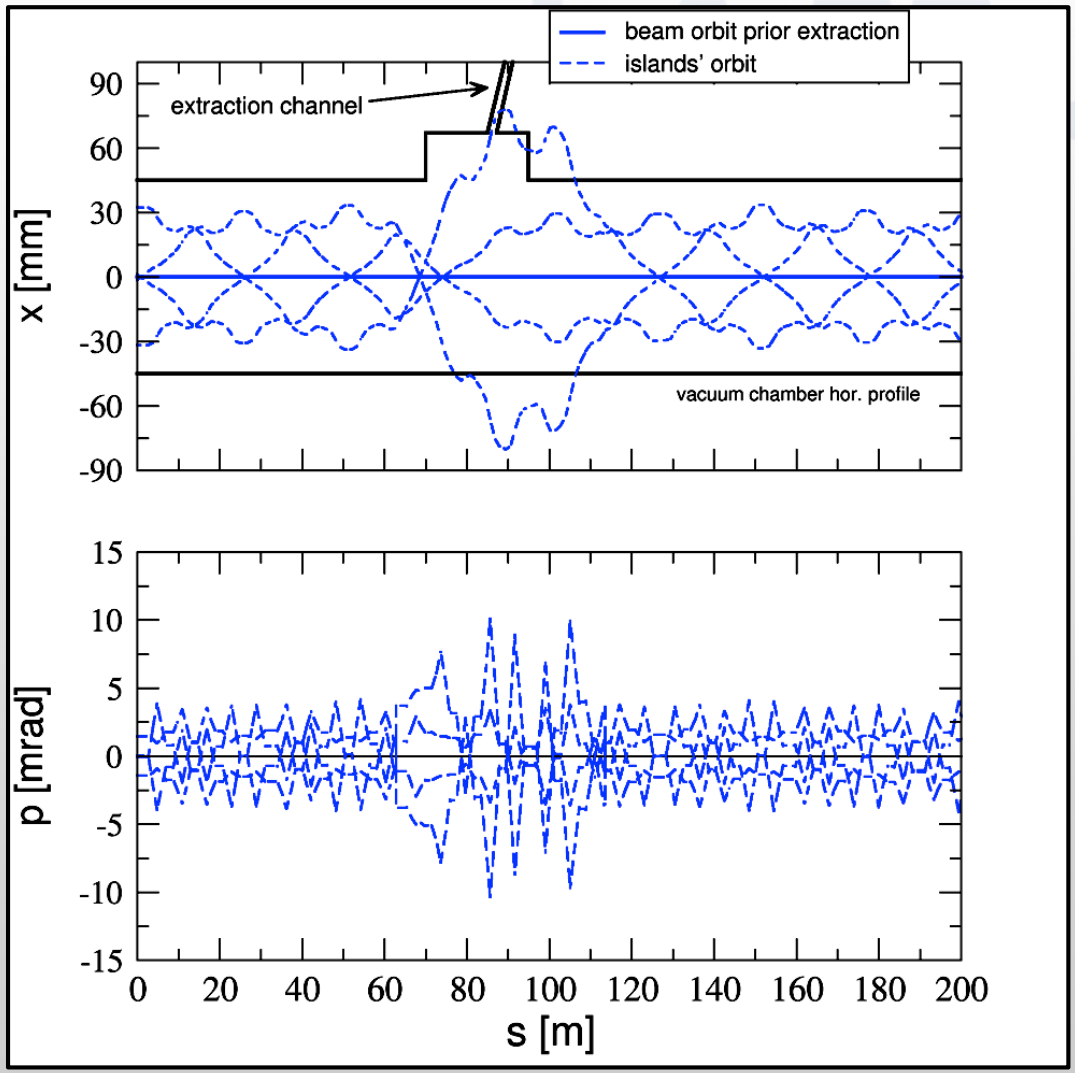
Fast Extraction with 4th order resonance



step 1: generate (though do not populate) four islands. the beam remain on axis

On-axis inj/ext without septum magnets

Fast Extraction with 4th order resonance

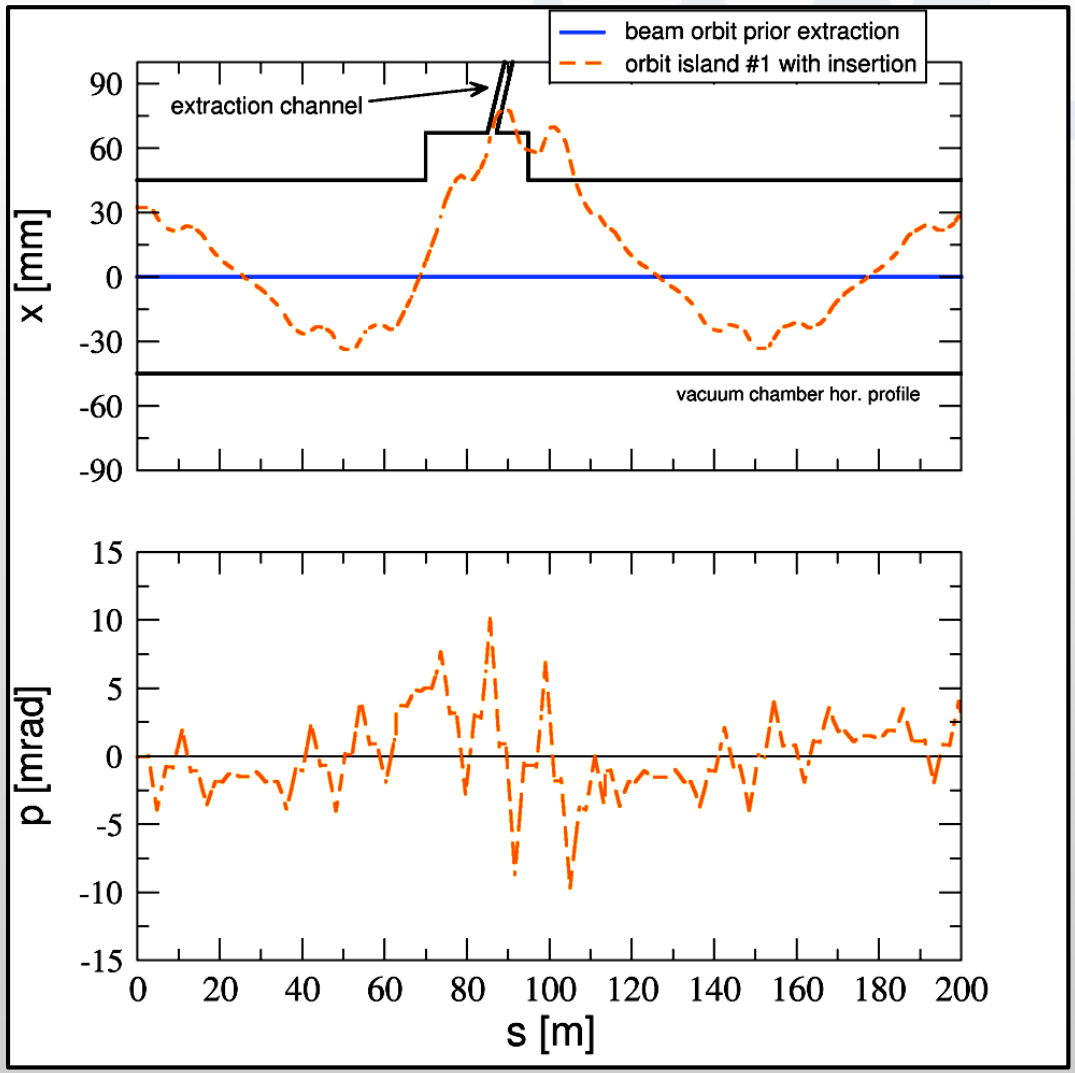


step 1: generate (though do not populate) four islands. the beam remain on axis

step 2: introduce the insertion optics via quadrupole bumpers, not kickers (actually not needed)

On-axis inj/ext without septum magnets

Fast Extraction with 4th order resonance

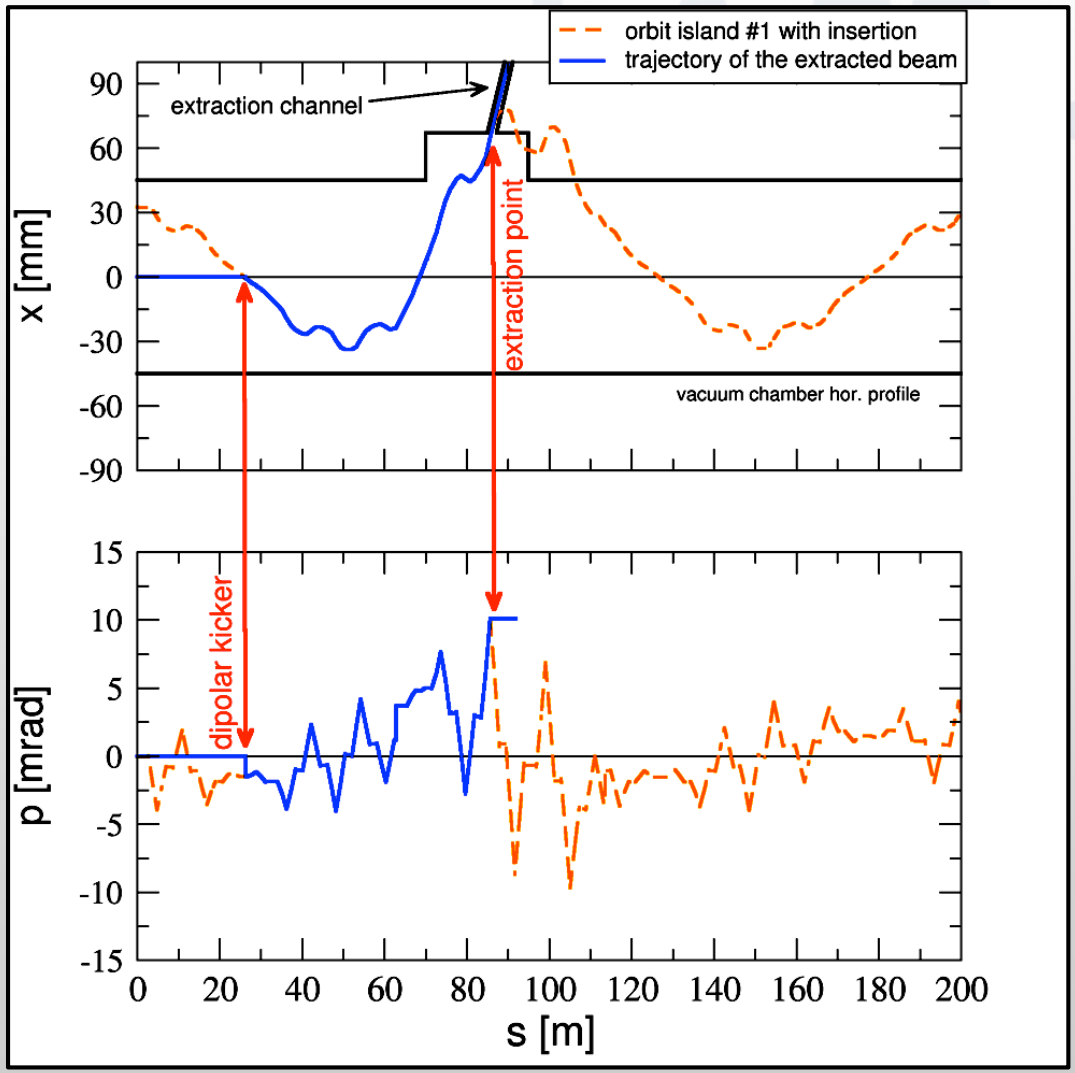


step 1: generate (though do not populate) four islands. the beam remain on axis

step 2: introduce the insertion optics via quadrupole bumpers, not kickers (actually not needed)

On-axis inj/ext without septum magnets

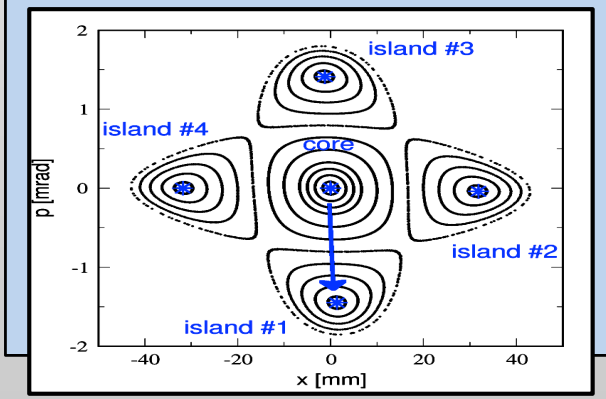
Fast Extraction with 4th order resonance



step 1: generate (though do not populate) four islands. the beam remain on axis

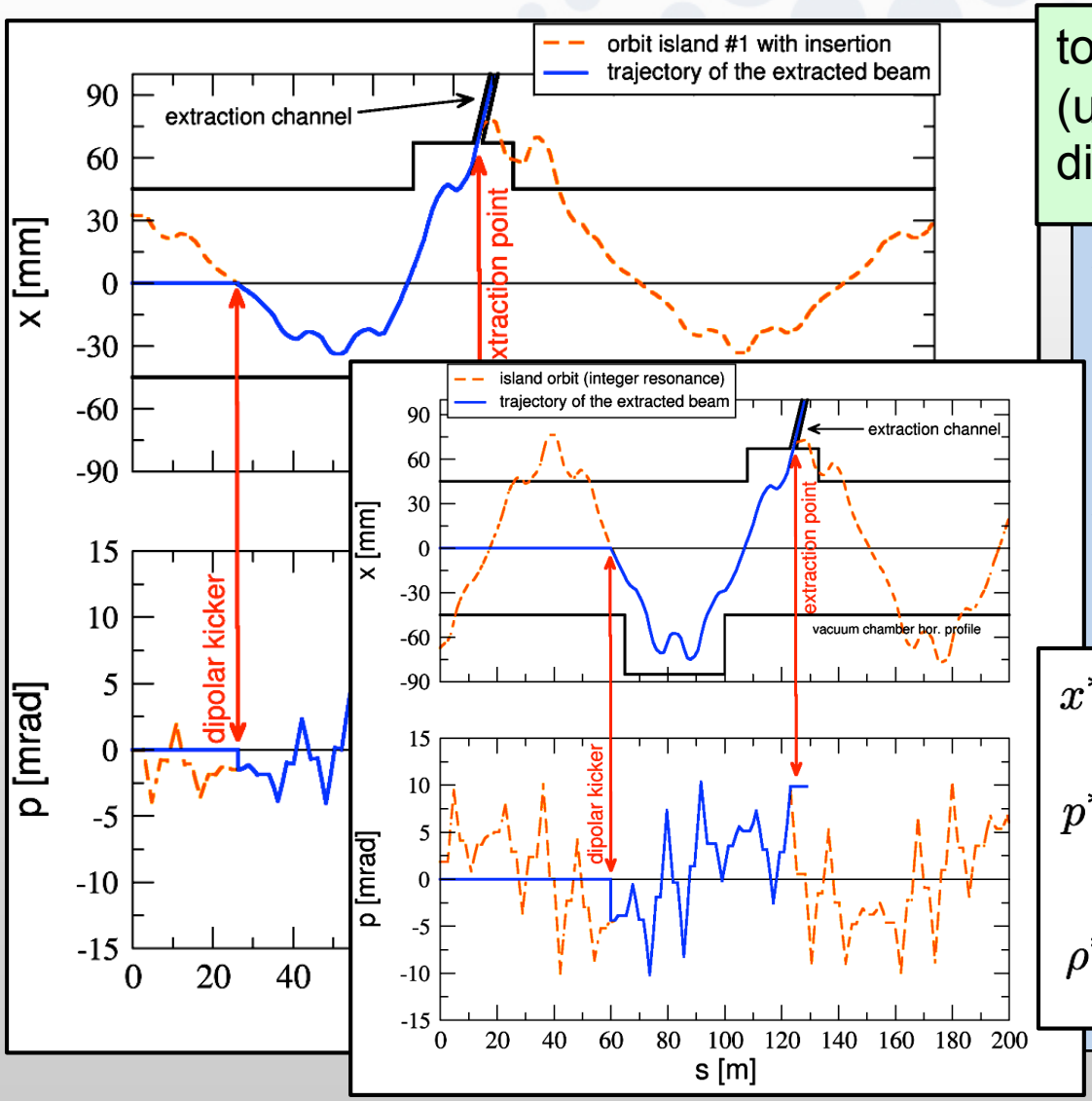
step 2: introduce the insertion optics via quadrupole bumpers, not kickers (actually not needed)

step 3: install and pulse a dipole kicker at a waist to move the beam from the axis to the island



On-axis inj/ext without septum magnets

Fast Extraction with 4th order resonance



to avoid insertion optics (unpopulated) islands may be displaced by moving Qx only

step 2: introduce the insertion optics via quadrupole bumpers, not kickers (actually not needed)

step 3: install and pulse a dipole kicker at a waist to move the beam from the axis

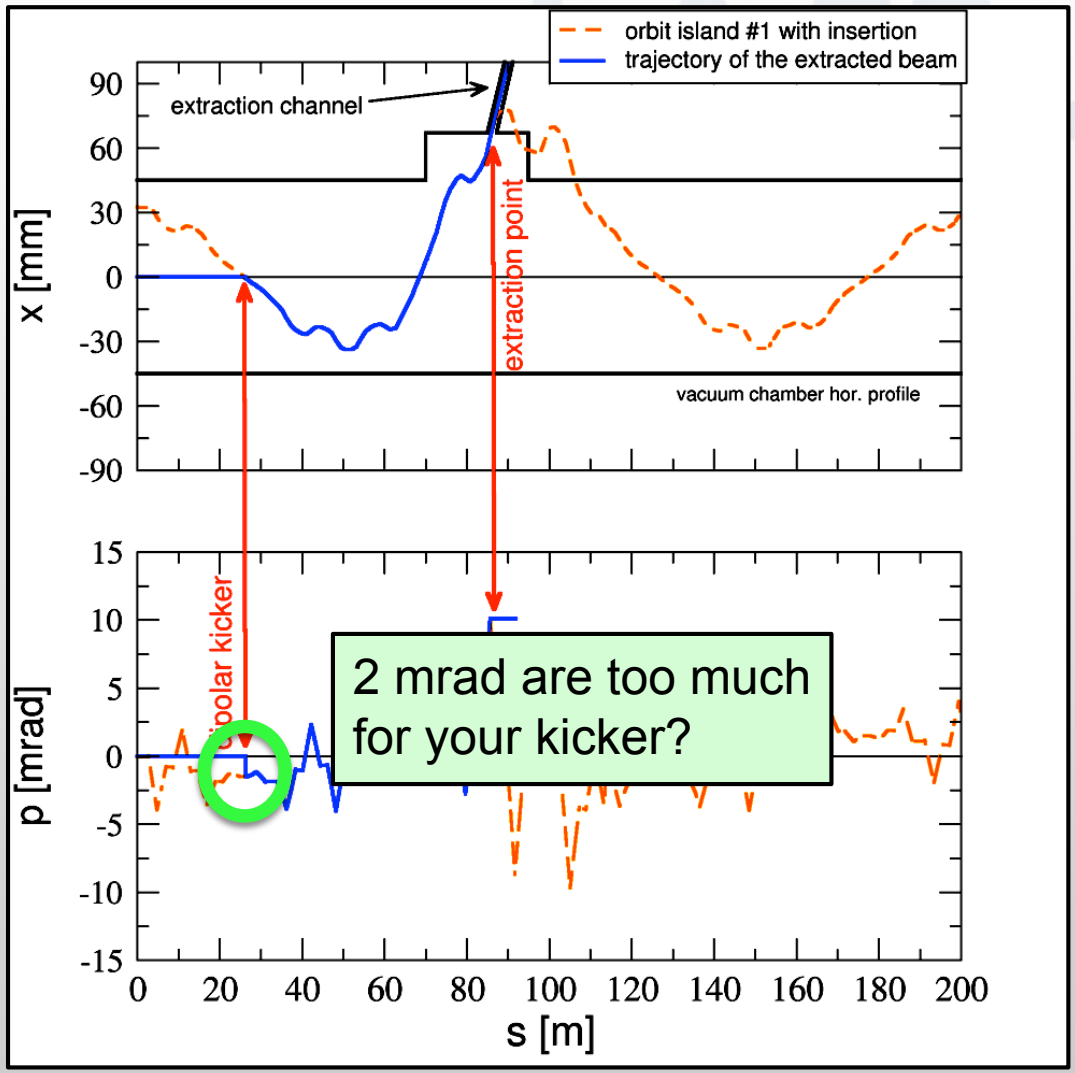
$$x^*(\Delta,\Omega_2,s) \propto \sqrt{\beta_x(s)}\,\rho^*(\Delta,\Omega_2)$$

$$p^*(\Delta,\Omega_2,s) \propto -\sqrt{\frac{\rho^*(\Delta,\Omega_2)}{\beta_x(s)}}$$

$$\rho^*(\Delta,\Omega_2) \simeq -\frac{2\pi\Delta}{\Omega_2} \quad \begin{cases} \Delta = Q_x - \overline{Q}_x \\ \Omega_2 = \text{detuning coefficient} \end{cases}$$

On-axis inj/ext without septum magnets

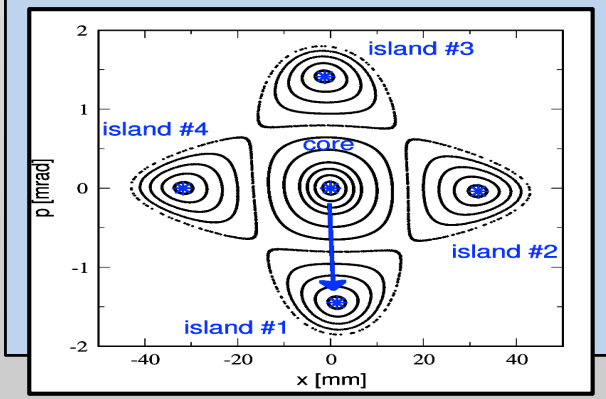
Fast Extraction with 4th order resonance



step 1: generate (though do not populate) four islands. the beam remain on axis

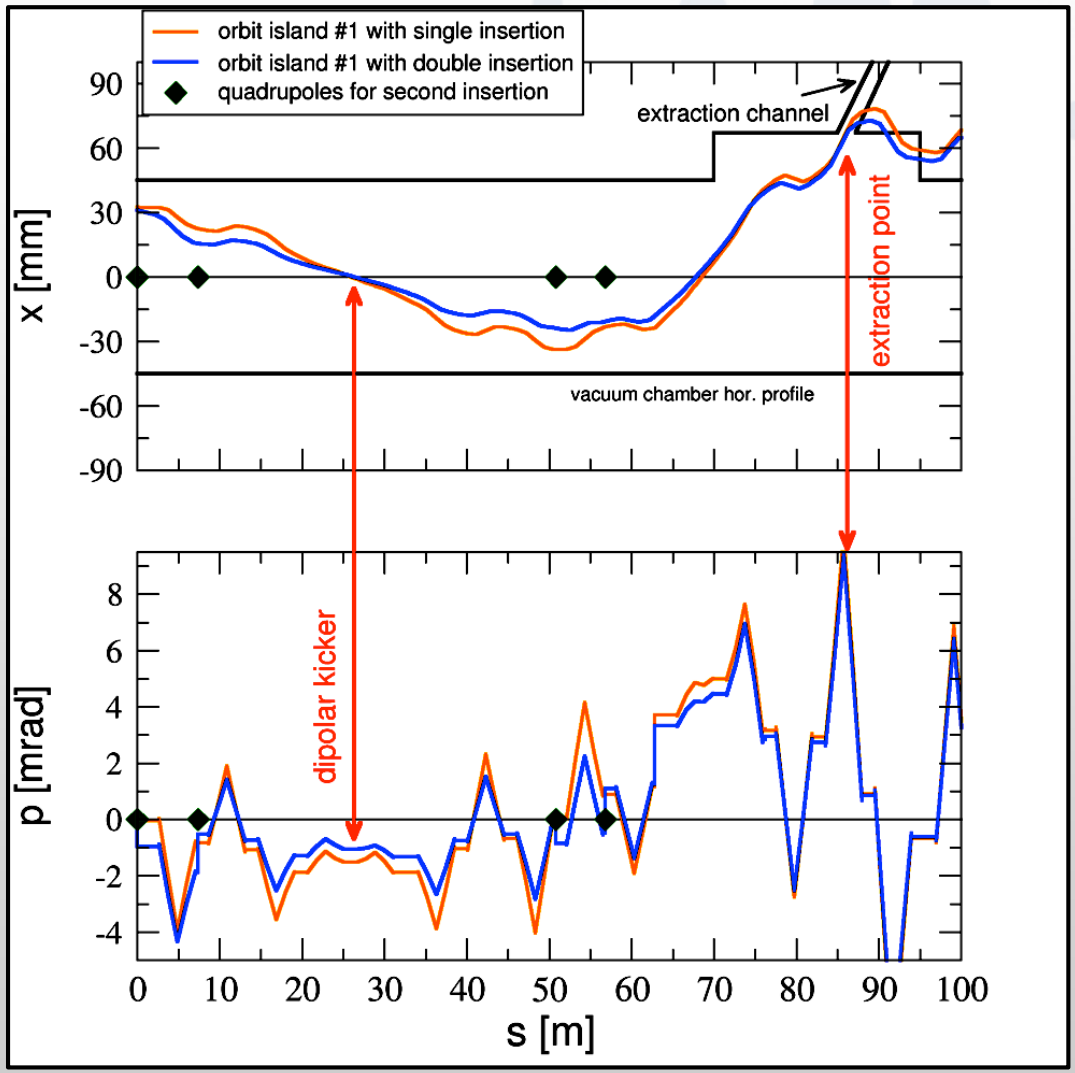
step 2: introduce the insertion optics via quadrupole bumpers, not kickers (actually not needed)

step 3: install and pulse a dipole kicker at a waist to move the beam from the axis to the island



On-axis inj/ext without septum magnets

Fast Extraction with 4th order resonance



step 1: generate (though do not populate) four islands. the beam remain on axis

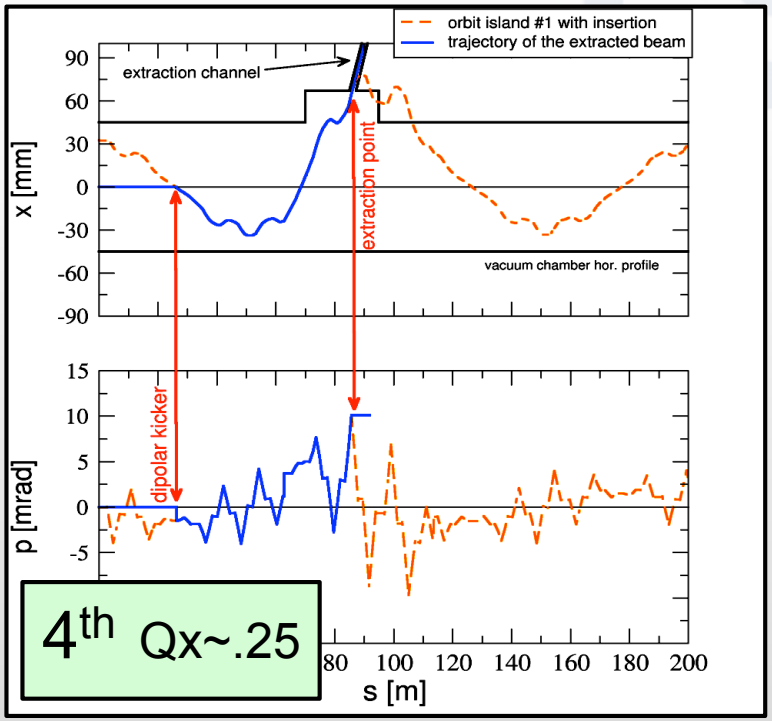
step 2: introduce the insertion optics via quadrupole bumpers, not kickers (actually not needed)

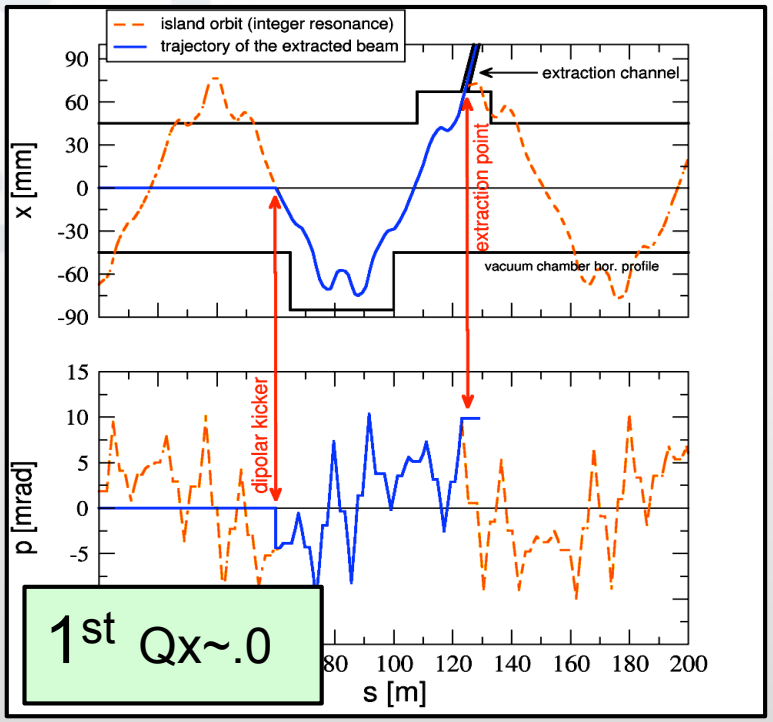
step 3: install and pulse a dipole kicker at a waist to move the beam from the axis to the island

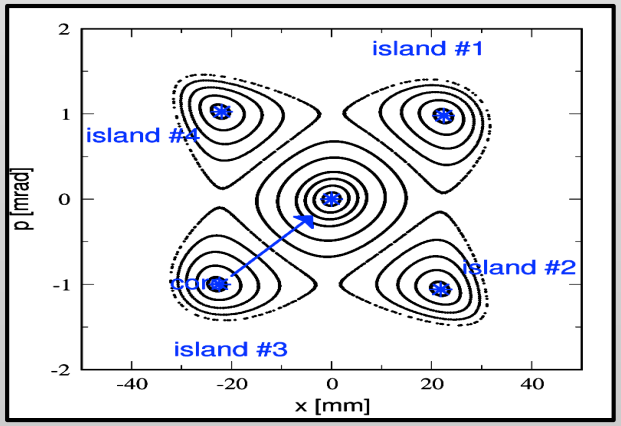
step 4: introduce an insertion optics around the waist (i.e. the kicker) to increase β_x and hence to reduce p_x & kicker strength

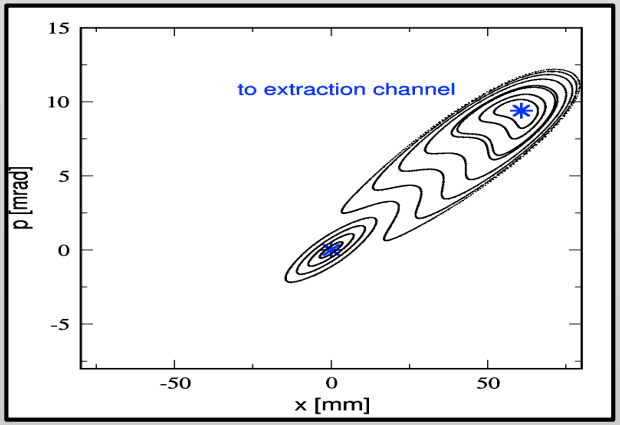
On-axis inj/ext without septum magnets

Fast Extraction with N^{th} order resonance









On-axis inj/ext without septum magnets

Septum-less fast extraction (injection)

- nonlinear optics designed to generate N unpopulated stable islands with one orbit suitable to enter the extraction channel (with quadrupole bumpers only, though not needed)
- only one dipole kicker is needed, whose strength may be minimized with high-β insertion optics

septum-less fast injection:

- as above, look at the plots from right to left.