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EMMA recent results
- Aperture and orbital period -

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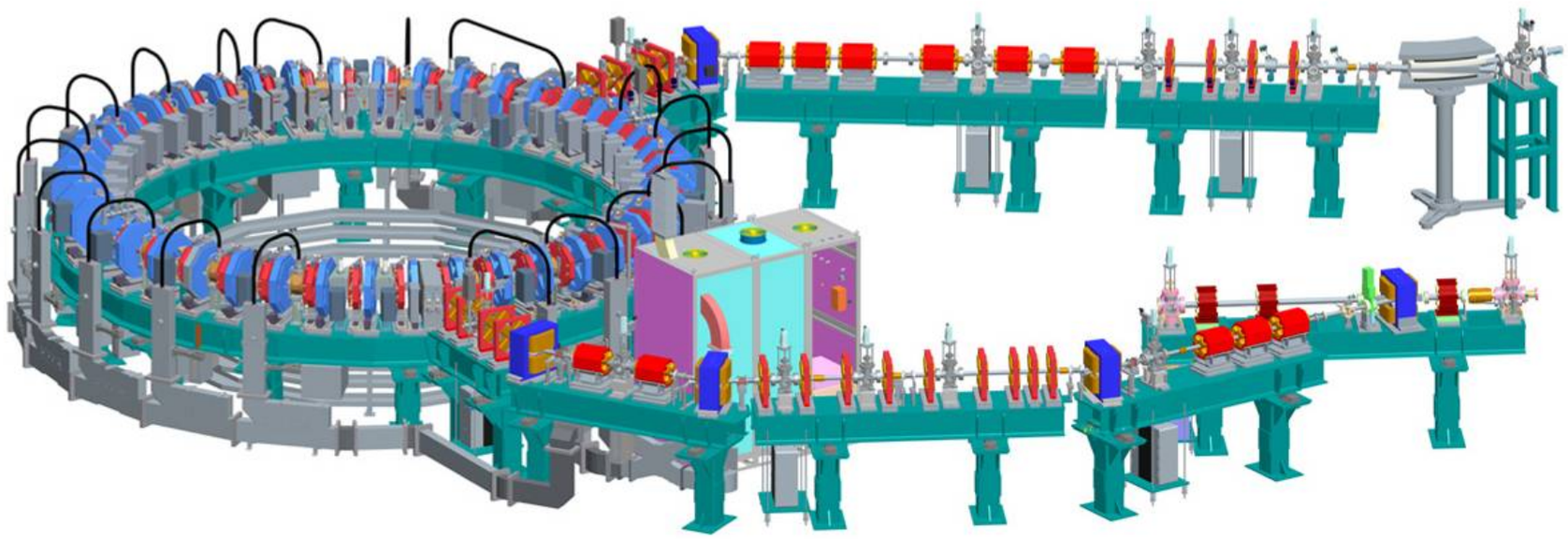
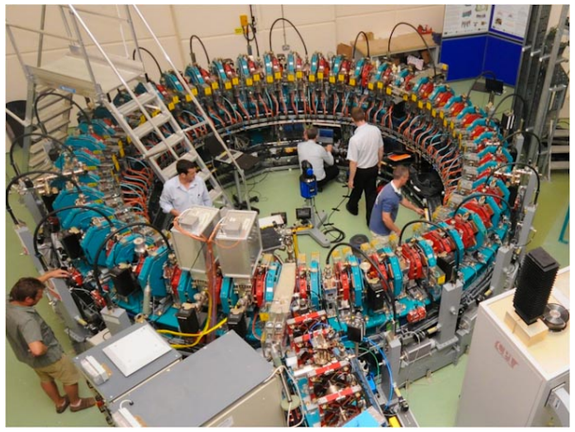
on behalf of the EMMA group
ASTeC/STFC Rutherford Appleton Laboratory
13-16 November 2012

Short introduction of EMMA (1)

- EMMA (Electron Model for Many Application) is the first non-scaling FFAG.
- It was constructed at Daresbury Laboratory purely for accelerator study.
- Use electron beams from ALICE injector.

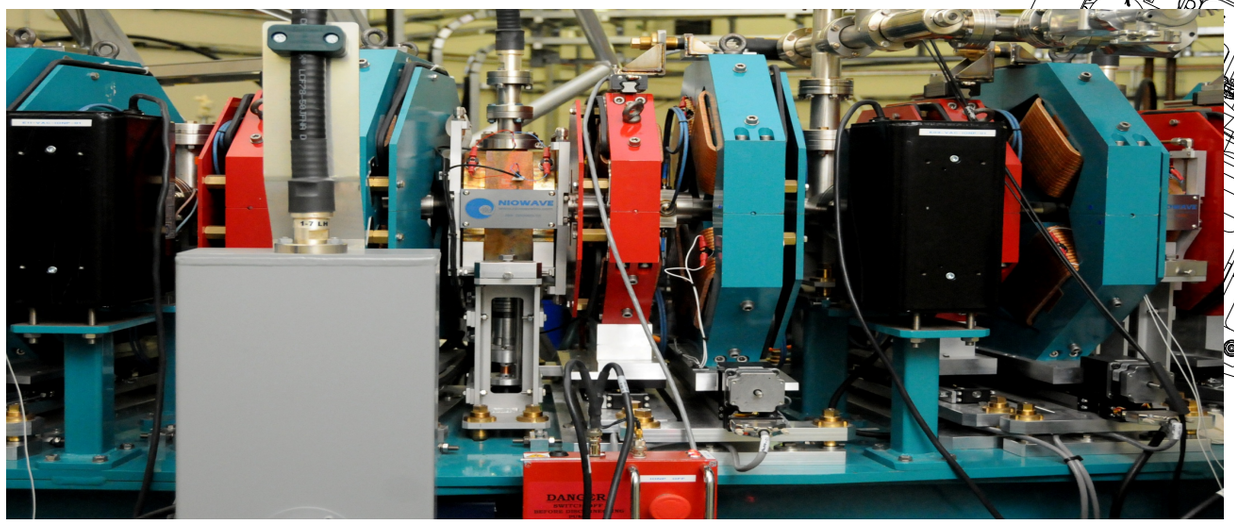




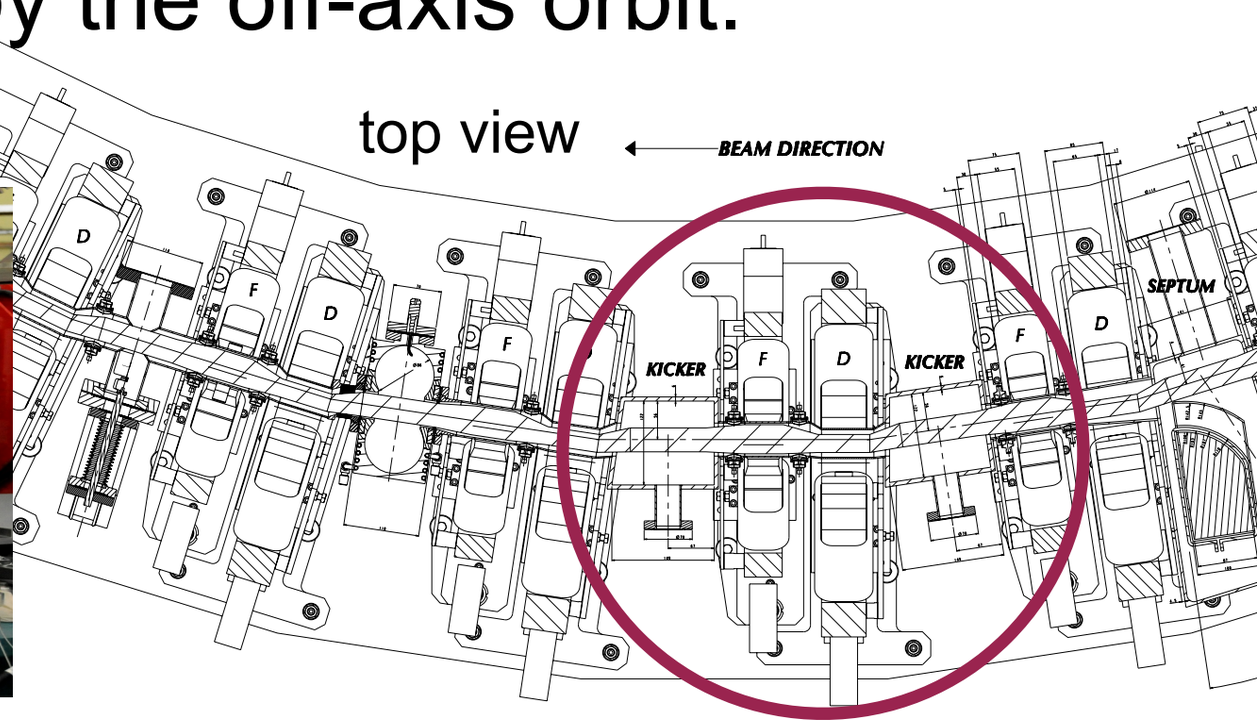
Short introduction of EMMA (2)

- Only linear gradient magnets (quadrupole) are used.
- Bending action is provided by the off-axis orbit.

side view



top view



- Looks similar to synchrotron, but field is constant.

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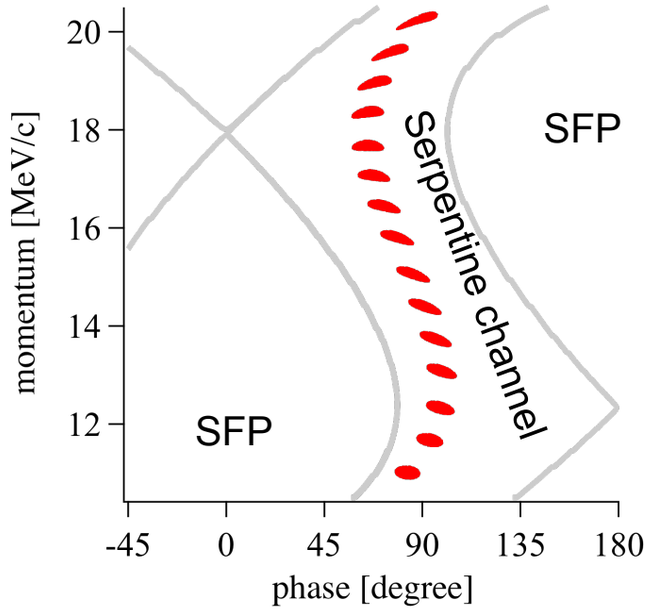
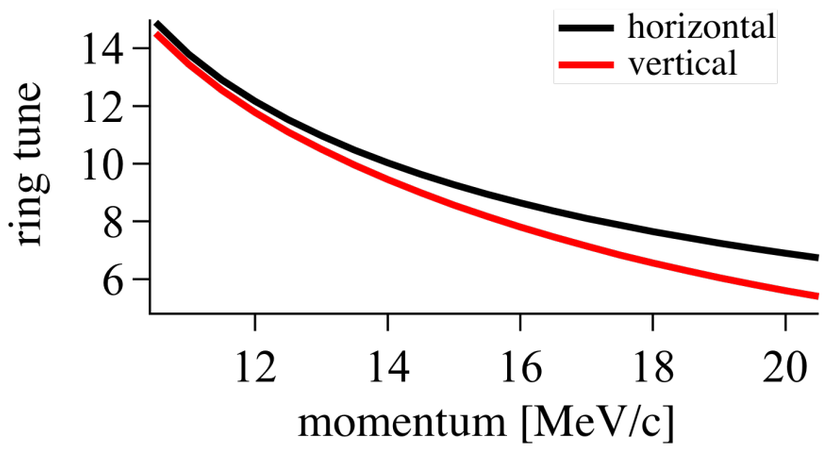
Short introduction of EMMA (3)

- Three main goals.

  - Acceleration in serpentine channel (outside rf bucket) in around 10 turns.





  - Large tune variation due to natural chromaticity during acceleration.

- Large acceptance for huge (muon) beam emittance.

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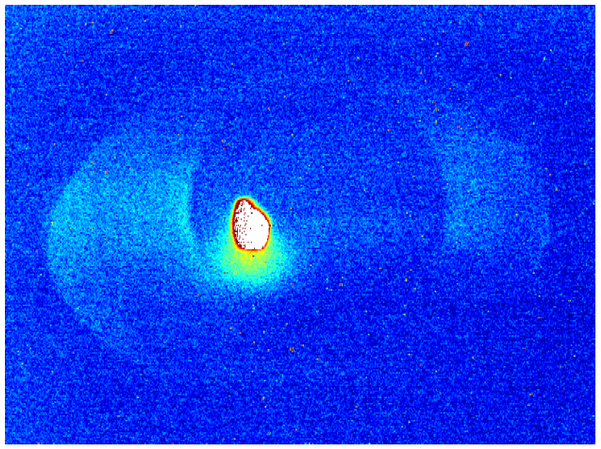
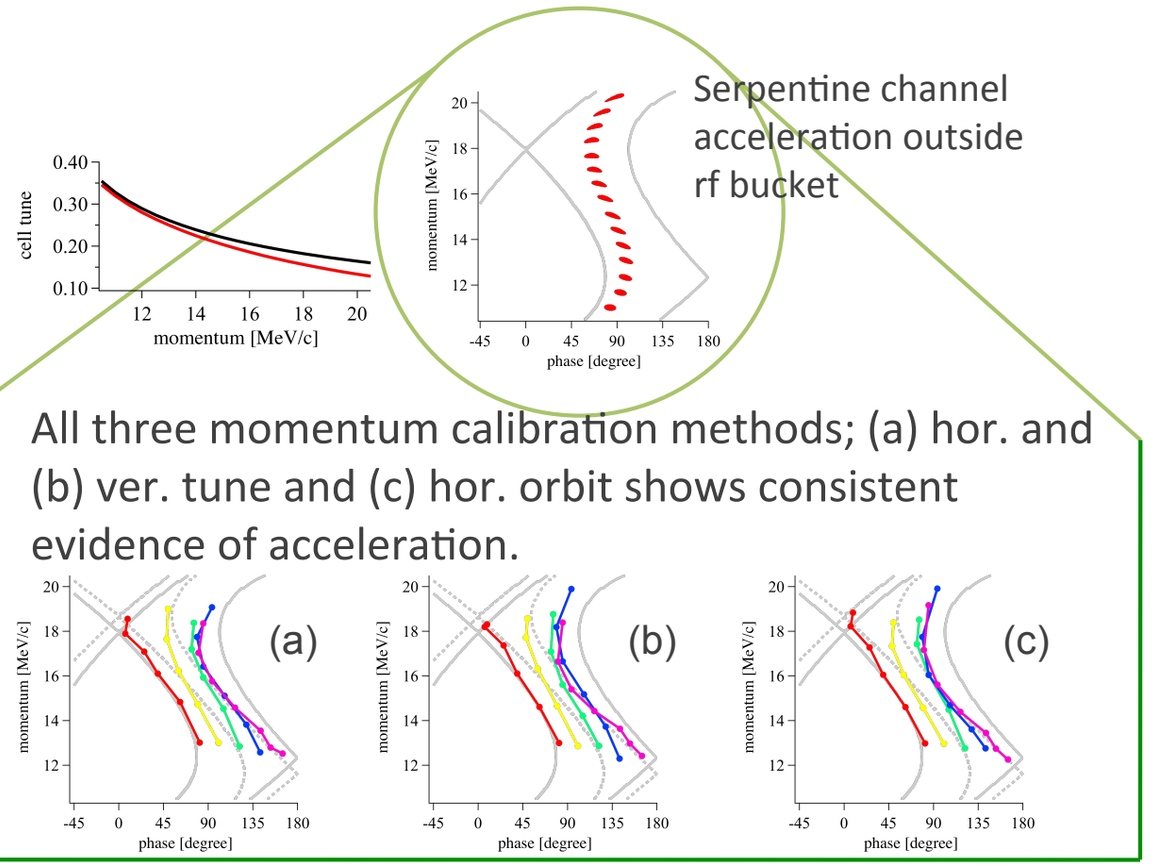
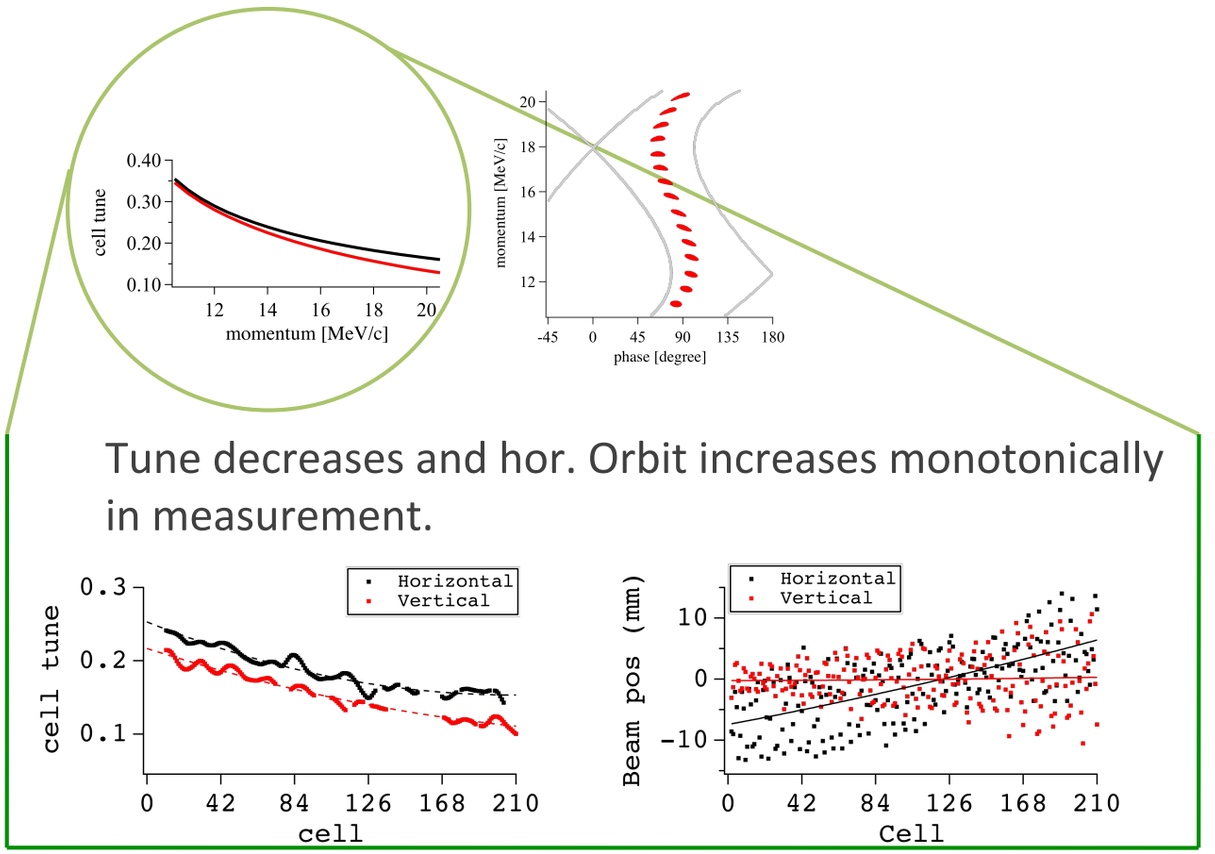


extracted beam

Short introduction of EMMA (4)

- Two of main goals were achieved in March 2011.





Machida *et al*., Nature Physics 8, 243 (2012)

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Since last year

- Study of COD and its correction (next talk by David) had the top priority because everything else would become easier and nicer.
- Aperture survey at fixed momentum.
- Amplitude dependent orbital period.
- Experiment for PRISM demonstration.
- Tune crossing experiment.
- Less priority among ALICE/EMMA project.
- A lot of hardware troubles.
  - No rf since April 2012
  - Unstable kickers

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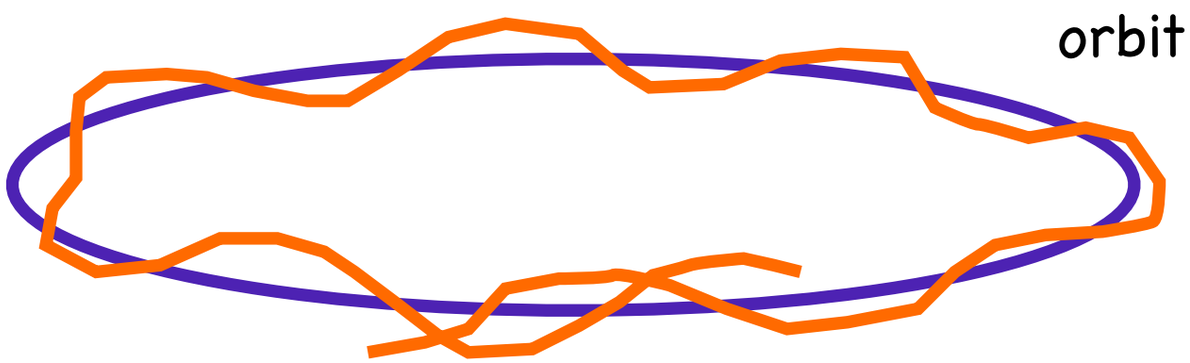
Aperture survey and amplitude dependent orbital period

- Muon acceleration in a non-scaling FFAG is one of the main driving forces of the development.
- Muon beam has large emittance, 30,000 pi mm mrad (normalised).
- Demonstration of large aperture of this type of FFAG.
- Experimental confirmation of amplitude dependent orbital period.

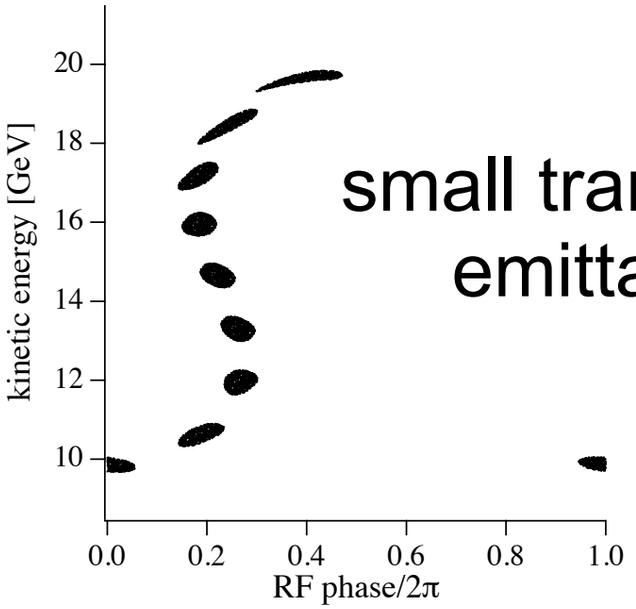
Amplitude dependent orbital period

- A particle with small betatron oscillations (blue) circulates faster than the one with large betatron oscillations (red).

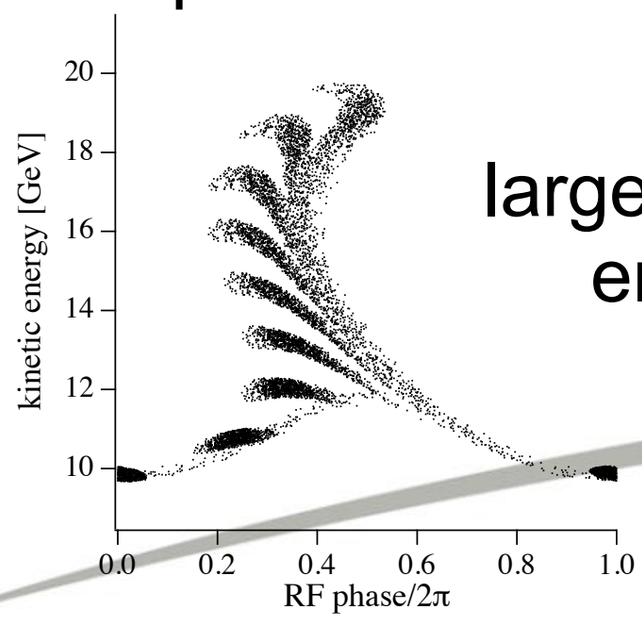


- This different becomes significant for muon beams whose emittance is huge.

longitudinal phase space



small transverse emittance



large transverse emittance

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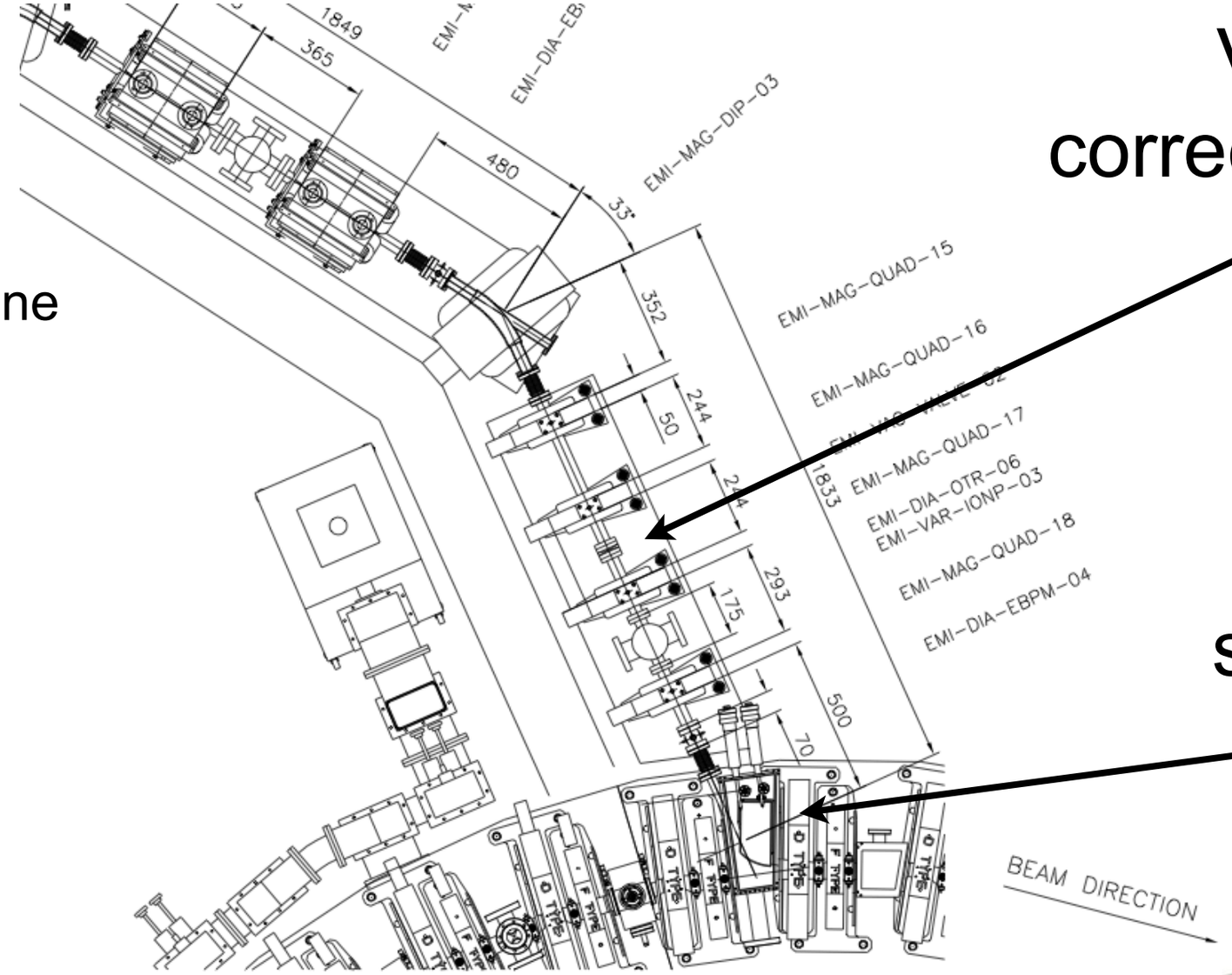
Aperture survey and amplitude dependent orbital period measurement (1)

- In practice, these two measurements can be done at the same time.
  - Deflect a beam orbit before the injection point in horizontal and/or vertical direction.
  - The larger deflection makes the larger initial transverse amplitude.
  - The range of deflection which gives successful injection tells transverse aperture.
  - The orbital period measurement for each deflection (or each transverse amplitude) tells amplitude dependent orbital period.

Aperture survey and amplitude dependent orbital period measurement (2)

- Knobs to deflect a beam and scan the phase space.

injection line



Vertical:
corrector strength

Horizontal:
septum strength

EMMA ring

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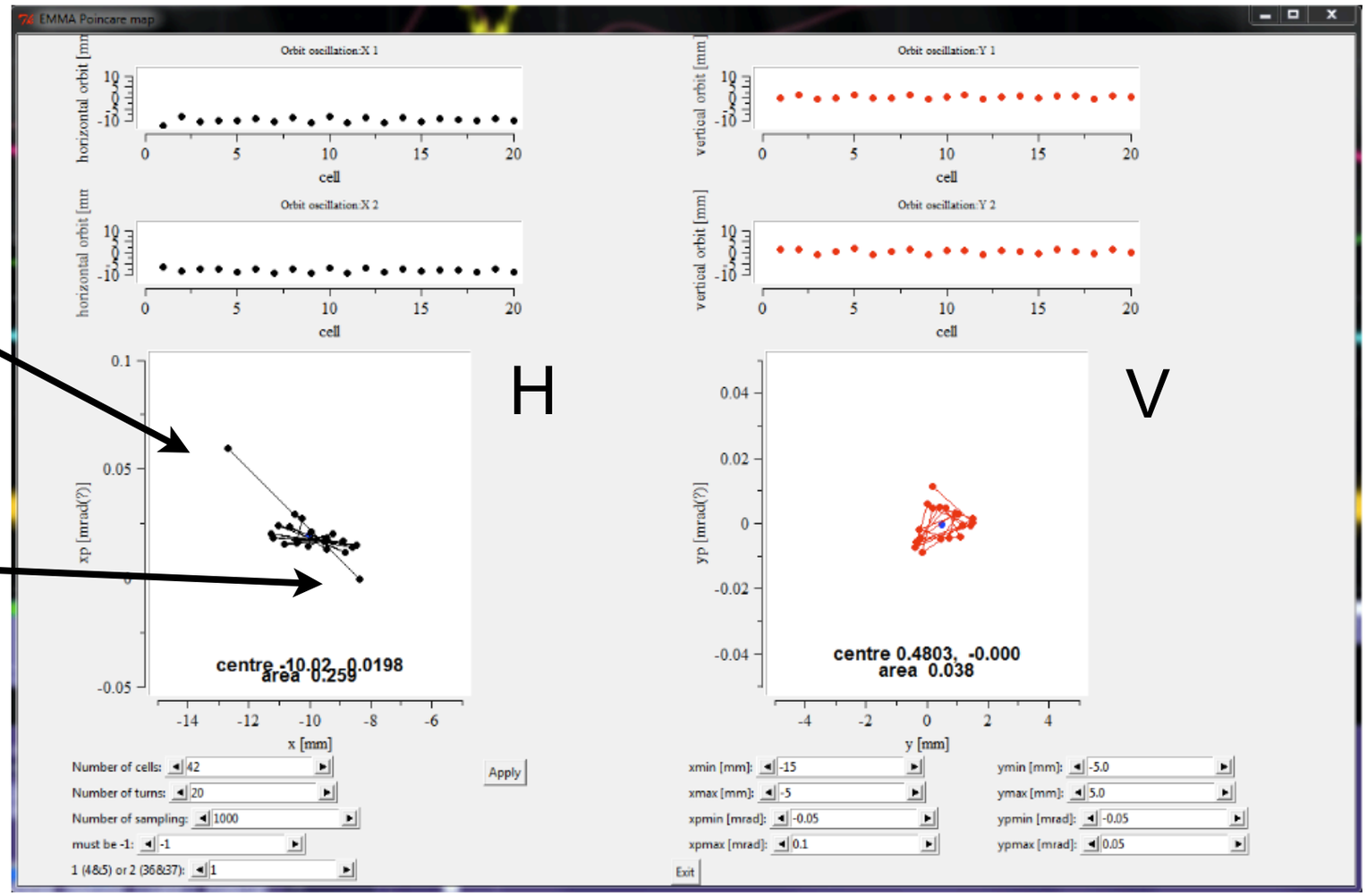
Poincare monitor

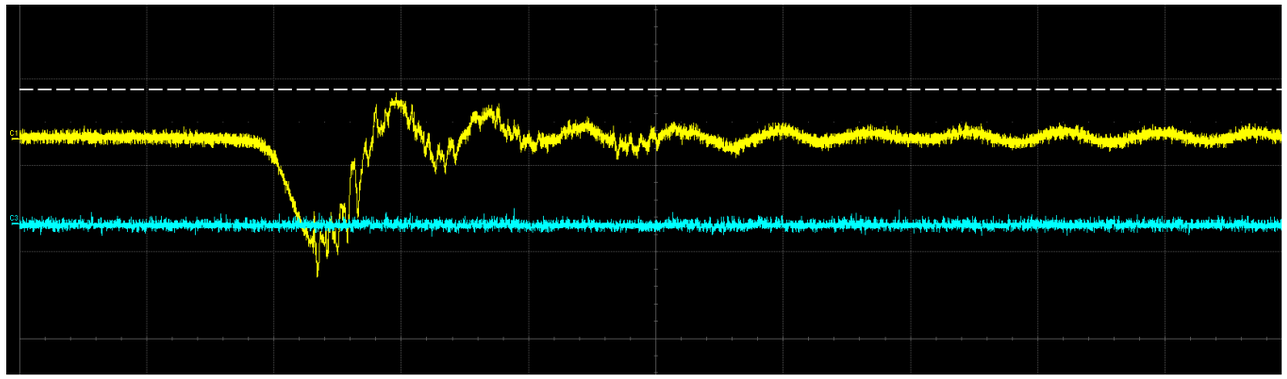
- Online Poincare monitor tells where a beam is injected.

This is before kickers.

Kicker kicks at the second turn also.



50 ns (cf. 55 ns/turn)



kicker signal

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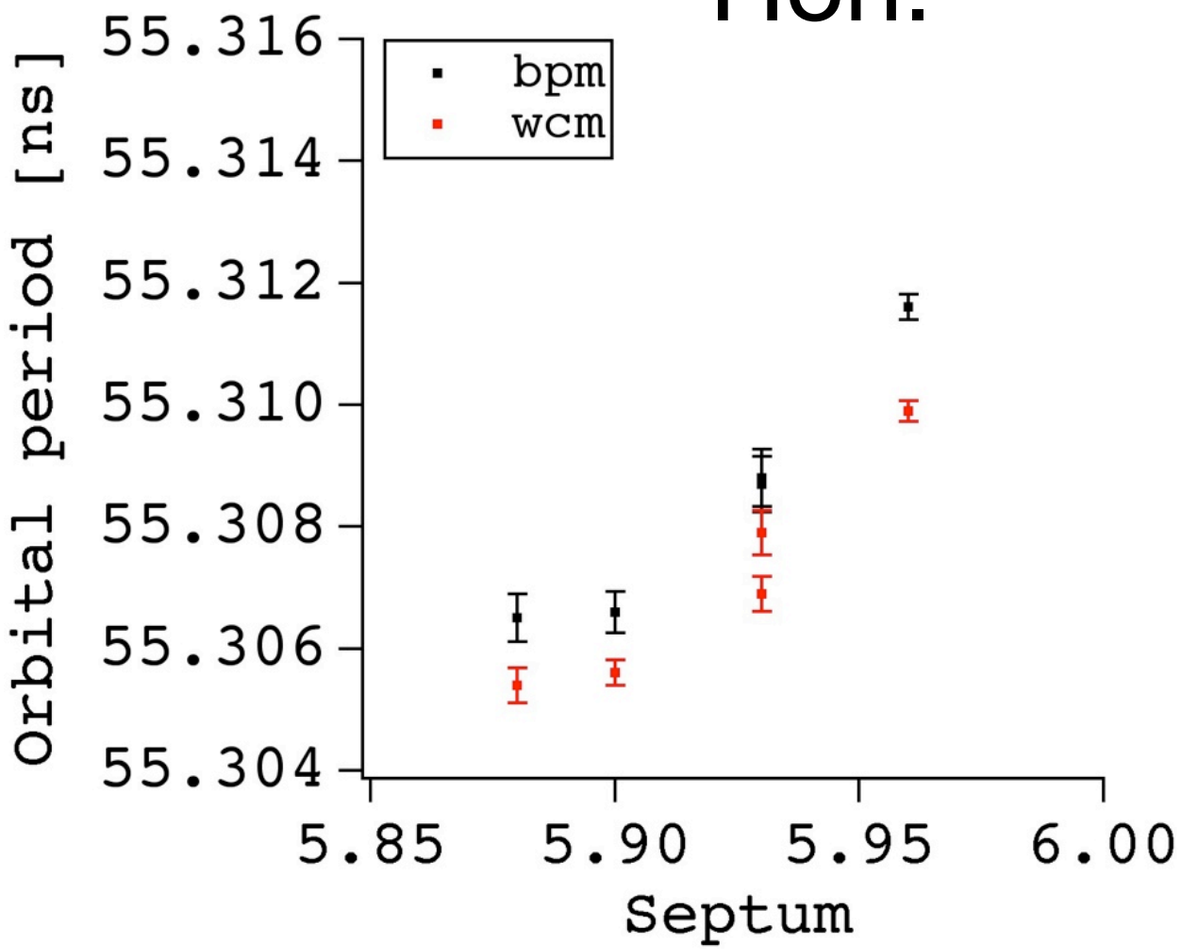
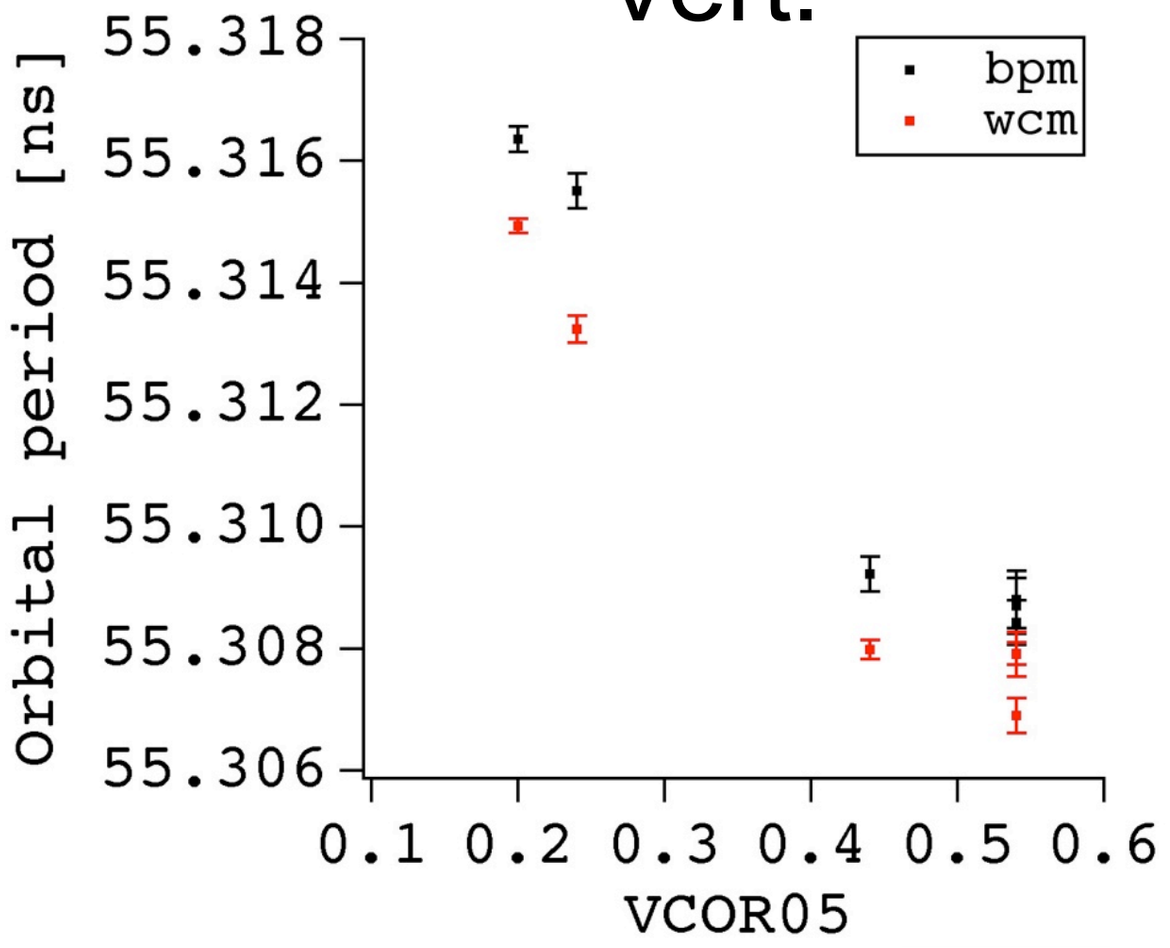
Experimental results (preliminary)

- Measurement at 16.15 MeV/c.

Hori.



Vert.



Theory

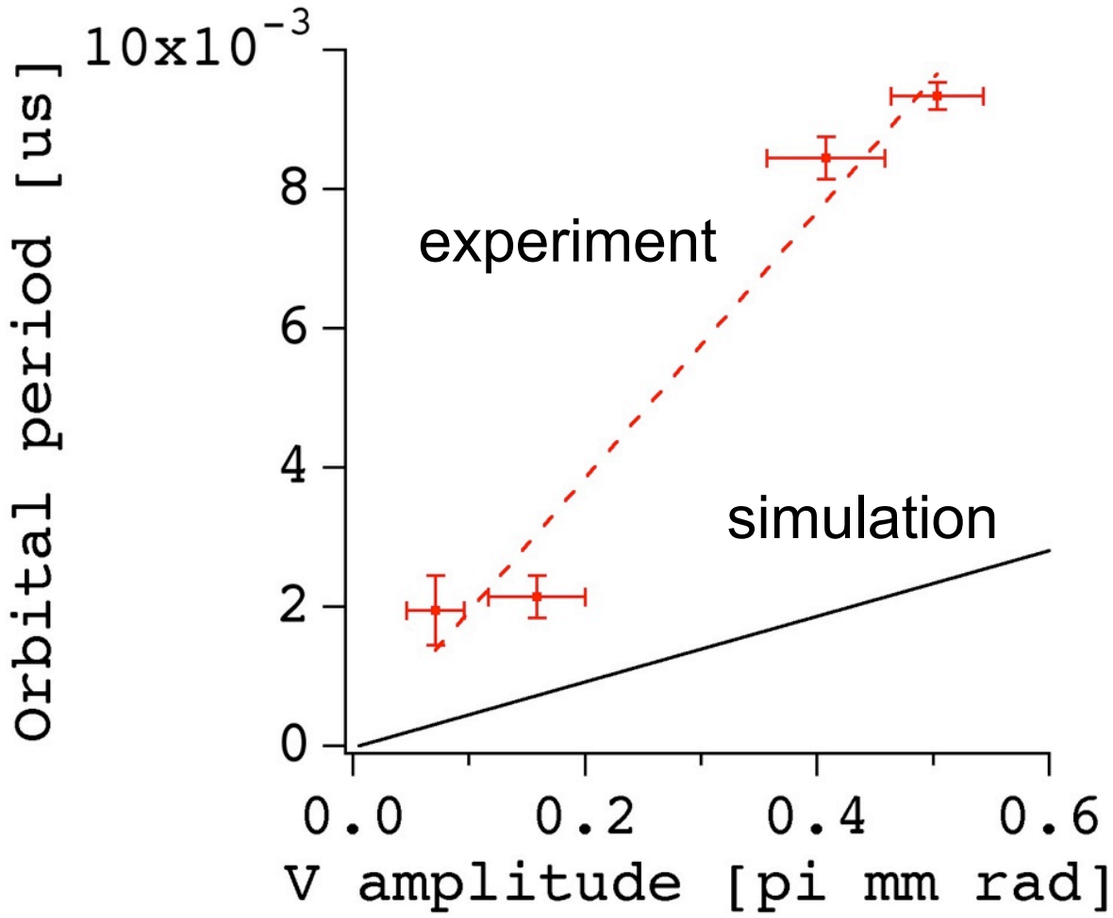
- We know that orbital period depends on the transverse amplitude as (Berg, NIMA 570 15 (2007))

$$\Delta t \propto \xi J + O(J^{3/2})$$

- where *xi* is chromaticity and *J* is transverse amplitude (or action).

Comparison (preliminary) between experiment and simulation

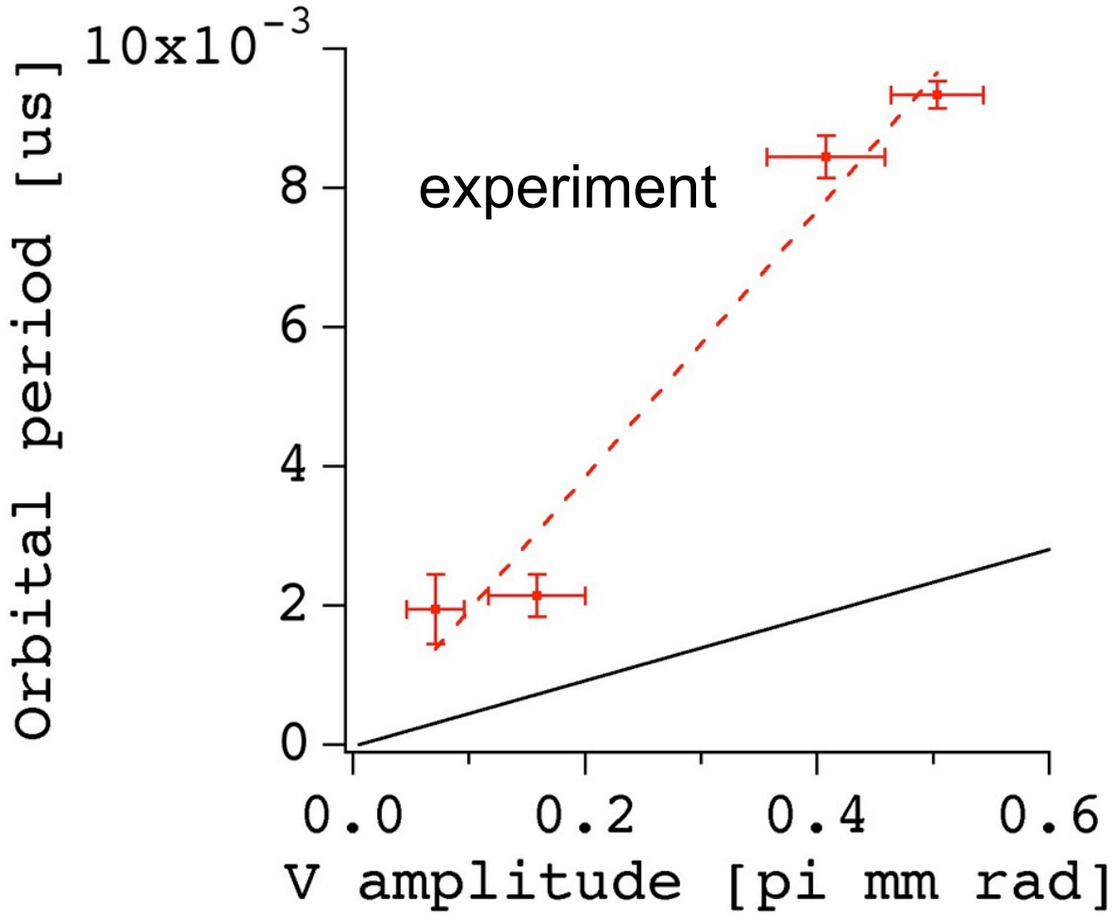
- Data taken on 3/4 October
- Does not show good agreement
  - Assuming horizontal amplitude is zero.
  - Beta function is wrong?



- Another set of data was taken on 8 October, but not analysed yet.

Measured aperture without COD correction

- The same figure also shows that there is an aperture limit around 0.5 ~ 0.6 pi mm rad.
- Design value is 3 pi mm rad.



- This is obviously due to large closed orbit distortion.

Summary

- Preliminary results of amplitude dependent orbital period does not agree with simulation. Need to find out the source of discrepancy.
- Aperture is smaller than the design value. However, we know that COD of a few mm could reduce the aperture a lot.
- More systematic measurements are going on.