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BASROC CONFORM

# First results from the EMMA experiment

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for the EMMA collaboration

ASTeC/STFC/RAL

New Acceleration Techniques session at IPAC11

06 September 2011

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# Contents

- Demands for new accelerator (10 slides)
- EMMA commissioning results in 2010 (10 slides)
- EMMA commissioning results in 2011 (7 slides)
- Future plans (3 slides)

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- Demands for new accelerator
- EMMA commissioning results in 2010
- EMMA commissioning results in 2011
- Future plans

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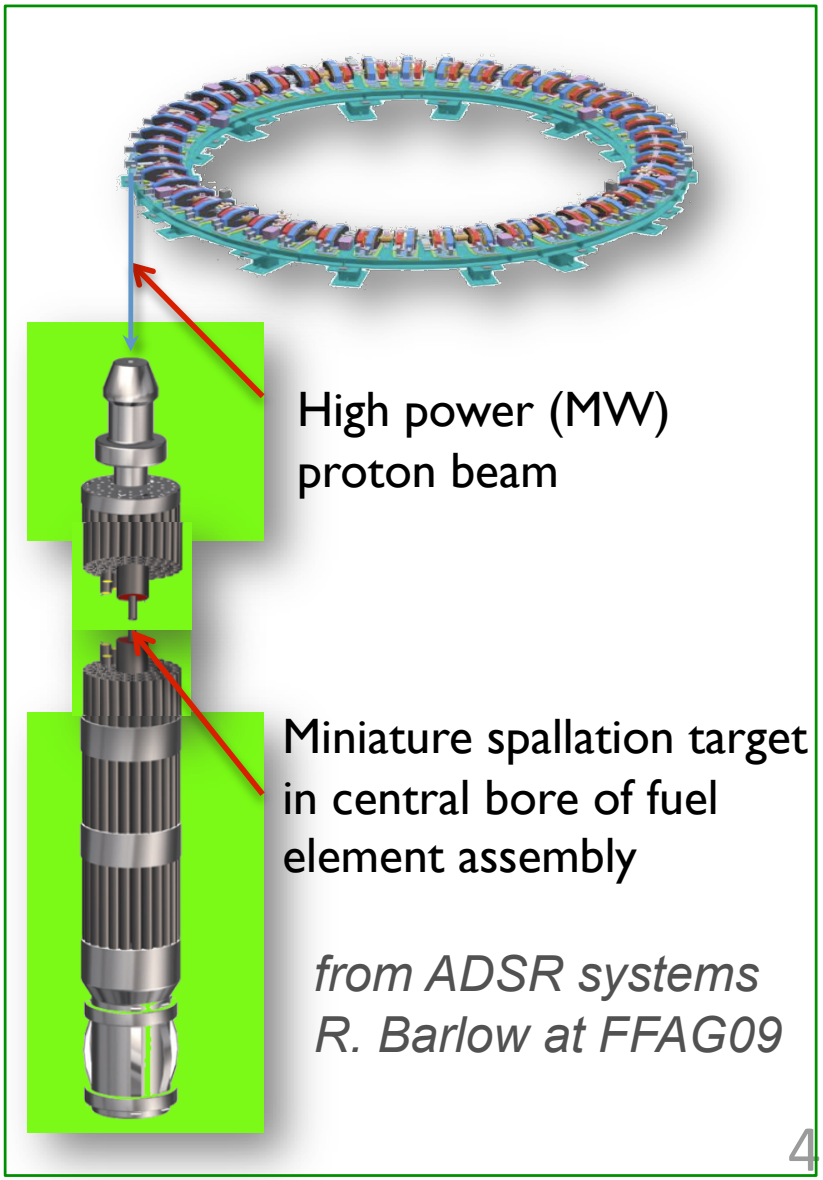
# High power hadron accelerator

- ADSR (Accelerator Driven Subcritical Reactor)
- Neutron and muon production

Accelerator beyond SNS, J-PARC, ESS.



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# Muon accelerator in neutrino factory and muon collider

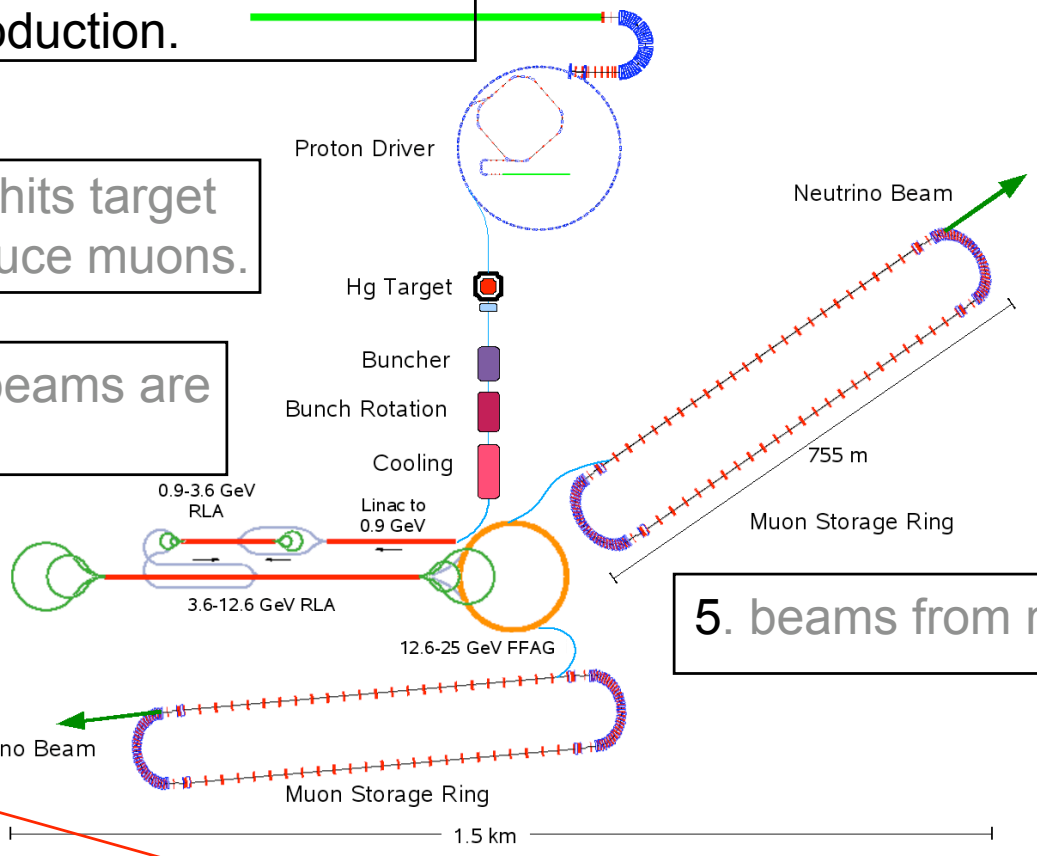
1. High power proton beam for muon production.

2. Proton hits target and produce muons.

3. Muon beams are cooled.

4. Acceleration of muon beams to 20-50 GeV.

5. beams from muon decay.




Quick acceleration of a large emittance beam.

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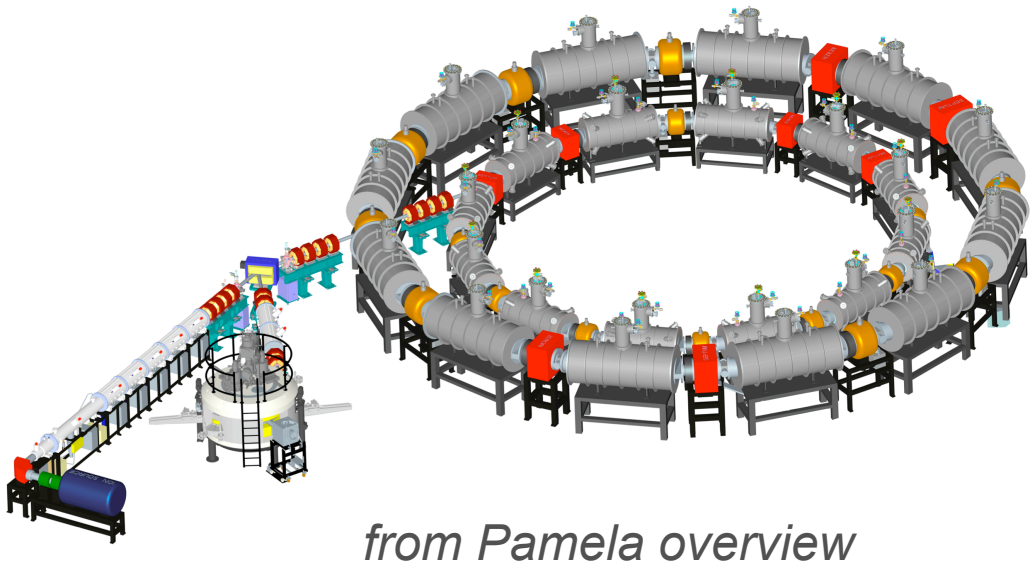
# Accelerator in other area

- Particle therapy
- Industrial applications

Accelerator which is compact and flexible.



*from Pamela overview*
*S. Sheehy at FFAG10*

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# What about Fixed Field Alternating Gradient accelerator?

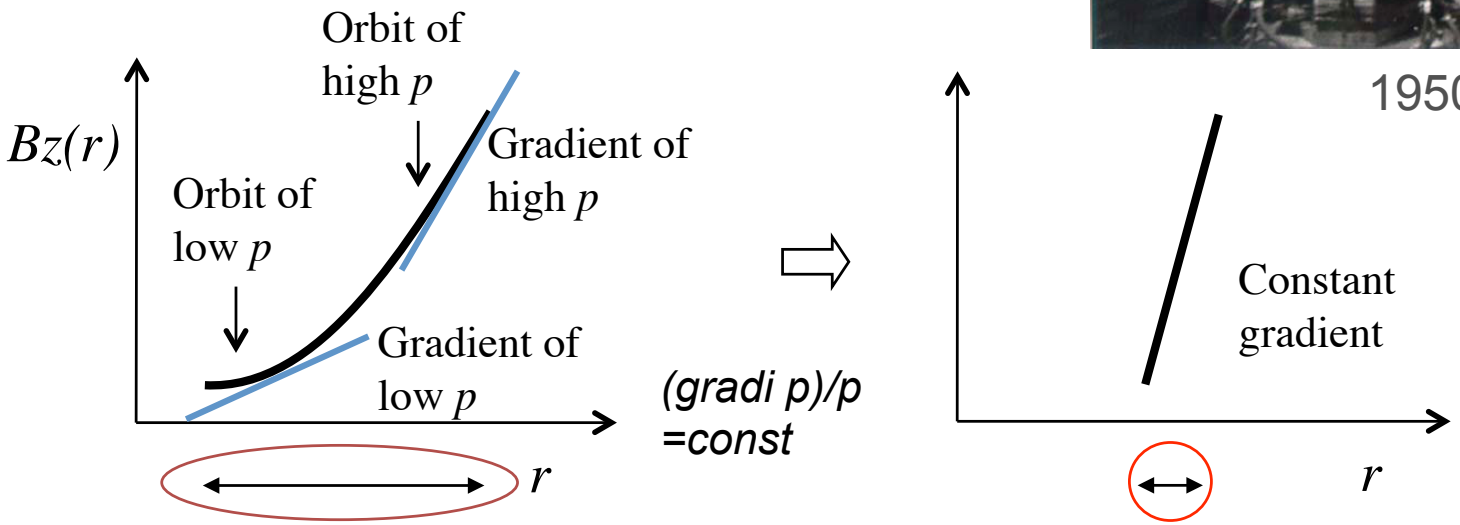
- Fixed field magnets enables quick acceleration.
  - Beam power can be increased with high repetition.
  - Acceleration within muon lifetime is possible.
- Similar momentum range with synchrotron.
- Fixed field magnets provide flexibility and reliability.

# Non-scaling FFAG

- FFAG idea is old, however, simplified design called non-scaling FFAG strengthens the advantages.


1950s

- From scaling to non-scaling FFAG



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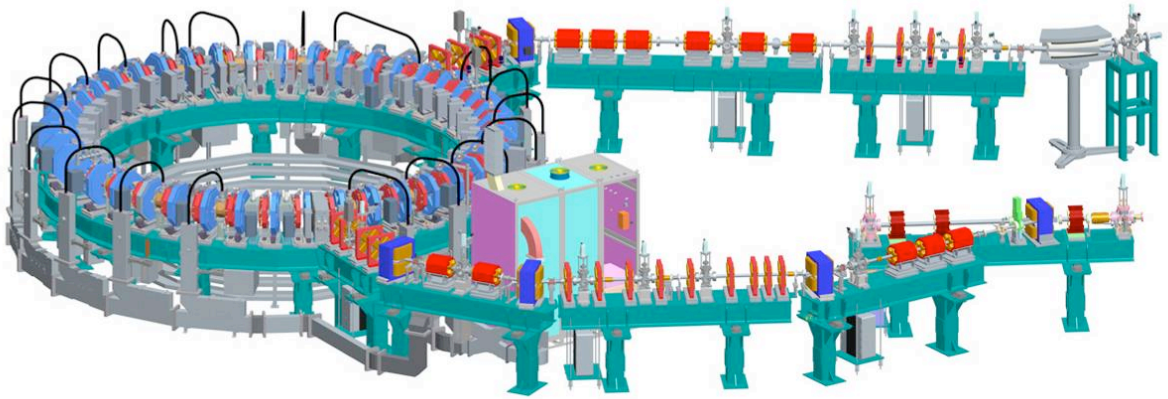
# ns-FFAG works as expected?

- Demonstration of a linear non-scaling Fixed Field Alternating Gradient accelerator was long waited.



- EMMA is

  *Electron Model for Many Applications*

- Although initial experiment more focuses on

  *Electron Model of Muon Acceleration*

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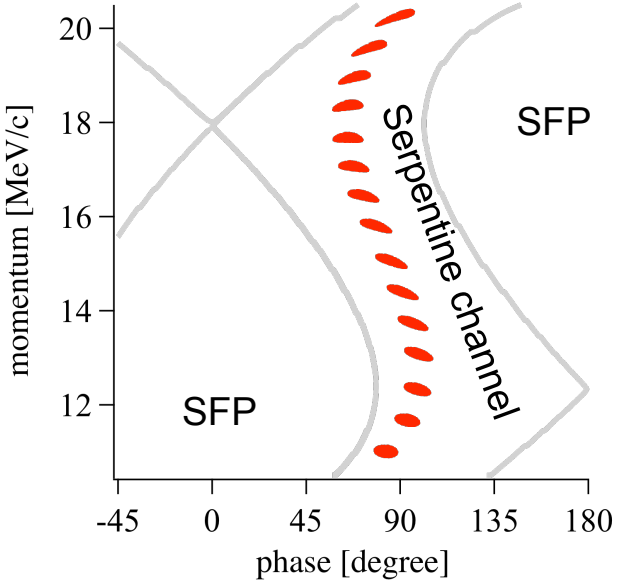
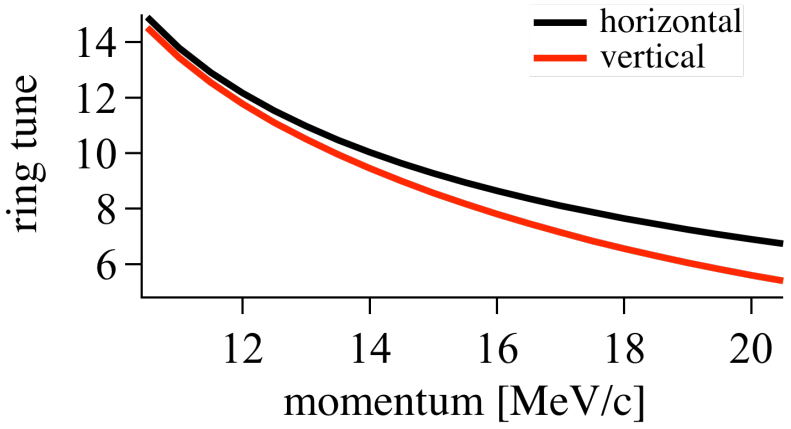
# Three main goals

- 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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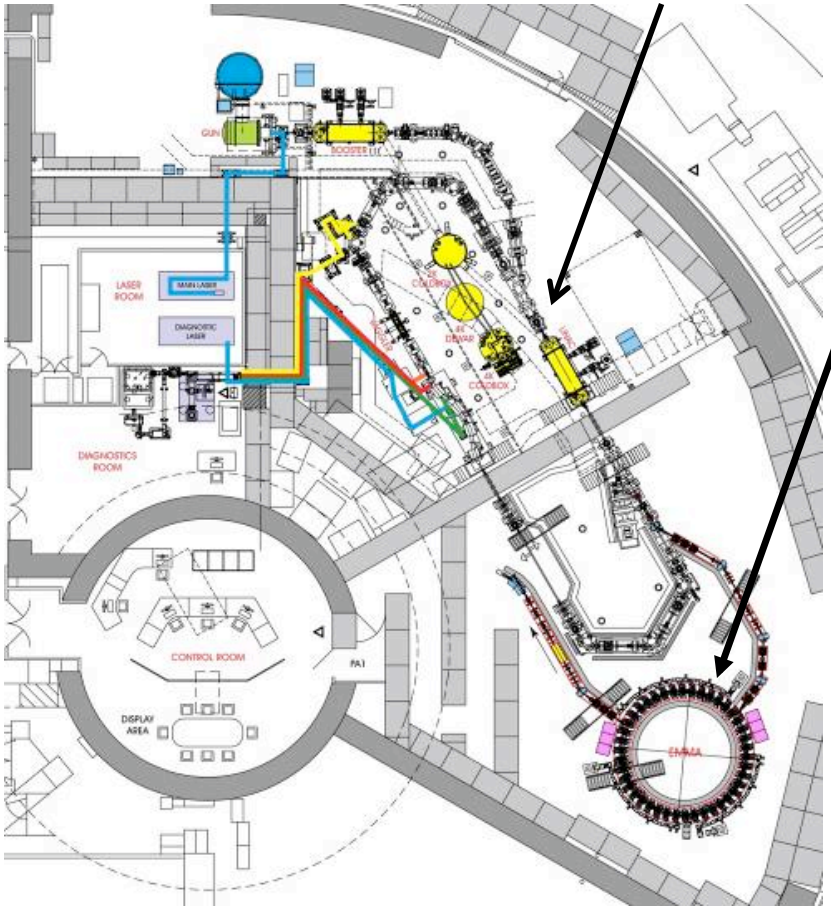
# ALICE/EMMA at Daresbury

## Accelerators and Lasers in Combined Experiments




| Parameter | Value |
|---|---|
| Particle | electron |
| Momentum | 10.5 to 20.5 MeV/c |
| Cell | 42 doublet |
| Circumference | 16.57 m |
| RF Frequency | 1.301 GHz |
| RF voltage | 2 MV with 19 cavities |

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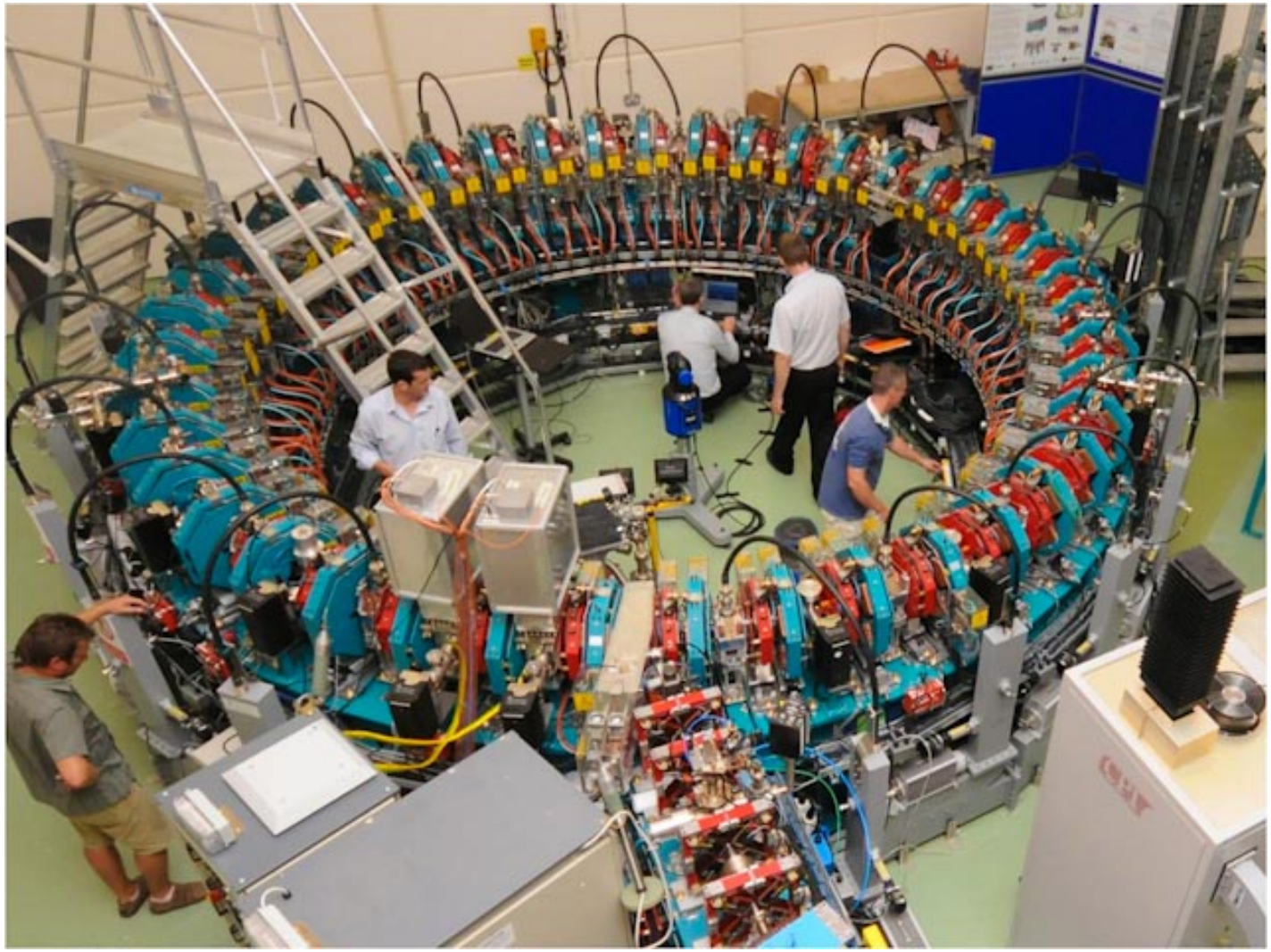
# EMMA in pictures (1)



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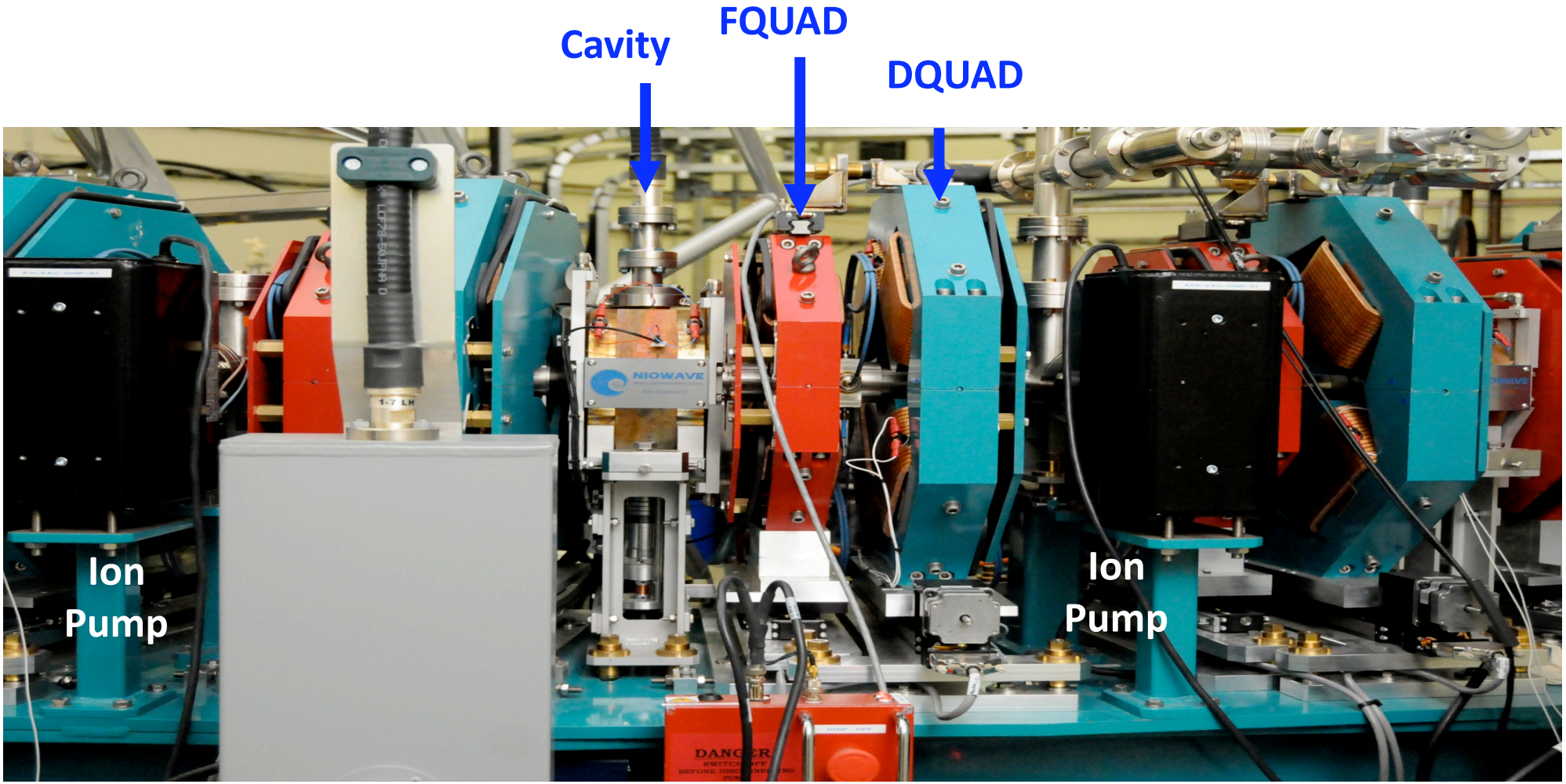
# EMMA in pictures (2)




- Demands for new accelerator
- EMMA commissioning results in 2010
- EMMA commissioning results in 2011
- Future plans

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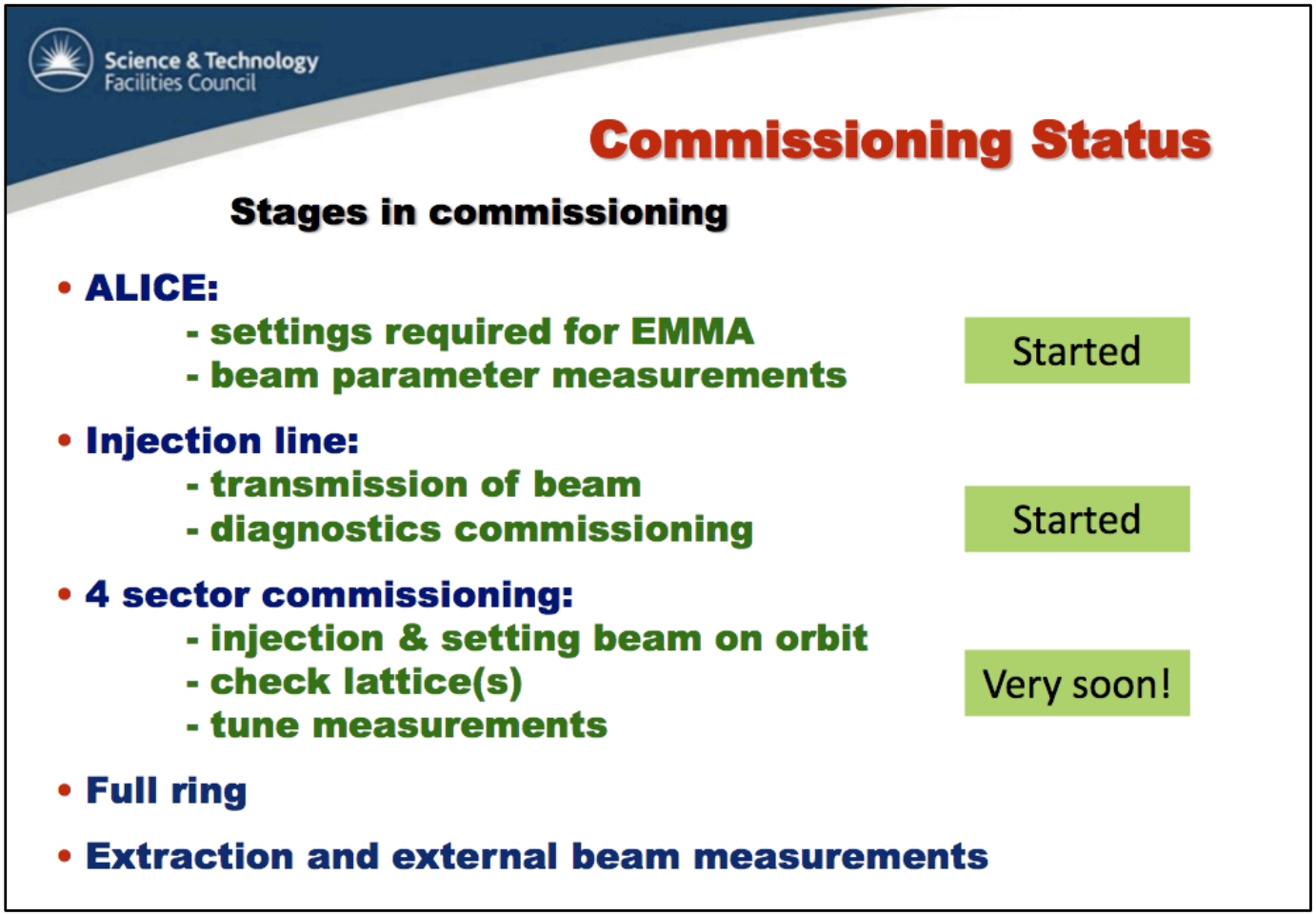
# Where we were last year

- Presentation at IPAC10 by R. Edgecock



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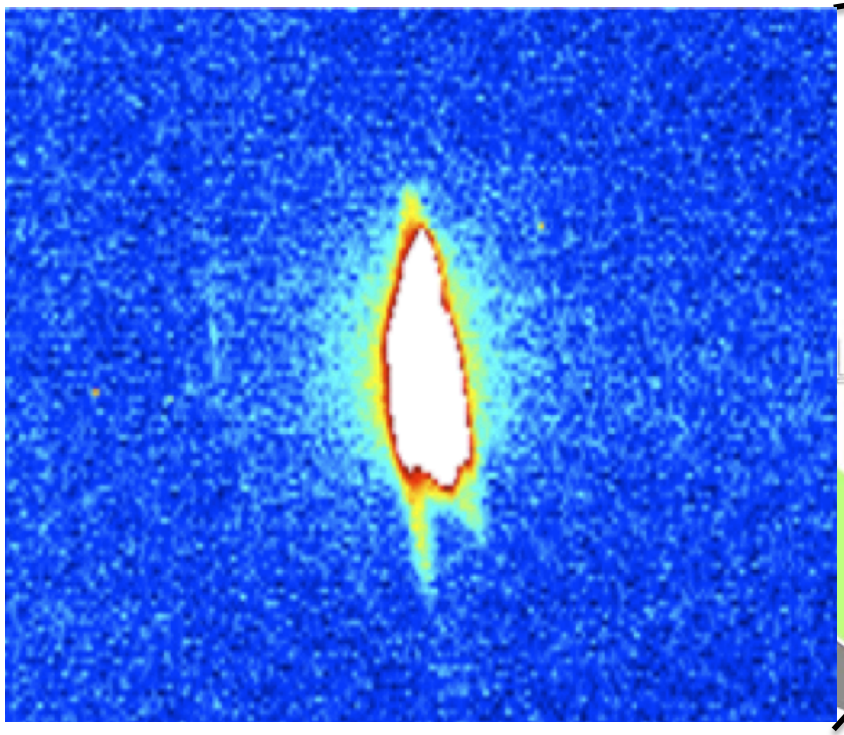
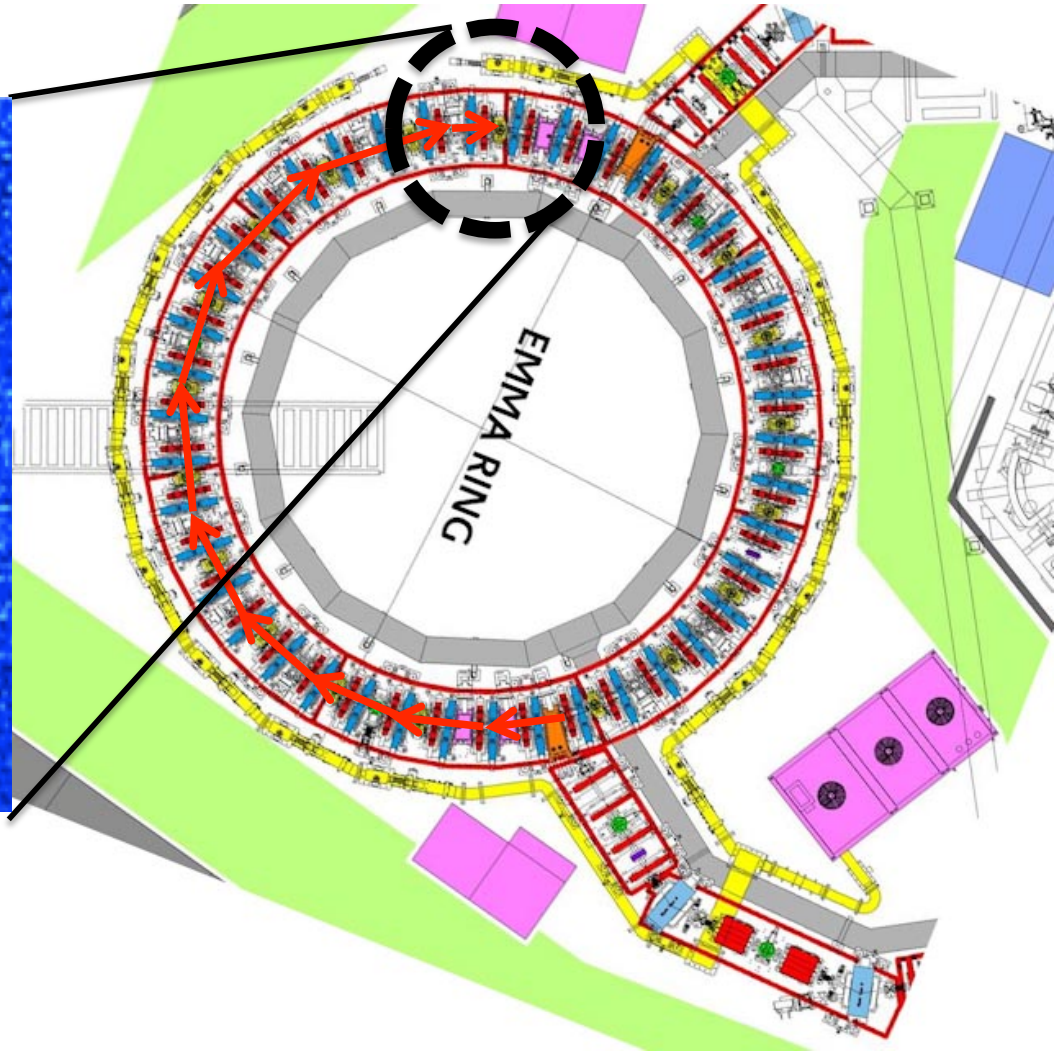
# Four sector commissioning

- Beam image on screen at the end of 4 sectors.

  22:37 on 22 June 2010





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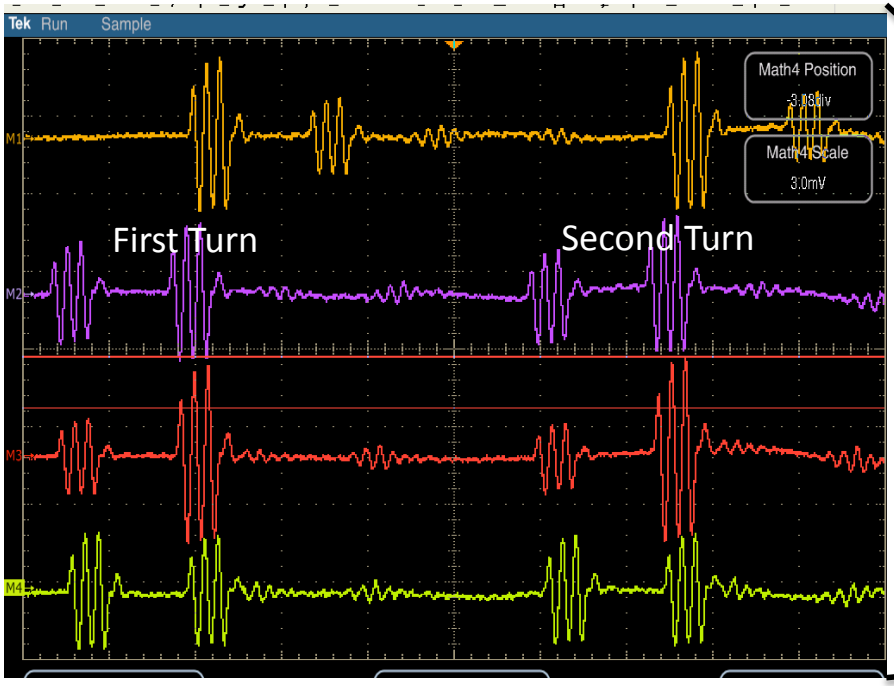
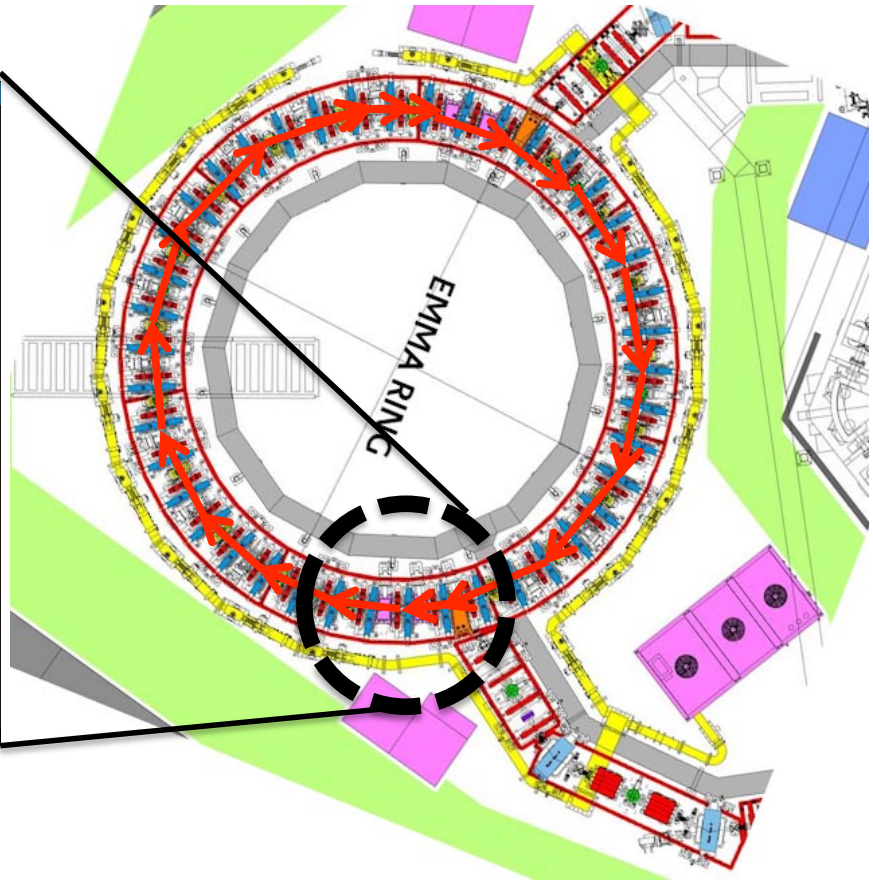
# Complete ring

- A beam circulates first for three turns and then for thousands of turns a few day later.

  16 August 2010



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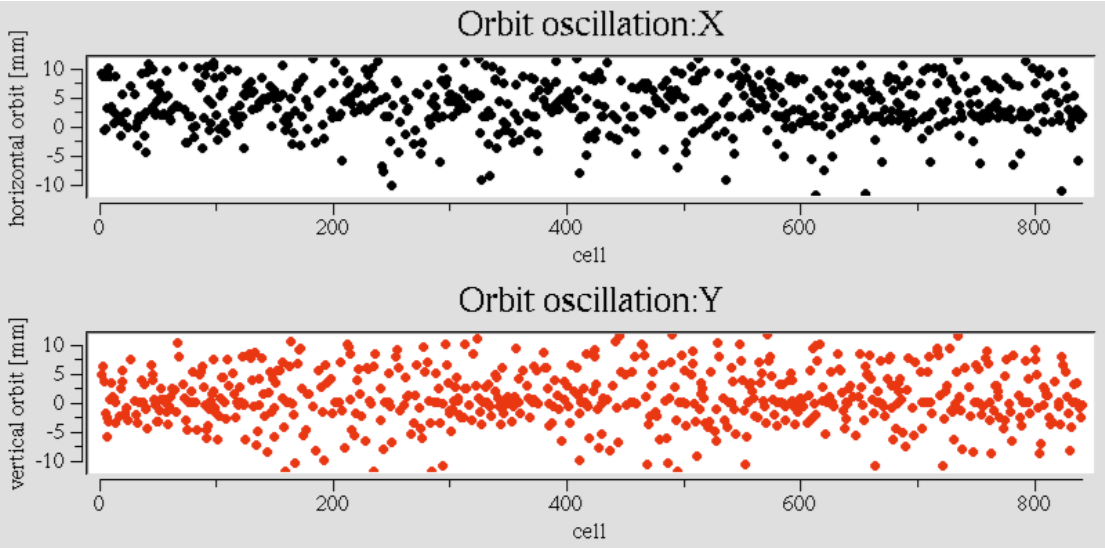
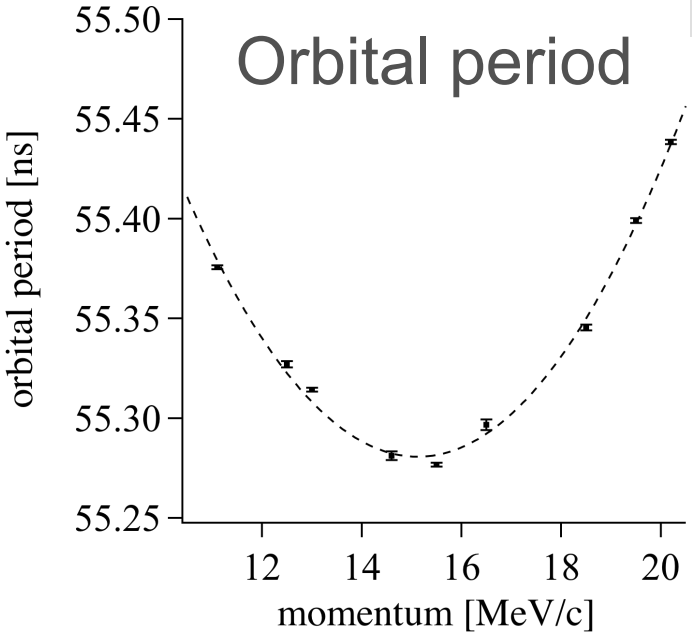
# Measurement of basic parameters

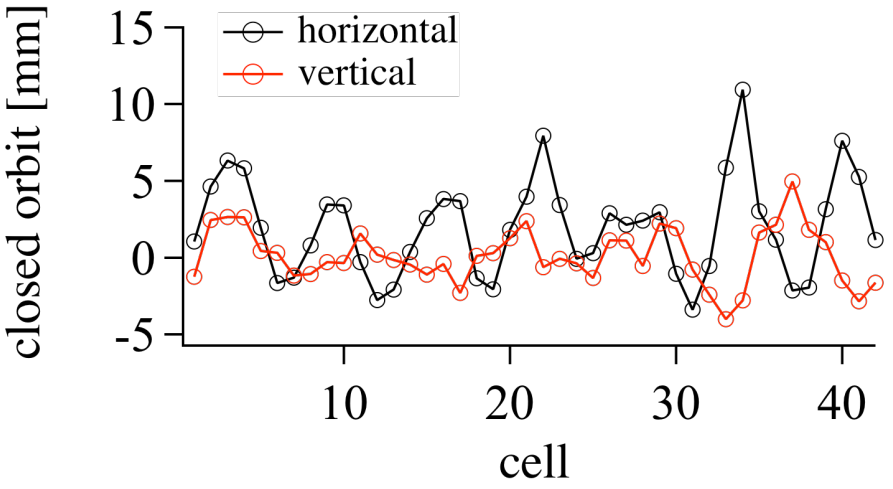
## Betatron oscillations




## Orbital period




## Closed orbit distortion




# Two major problems identified

- Closed orbit distortion was rather large (~+/- 5 mm) in both horizontal and vertical.

- rf vector sum of 19 cavities was lower than expected. Cavity phase was not correctly adjusted.

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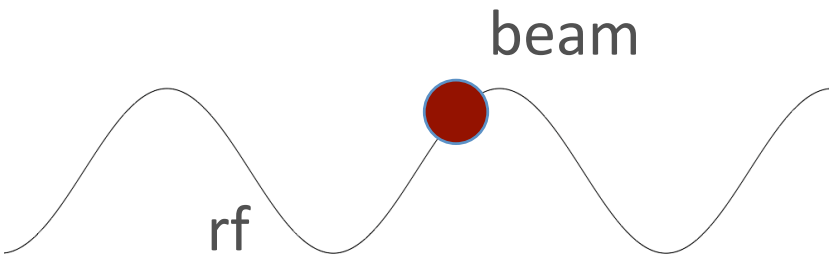
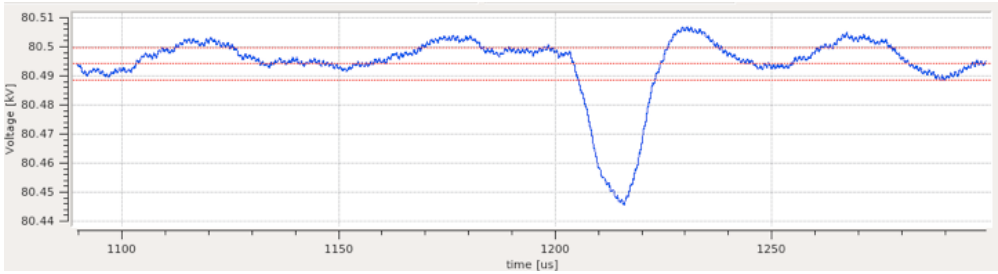
# Cavity phase adjustment with beam loading signal

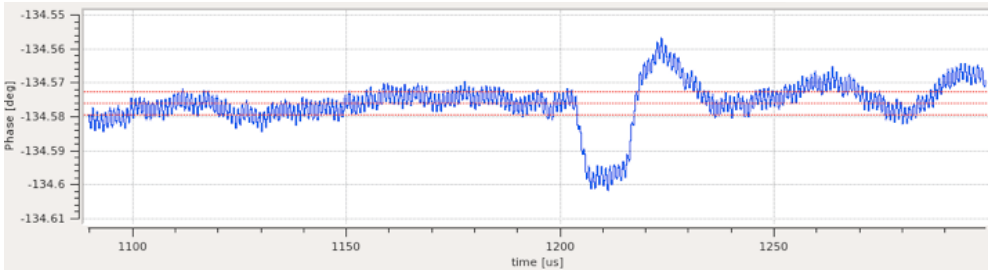



For each cavity, observe sign of loading signal as a function rf phase offset.

- Monitor amplitude




- Monitor phase



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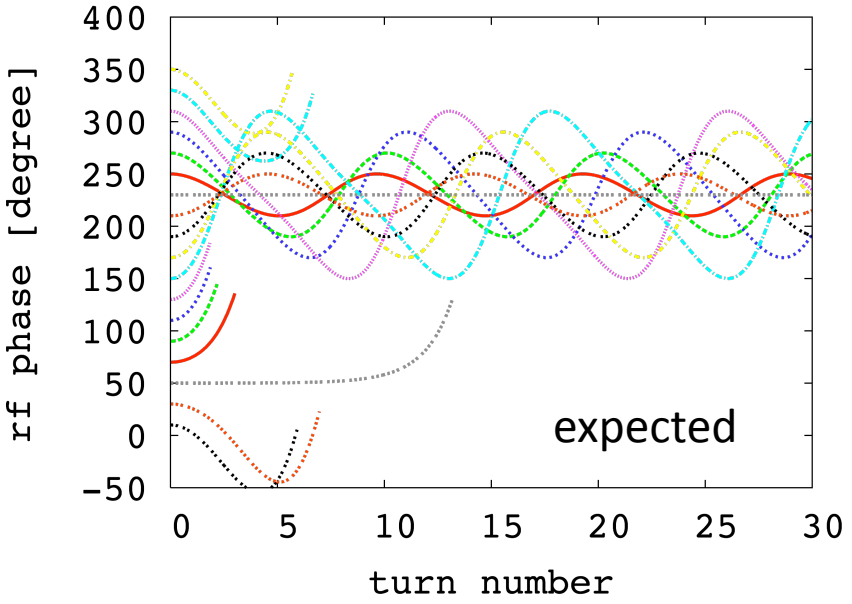
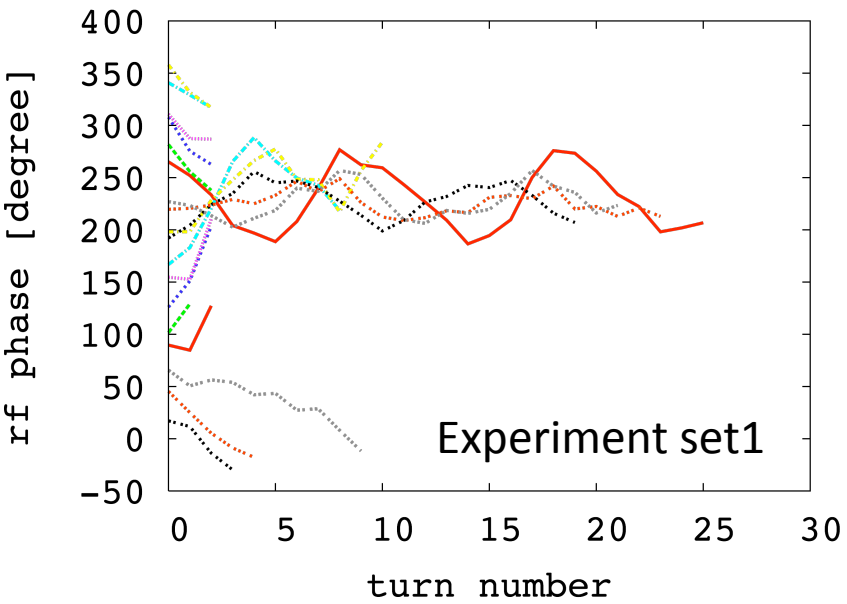
# Synchrotron oscillation in a bucket

- Consistent synchrotron oscillation period in experiment and simulation suggests

Vector sum ~ 19 (# of cavity) x voltage



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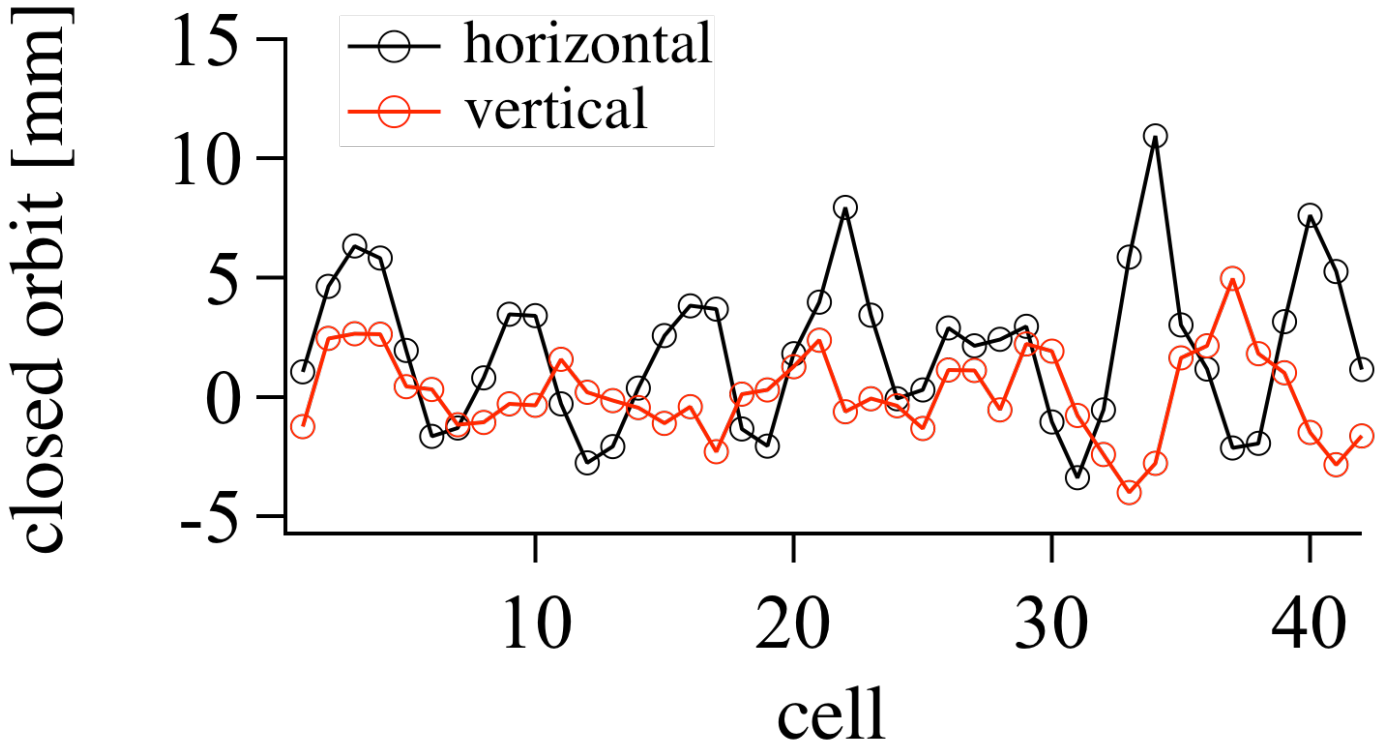
# Source of COD

- Misalignment turns out worse than expected.
- Re-alignment during shutdown should have made COD less than +/- 1 mm. But…



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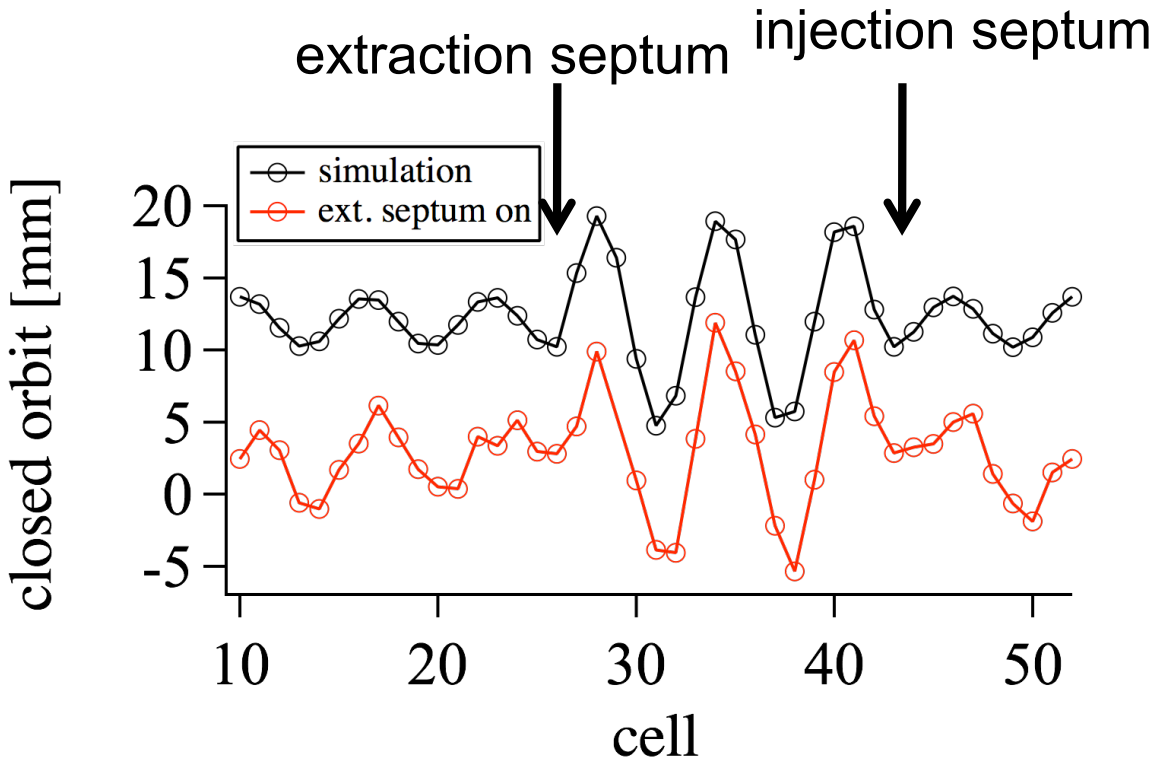
# COD caused by septum

- Kick with the strength of 0.0006 [Tm] at both septa makes a similar COD observed.




- Source of vertical COD is not yet identified.

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# Conclusion from runs in 2010

- Stability of optics with very small dispersion function has been illustrated.
- Dependence of orbital period on beam momentum is confirmed.

  *Optics is fine.*

- Large COD suggests integer tune crossing could be harder than initially thought.

  *Acceleration seems difficult.*


- Demands for new accelerator
- EMMA commissioning results in 2010
- EMMA commissioning results in 2011
- Future plans

# Quick and dirty?

- Fast acceleration with maximum possible rf voltage

  To overcome possible beam deterioration due to integer tune crossing.

  *Brute force, but why not.*

- Serpentine channel opens with 1 MV per turn.
- Increase the voltage to ~ 2 MV and see what happen.
- NAFF algorism is used to calculate instantaneous tune.

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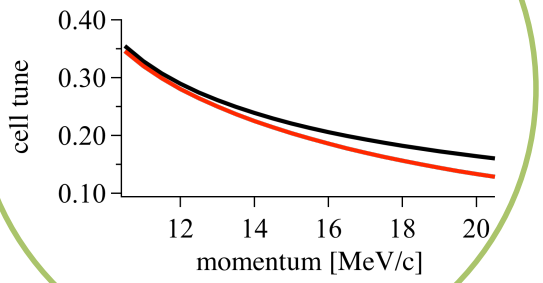
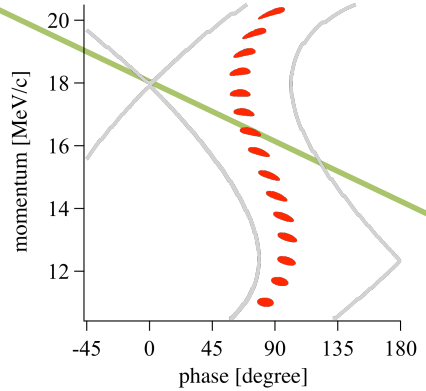
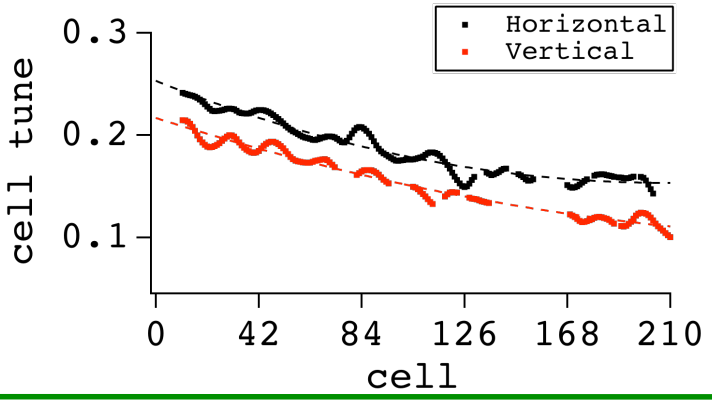
# with 1.9 MV rf (1)

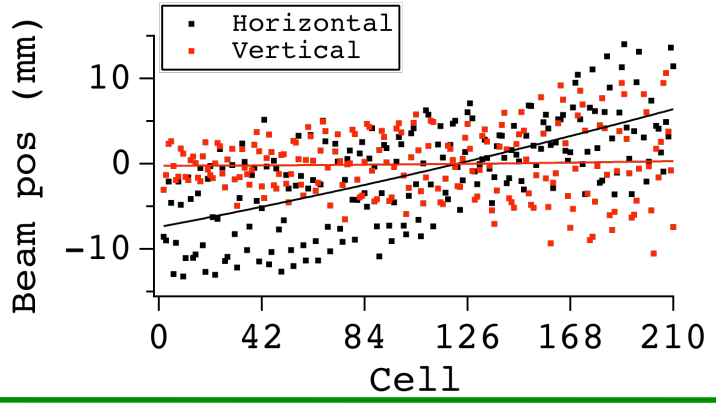
Rapid acceleration with large tune variation




Tune decreases and hor. Orbit increases monotonically in measurement.



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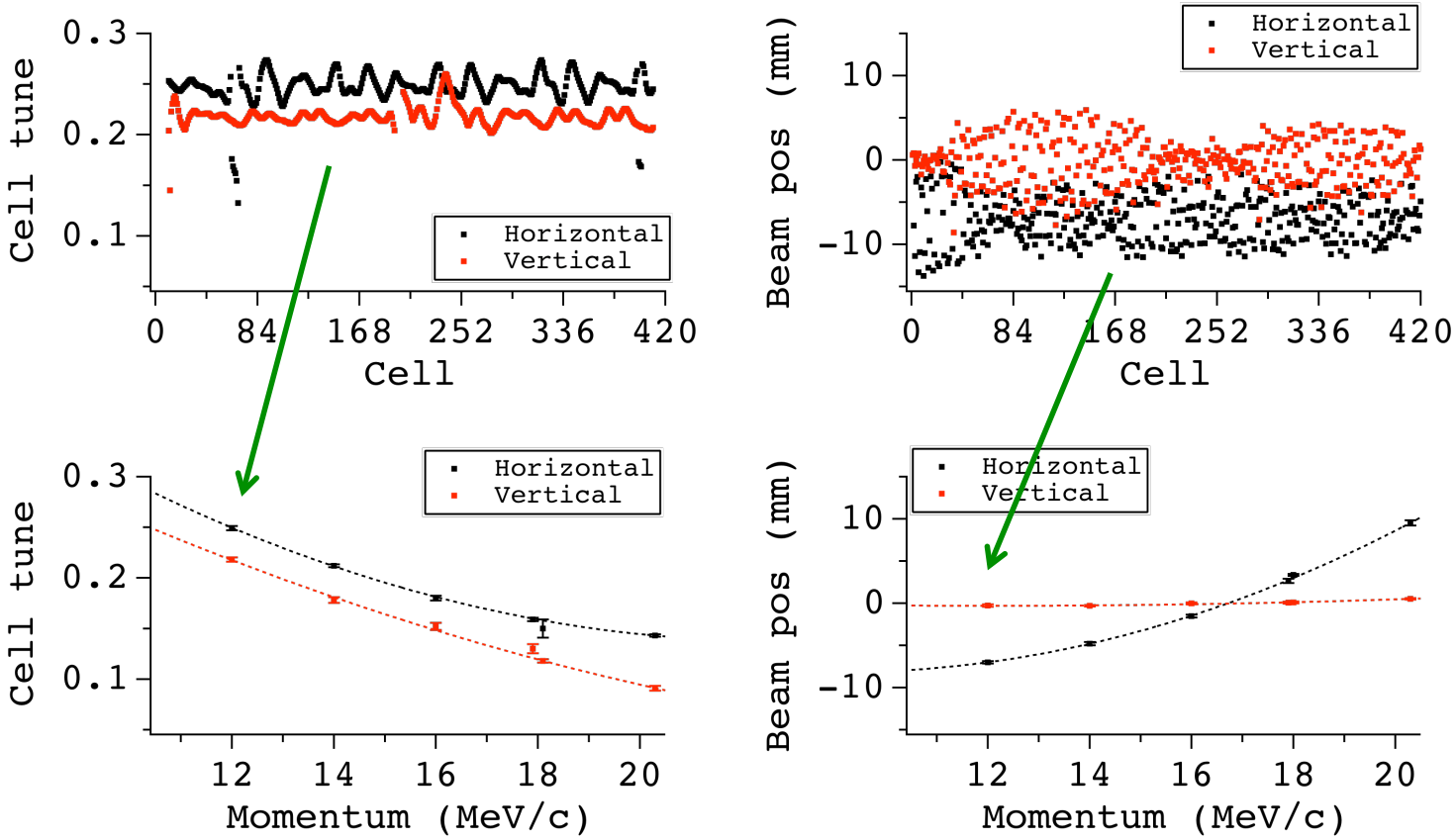
# without rf

- Beam position and tune with fixed momentum.



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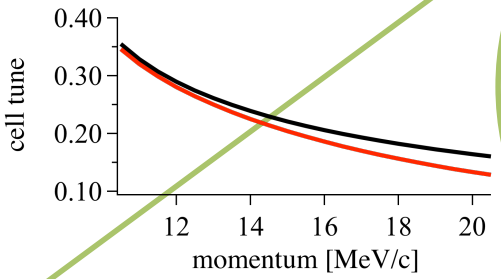
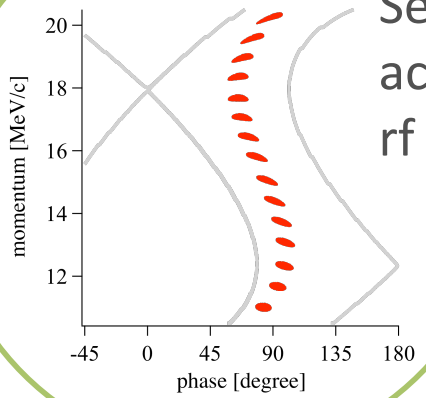
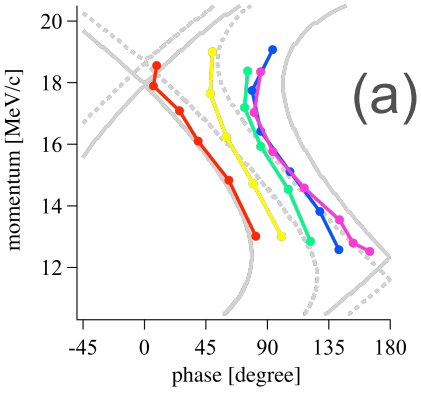
# with 1.9 MV rf (2)

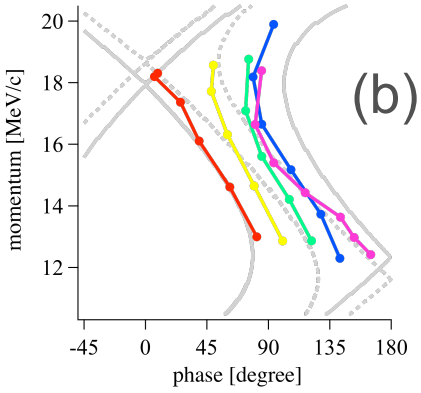


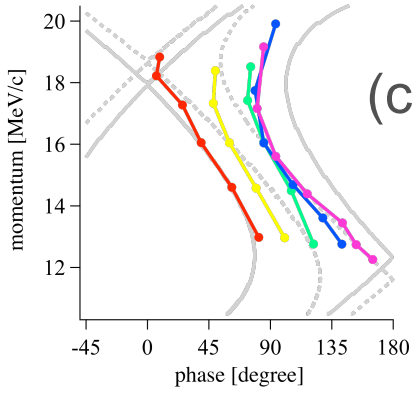




Serpentine channel acceleration outside rf bucket

All three momentum calibration methods; (a) hor. and (b) ver. tune and (c) hor. orbit shows consistent evidence of acceleration.



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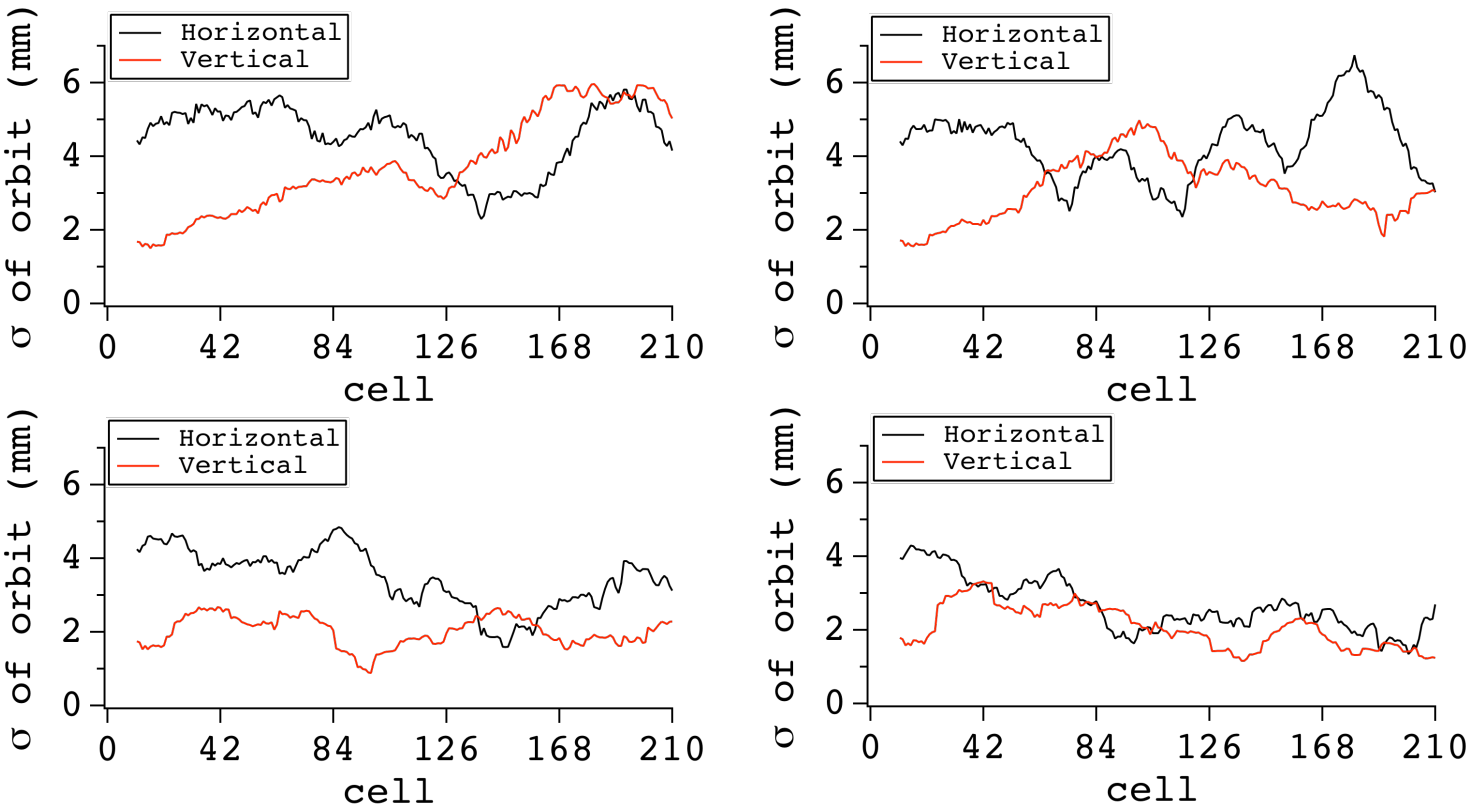
# with 1.9 MV rf (3)

- No distortion to betatron oscillations with integer tune crossing.



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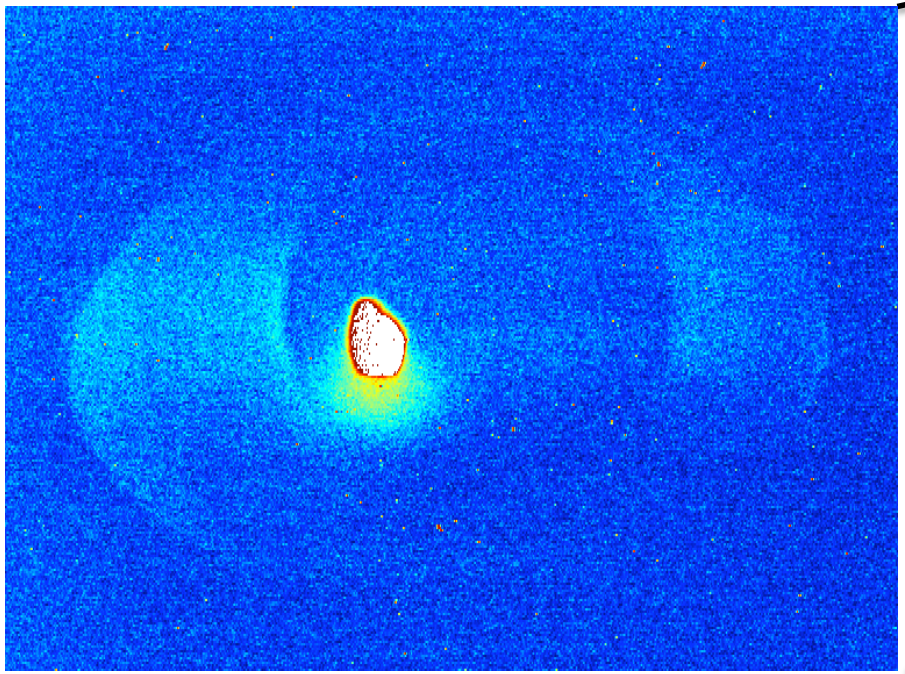
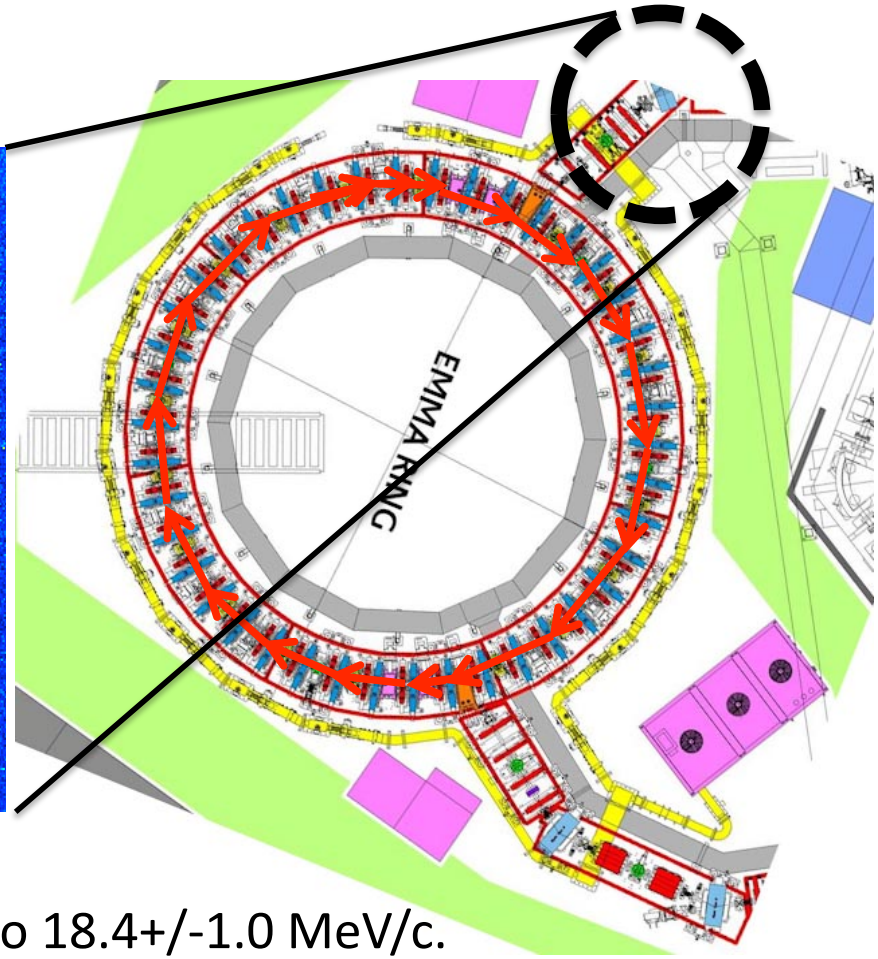
# Momentum measurement

- Beam image on screen in the extraction line.

  18 April 2011






12.0+/-0.1 MeV/c beam is accelerated to 18.4+/-1.0 MeV/c.


# Conclusion from runs in 2011

- EMMA proves that a linear non-scaling FFAG works.

  A big step forward to the muon acceleration in a neutrino factory and muon collider as well as to other applications.

- Two out of three main goals are achieved.

  Still need to show large acceptance.


- Demands for new accelerator
- EMMA Commissioning results in 2010
- EMMA Commissioning results in 2011
- Future plans and EMMA upgrade


# Where we are now?

- "Proof of principle" phase (~publication of a letter)

  June to October 2010: injection, lattice tuning, measurement of basic parameters, rf setup

  January to March 2011: acceleration/deceleration

- Detailed measurement (~publication of full papers)

  April 2011 to March 2013: list in the following page

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# Plan for the next 1~2 yrs (1)

*more EMMA run*

- Serpentine channel acceleration
  - Set frequency and voltage to achieve desired parameters
  - Measure mapping of longitudinal phase space
  - Dependence of transverse amplitude
- Acceleration with varying phase advance
  - Local and/or global correction of the COD, it is a challenge.
  - Effect of magnet errors
  - Slowly cross individual resonance
  - Examine effects of space charge

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# Plan for the next 1~2 yrs (2)

*more EMMA run (continued)*

- Show large longitudinal and transverse acceptance
  - Scan injected beam in horizontal phase space
  - Scan injected beam in vertical phase space
  - Scan injected beam in longitudinal phase space, etc.

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# Summary

- EMMA proves that a linear non-scaling FFAG works.
- With the success of serpentine channel acceleration, it is a big step forward to muon acceleration.

- So far, no big surprise.
- In two years, we will gain much more knowledge, both design and operational view point, on a linear non-scaling FFAG.
- Stay tuned!


# Thank you for your attention.