EMMA: Status and Prospects

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on behalf of the EMMA collaboration
ASTeC/STFC/RAL

12 January 2012

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- EMMA commissioning results in 2010 (7 slides)
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NATURE PHYSICS | ARTICLE

Acceleration in the linear non-scaling fixed-field alternating-gradient accelerator EMMA

S. Machida, R. Barlow, J. S. Berg, N. Bliss, R. K. Buckley, J. A. Clarke, M. K. Craddock, R. D'Arcy, R. Edgecock, J. M. Garland, Y. Giboudot, P. Goudket, S. Griffiths, C. Hill, S. F. Hill, K. M. Hock, D. J. Holder, M. G. Ibison, F. Jackson, S. P. Jamison, C. Johnstone, J. K. Jones, L. B. Jones, A. Kalinin, E. Keil
+ *et al.*

Affiliations | Contributions | Corresponding author

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Abstract

Abstract • Author information

In a fixed-field alternating-gradient (FFAG) accelerator, eliminating pulsed magnet operation permits rapid acceleration to synchrotron energies, but with a much higher beam-pulse repetition rate. Conceived in the 1950s, FFAGs are enjoying renewed interest, fuelled by the need to rapidly accelerate unstable

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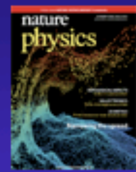
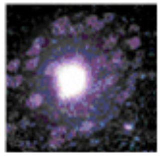


Selected feature

Nature Physics Insight: Complexity



The network takeover
Albert-László Barabási
Data-based mathematical models of complex systems are offering a fresh perspective.

Between order and chaos
James Crutchfield
Quantifying the notion of pattern and formalizing the process of pattern discovery go right to the heart of physical science.

Networks of networks
Jianxi Gao *et al.*
Many real-world networks interact with and depend on other networks.

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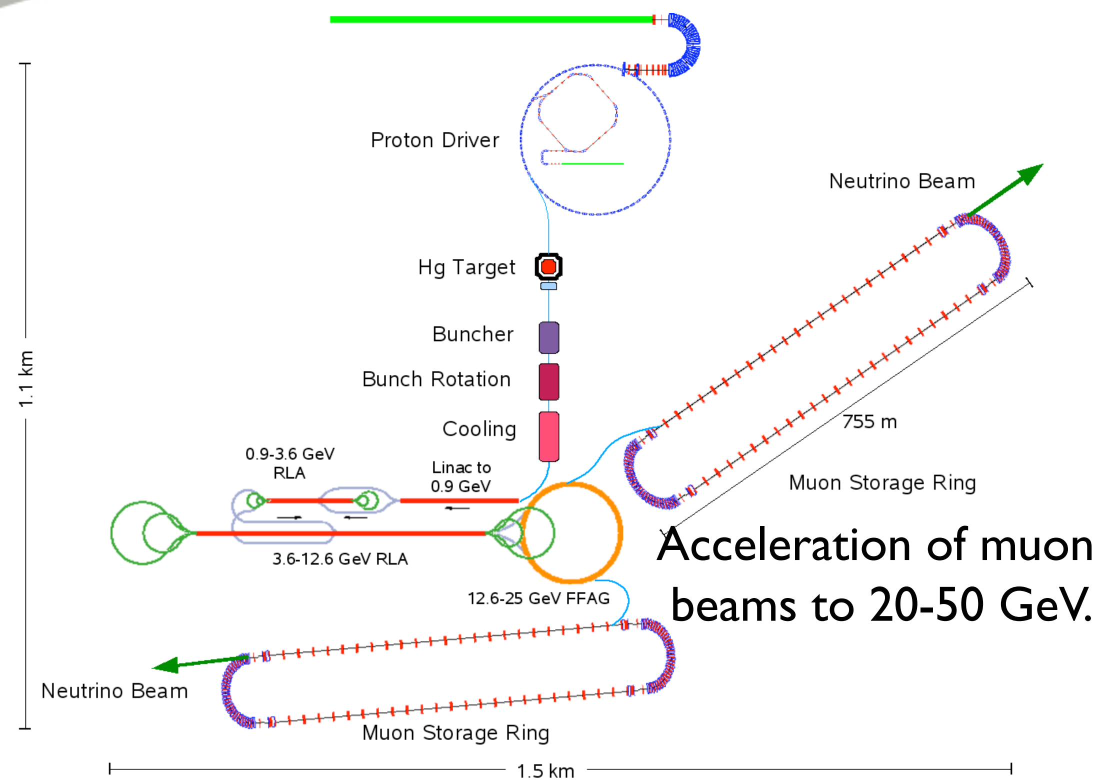
- Demands for new accelerator
- EMMA commissioning results in 2010
- EMMA commissioning results in 2011
- Plans

Demands for new accelerator

Neutrino Factory

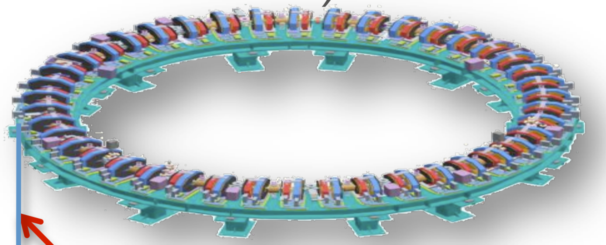


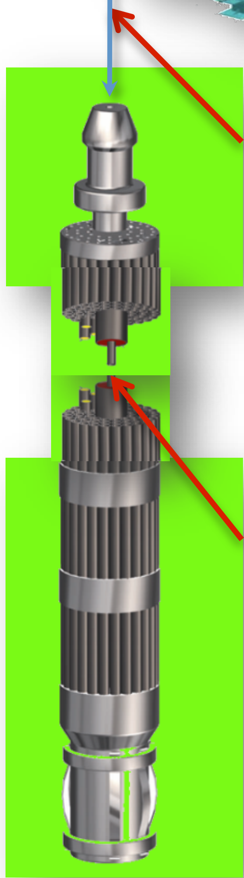
Acceleration of muon beams to 20-50 GeV.

Particle therapy and security application

Compact and flexible accelerator.

ADSR (accelerator driven subcritical reactor)

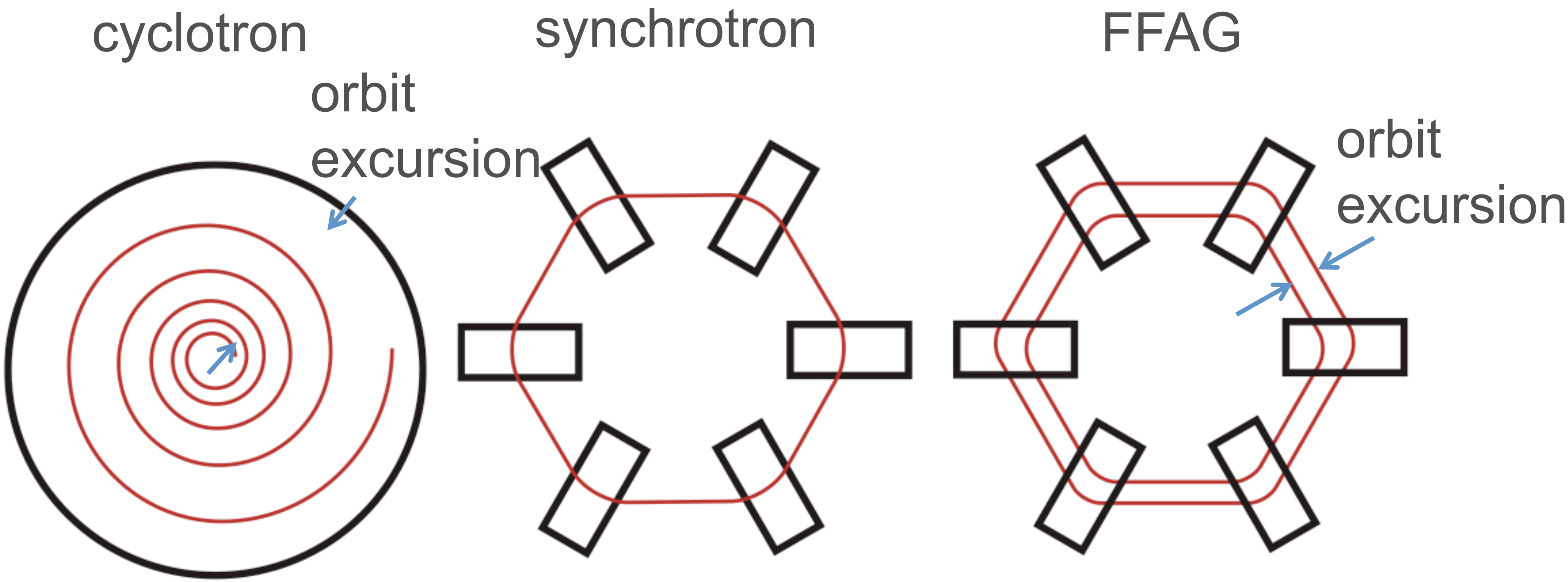




High power (MW) proton beam

Miniature spallation target in central bore of fuel element assembly

What about Fixed Field Alternating Gradient (FFAG) accelerator?



Black shape: lattice magnet
Red curve: orbit

From a presentation by Y. Mori

Advantages of FFAG

- Fixed field magnets enables quick acceleration.

  Beam power can be increased with high repetition, 1 kHz or more.

  ISIS (has maximum rep rate of synchrotron) is still 50 Hz.

- AG focusing pushes momentum to synchrotron range.
- Fixed field magnets provide flexibility and reliability.

From application point of view

- Neutrino factory

  Acceleration within muon lifetime is possible.

  Muon accelerator alternative to RLA

- High power proton driver for ADSR and neutron and muon source

  Almost continuous and high energy (a few to 10 GeV) proton

- Proton accelerator for medical and security

  Compact and inexpensive machine

Scaling (conventional) FFAG

- The idea is old in 1950s.
- Early work was at MURA.

  Frank Cole, Fred Mills, …
- KEK/Kyoto Univ. developed hardware and made a proton FFAG in 2000s.
- Basically followed the original design concept;

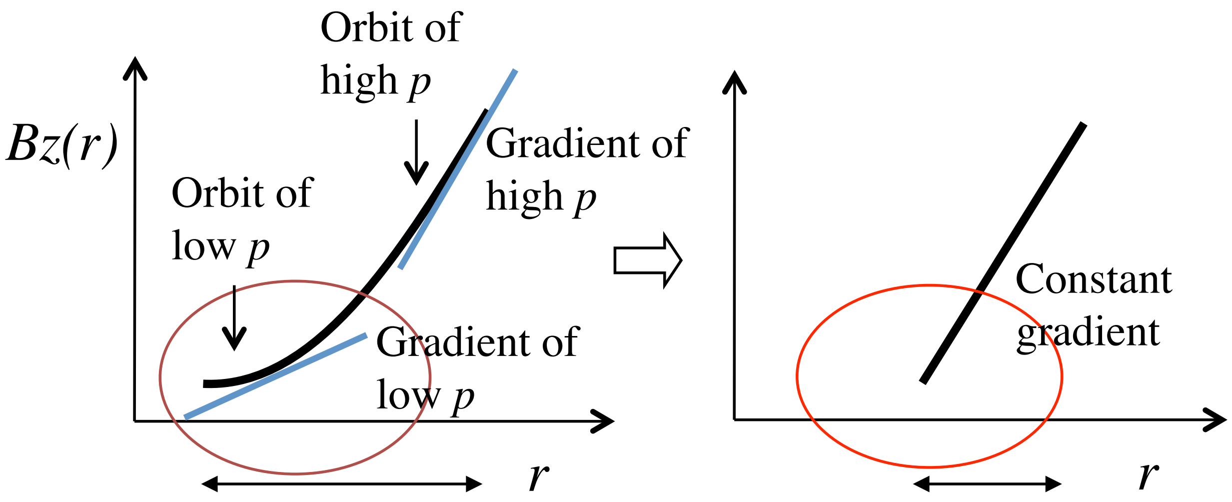
  Scaling law (constant tune).

Non-scaling FFAG

- Simplified design called non-scaling FFAG strengthens the advantages.

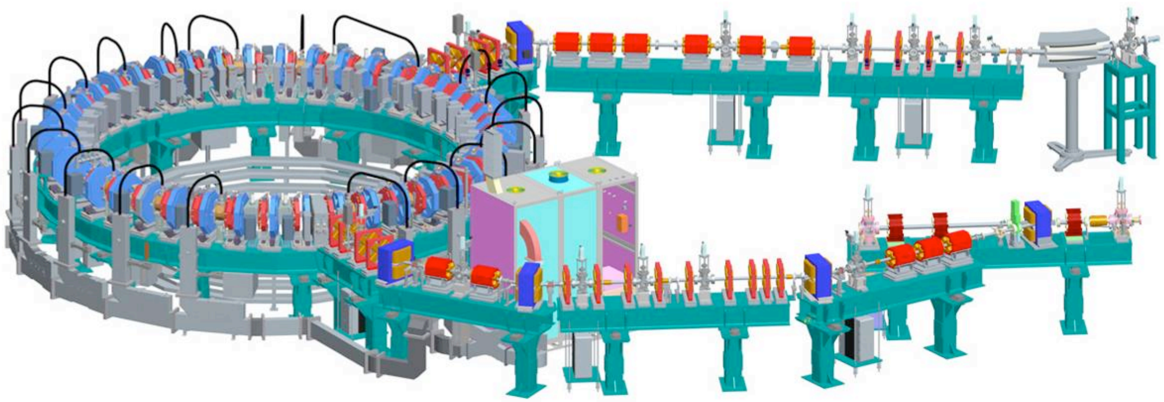
  Acceleration in “storage ring” with extremely small dispersion function

- From scaling to non-scaling FFAG



ns-FFAG works as expected?

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



- EMMA is

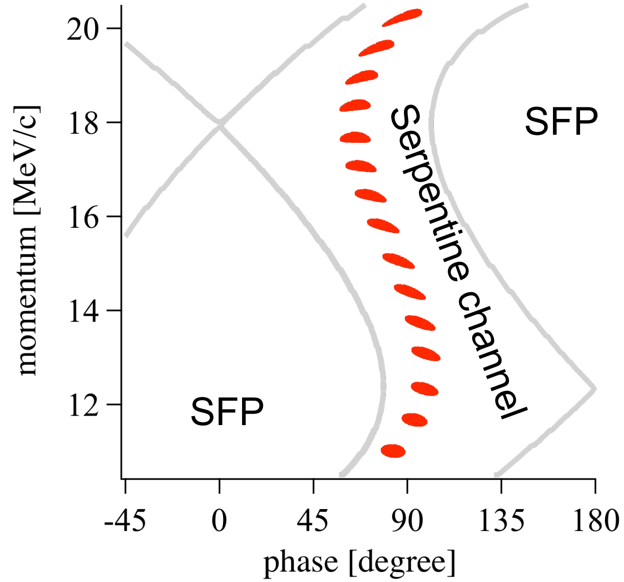
  Electron Model for Many Applications

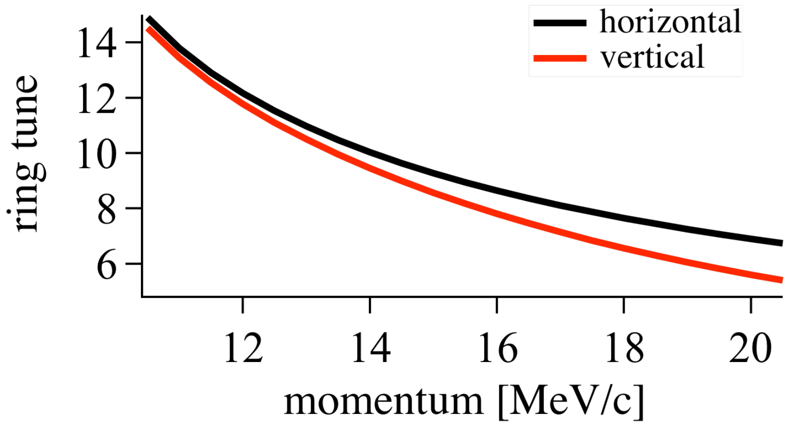
- Although initial experiment more focuses on

  Electron Model of Muon Acceleration

Three main goals

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



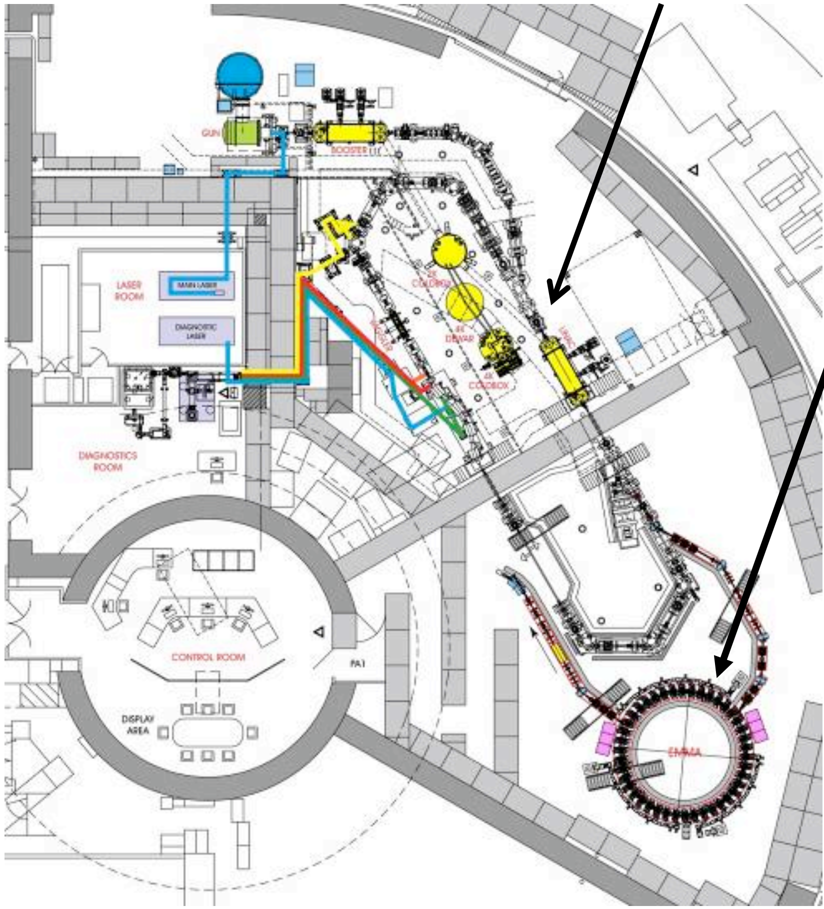


- Large tune variation due to natural chromaticity during acceleration.

- Large acceptance for huge (muon) beam emittance.

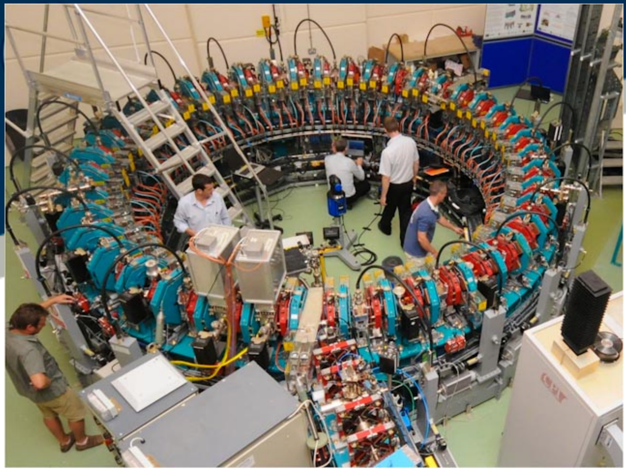
ALICE/EMMA at Daresbury

Accelerators and Lasers in Combined Experiments

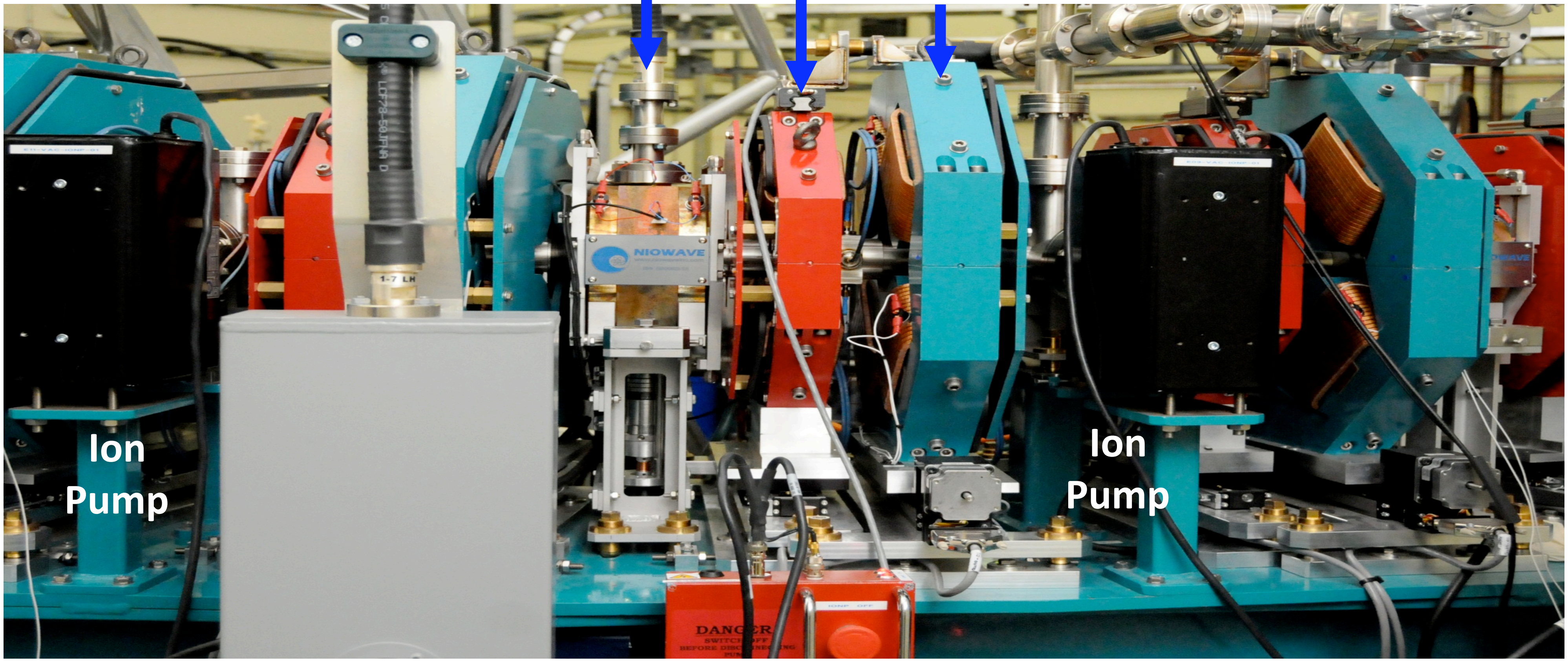


EMMA

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



EMMA in pictures



EMMA collaboration

- Funded by CONFORM (EPSRC basic technology grant).
- STFC provided significant support through ASTeC.
- Institutions include

  STFC/ASTeC

  Cockcroft Institute

  John Adams Institute

  Imperial College London

  Brunel University

  Fermi National Accelerator Laboratory

  Brookhaven National Laboratory

  CERN

  TRIUMF

  ……

- Demands for new accelerator
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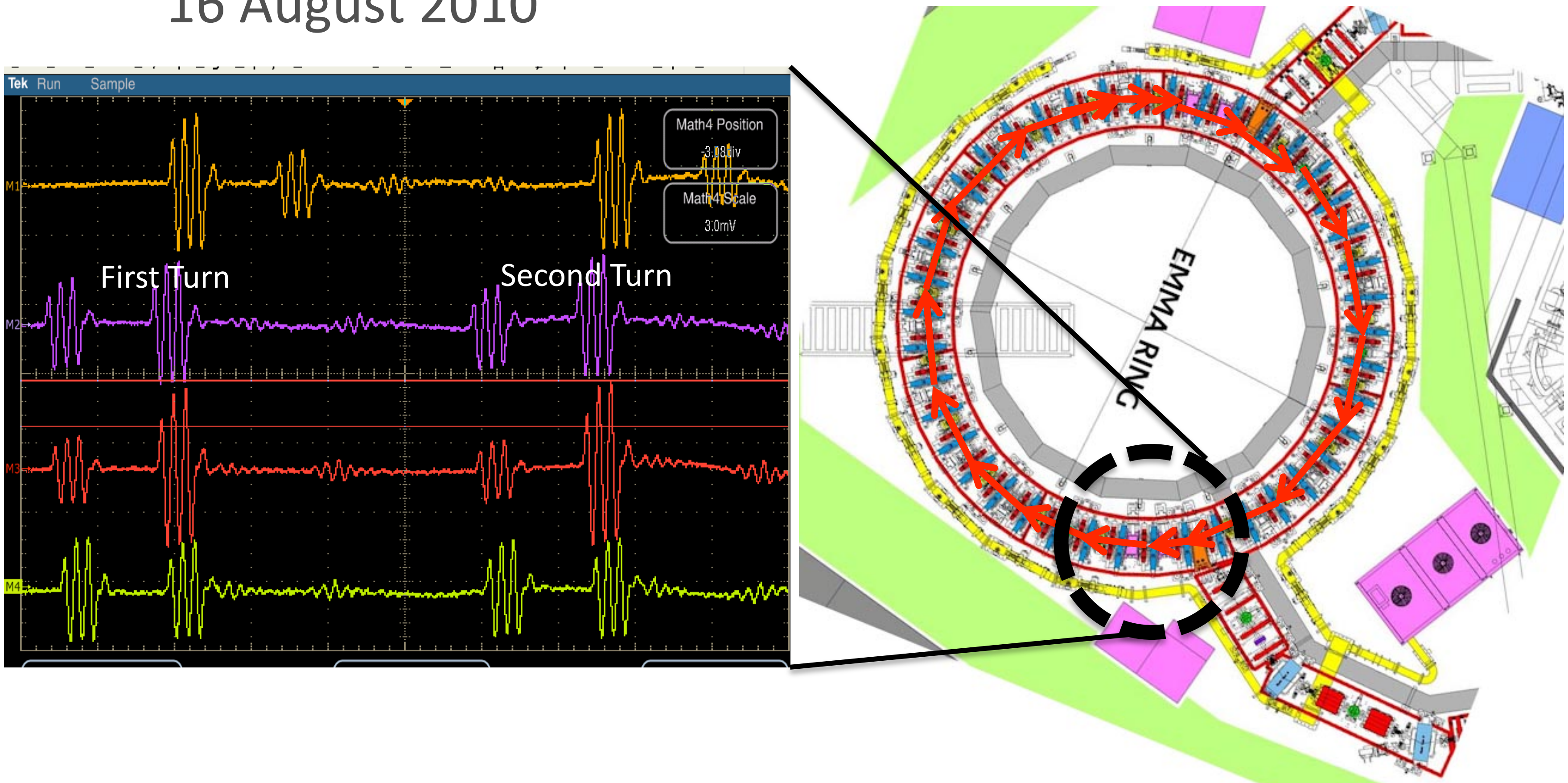
Complete ring

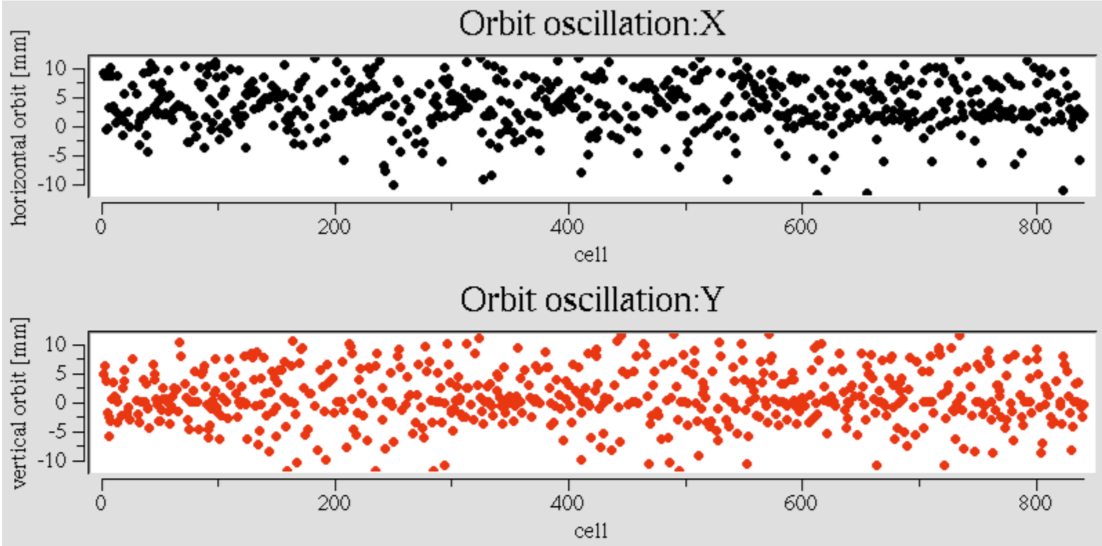
- A beam circulates first for three turns and then for thousands turns a few day later.

16 August 2010

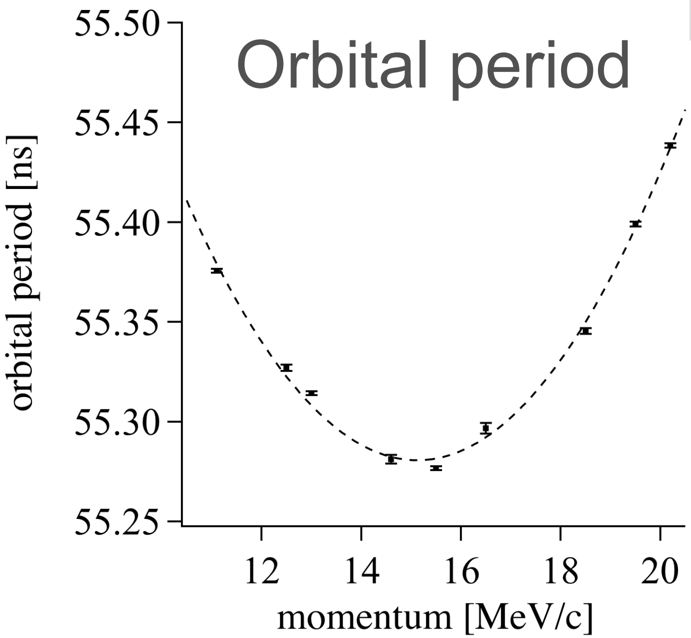


Measurement of basic parameters

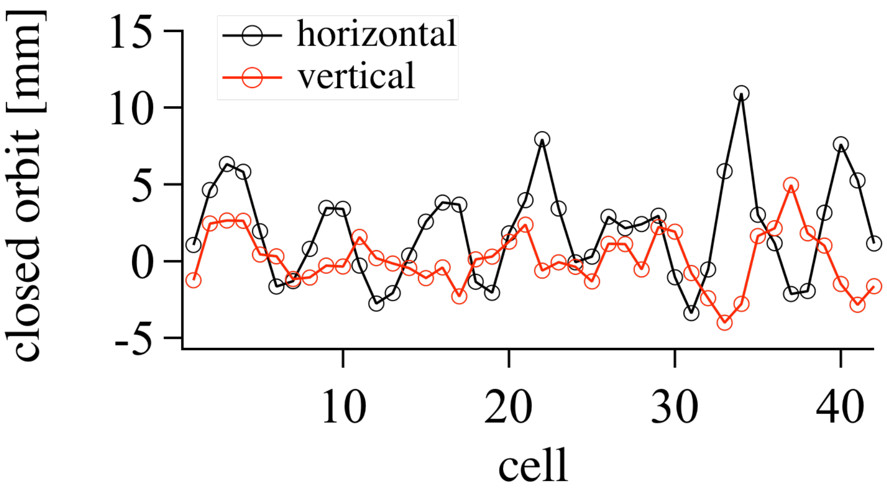
Betatron oscillations



Orbital period



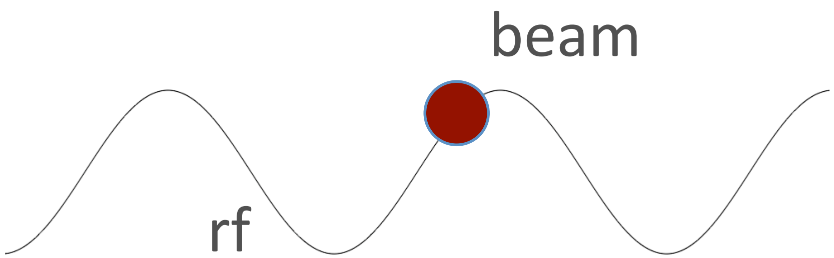
Closed orbit distortion



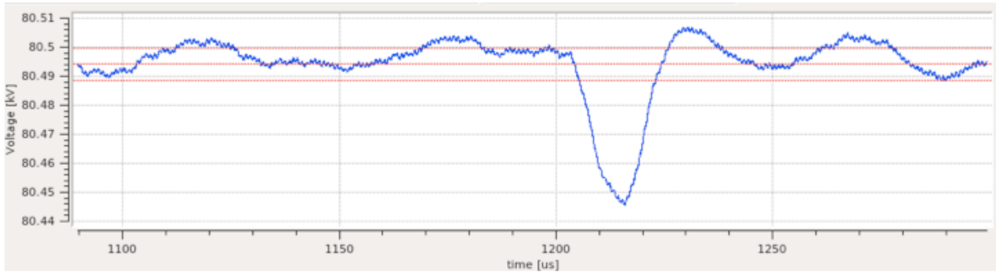
Two major problems identified

- 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.

Cavity phase adjustment with beam loading signal

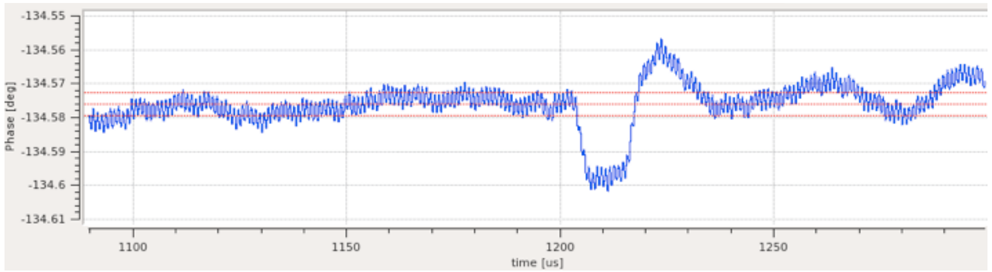


- Monitor amplitude



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

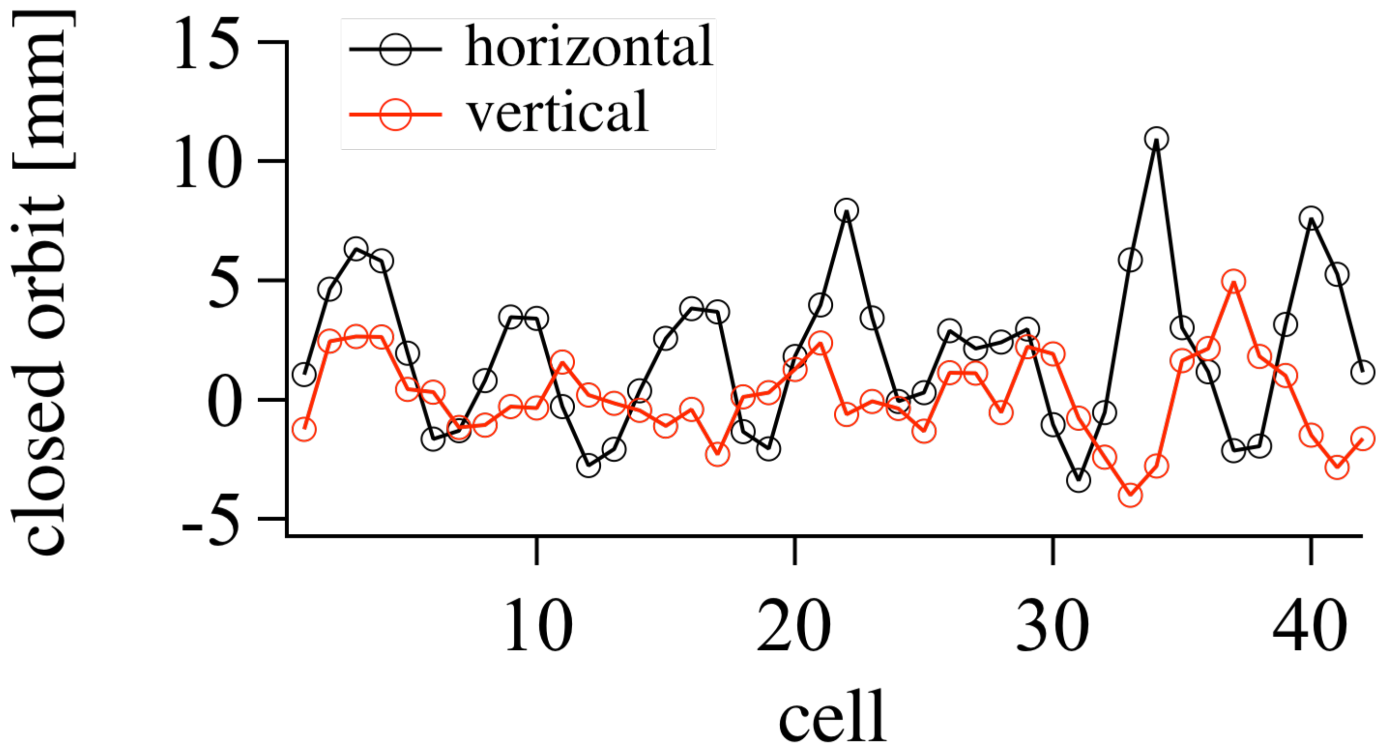
- Monitor phase



Vector sum ~ 19 (# of cavity) x voltage

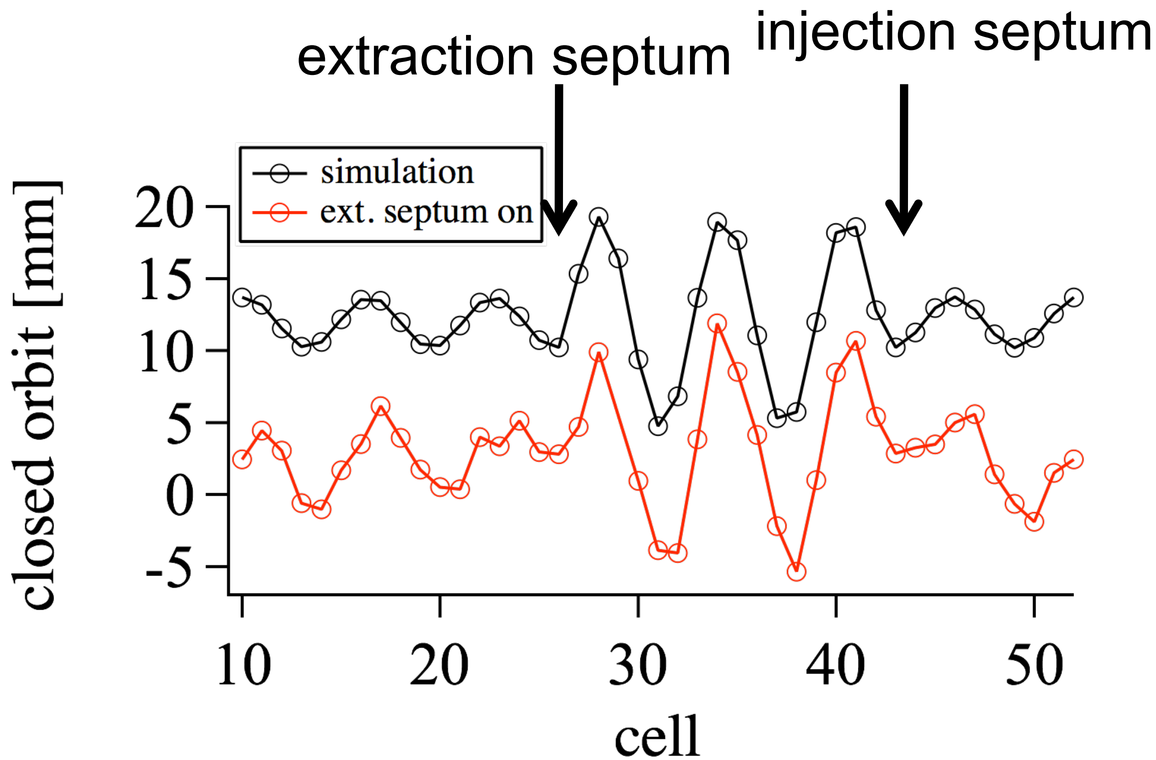
Source of COD

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



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.

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- Demands for new accelerator
- EMMA commissioning results in 2010
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Quick and dirty?

- Fast acceleration with maximum possible rf voltage

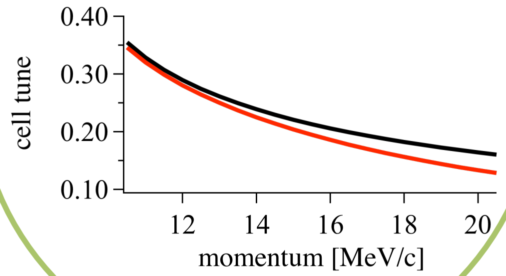
  To overcome possible beam deterioration due to integer tune crossing.

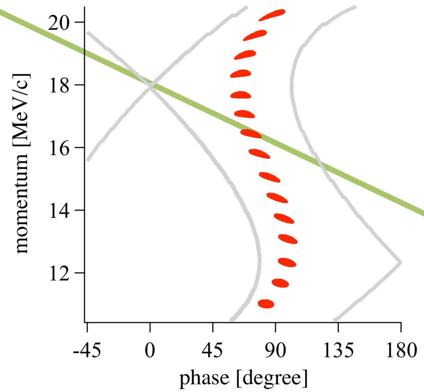
  Brute force, but why not.

- 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.

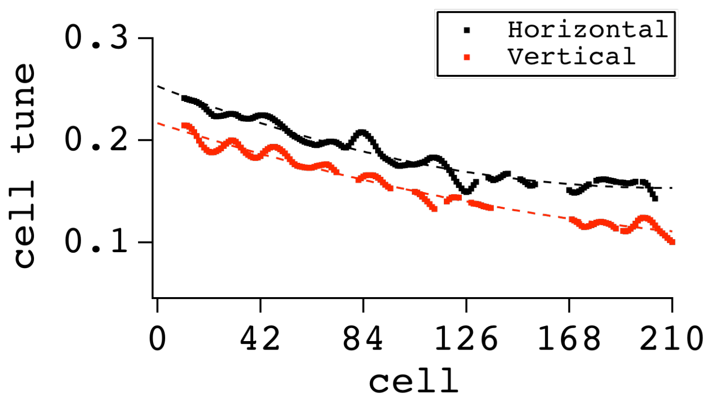
with 1.9 MV rf (1)

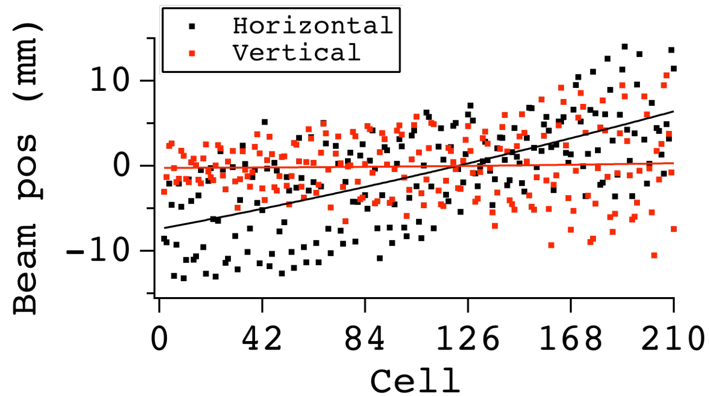
Rapid acceleration with large tune variation





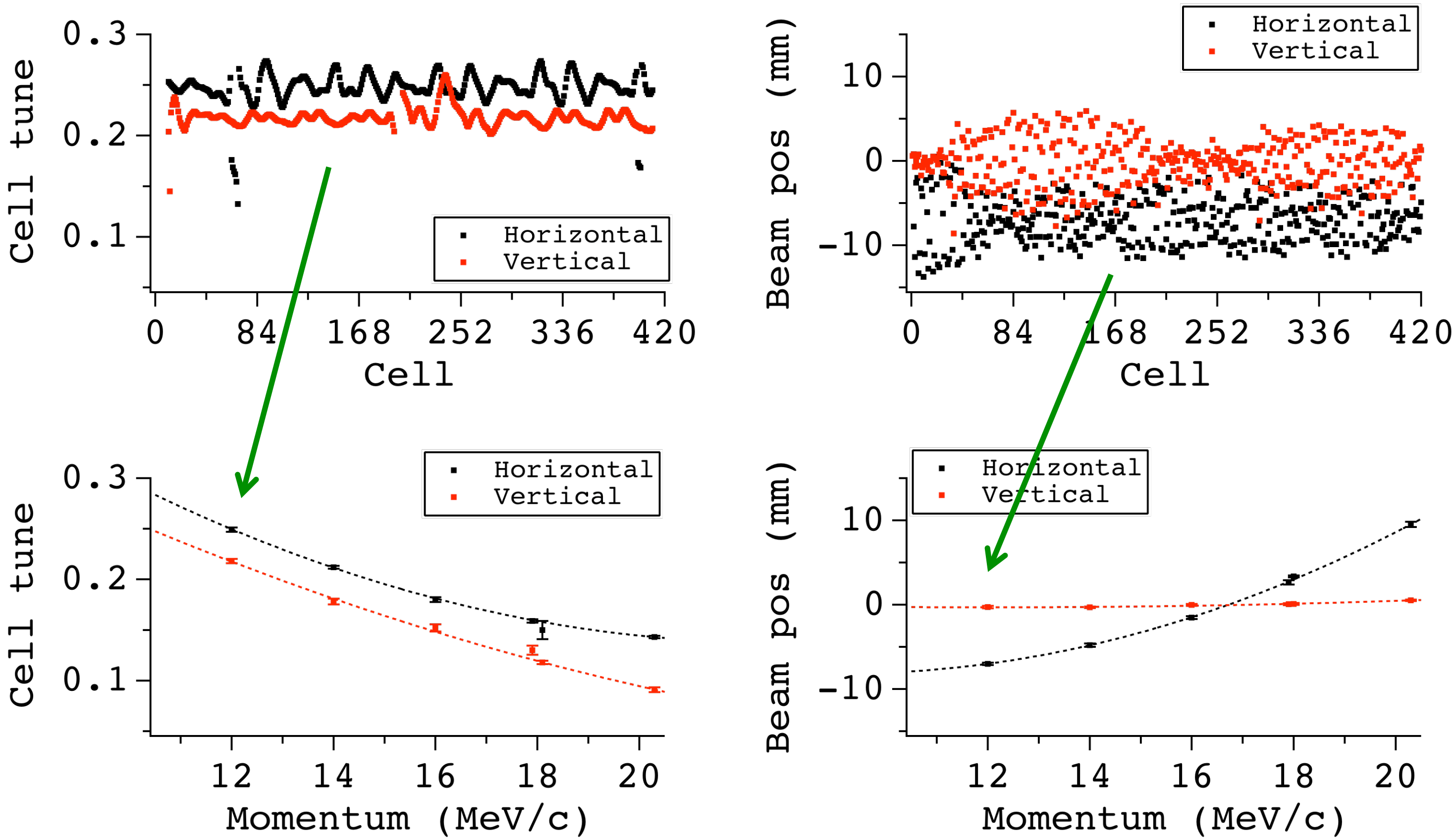
Tune decreases and hor. orbit increases monotonically in measurement.



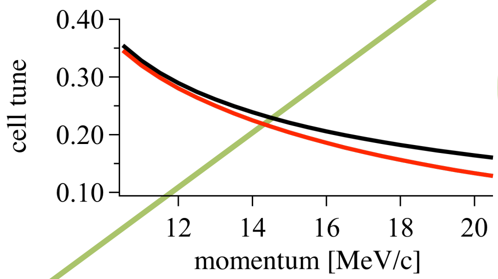


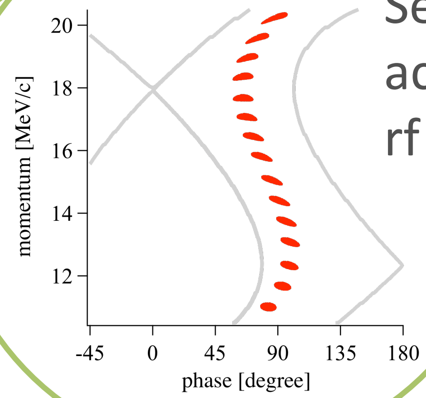
without rf

- Beam position and tune with fixed momentum.



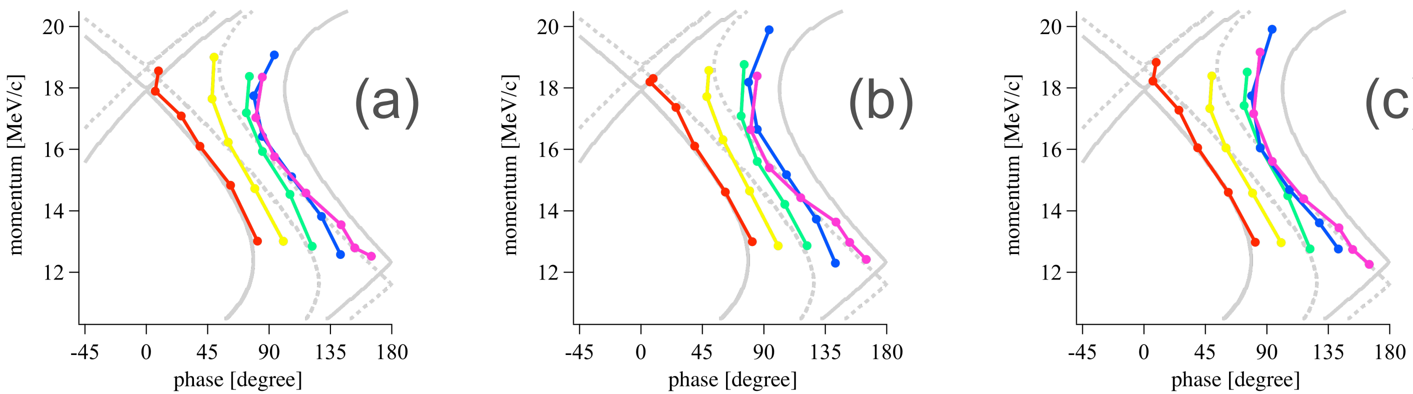
with 1.9 MV rf (2)





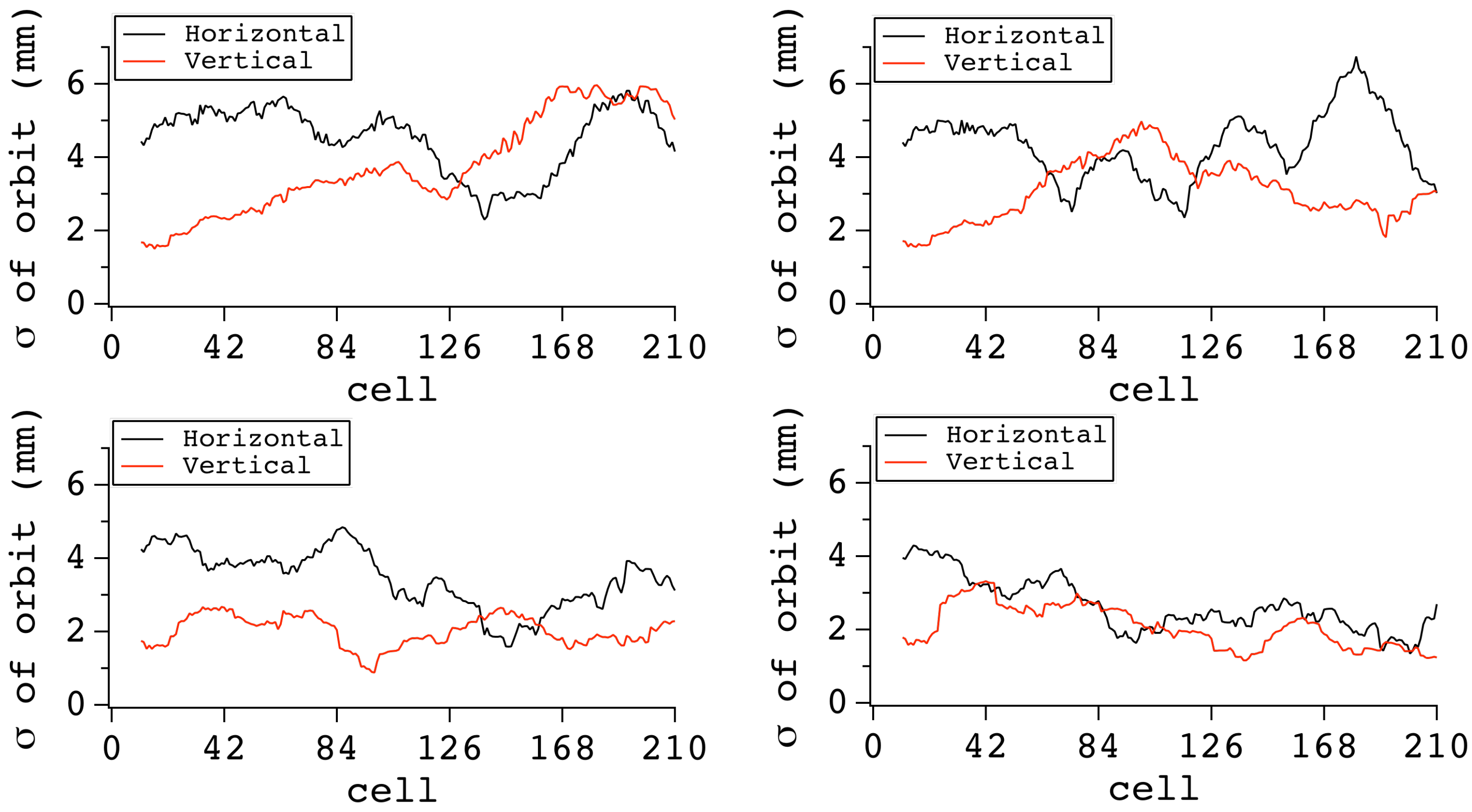
Serpentine channel acceleration outside rf bucket

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



with 1.9 MV rf (3)

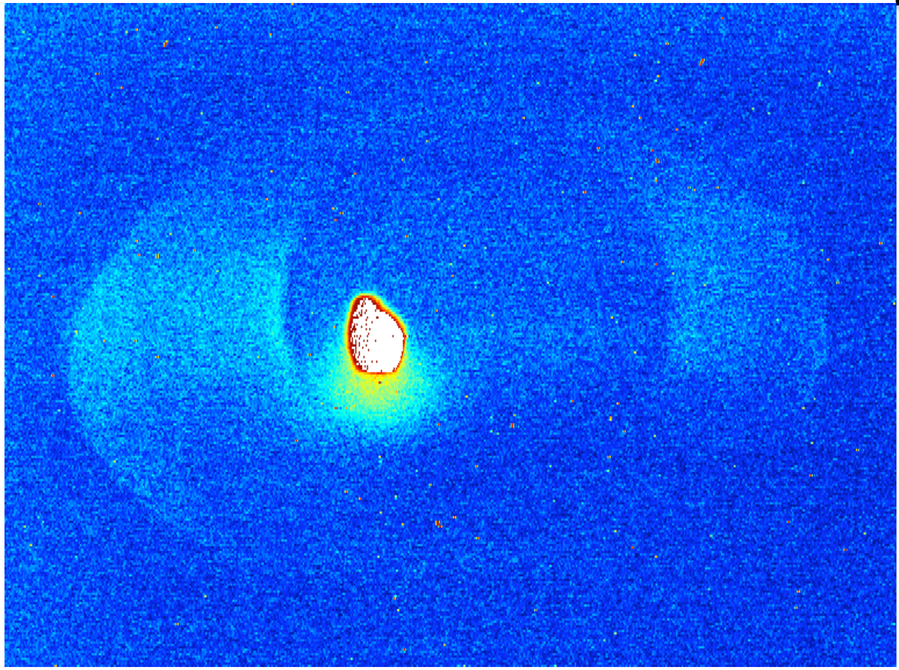
- Not much distortion to betatron oscillations with integer tune crossing.

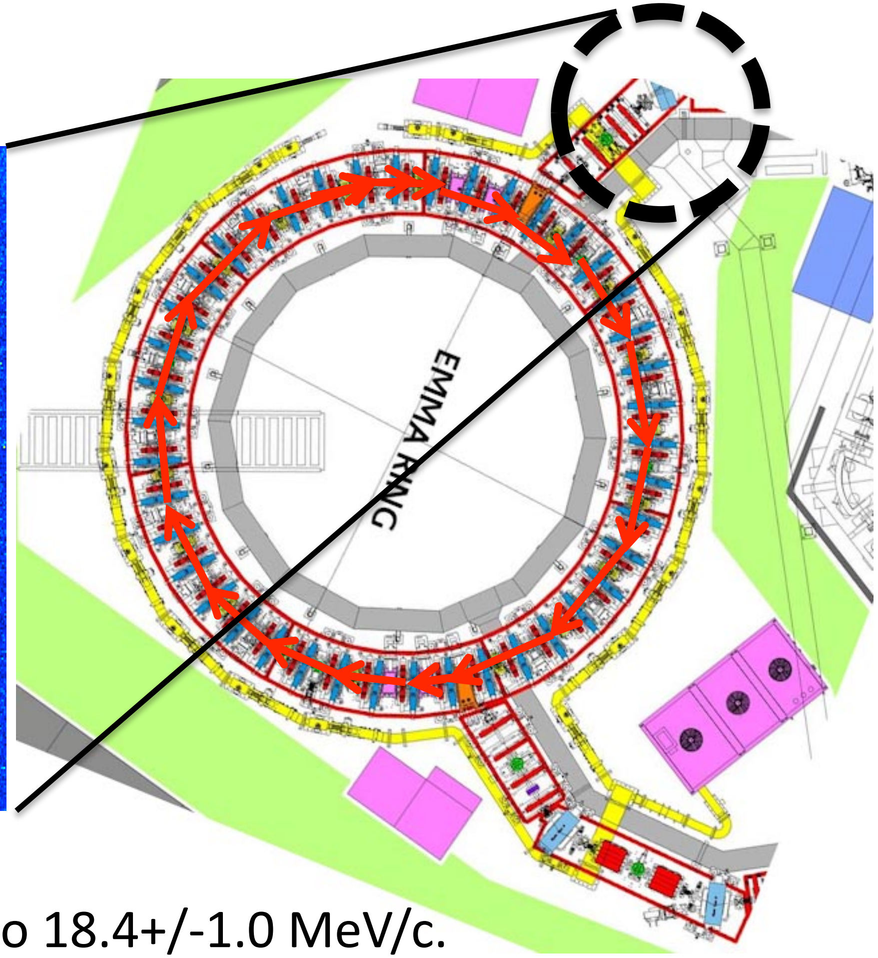


Momentum measurement

- 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 as well as to other applications.

- Two out of three main goals are achieved.

  Still need to show large acceptance.

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- Demands for new accelerator
- EMMA Commissioning results in 2010
- EMMA Commissioning results in 2011
- Plan in 2012 and prospects

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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

  First journal paper is published in Nature Physics on 10 January 2012.

- Detailed measurement (~publication of full papers)

  In the next year: list in the following page

Plan for the next year

more EMMA run

- Acceleration with varying phase advance
  - Effect of magnet errors and misalignments
  - Slowly cross integer tune
  - Examine effects of space charge, etc.
- Serpentine channel acceleration
  - Measure mapping of longitudinal phase space
  - Study parameter dependence of longitudinal phase space
  - Dependence of transverse amplitude, etc.
- Show large longitudinal and transverse acceptance
  - Scan injected beam in horizontal, vertical and longitudinal phase space

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Summary

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

- So far, no big surprise.
- We will gain much more knowledge in the next year, both design and operational view point, on a linear non-scaling FFAG.

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From application point of view

- Neutrino factory

  Acceleration within muon lifetime is possible

  Muon accelerator alternative to RLA

- High power proton driver

  Almost continuous and high energy (a few to 10 GeV) proton

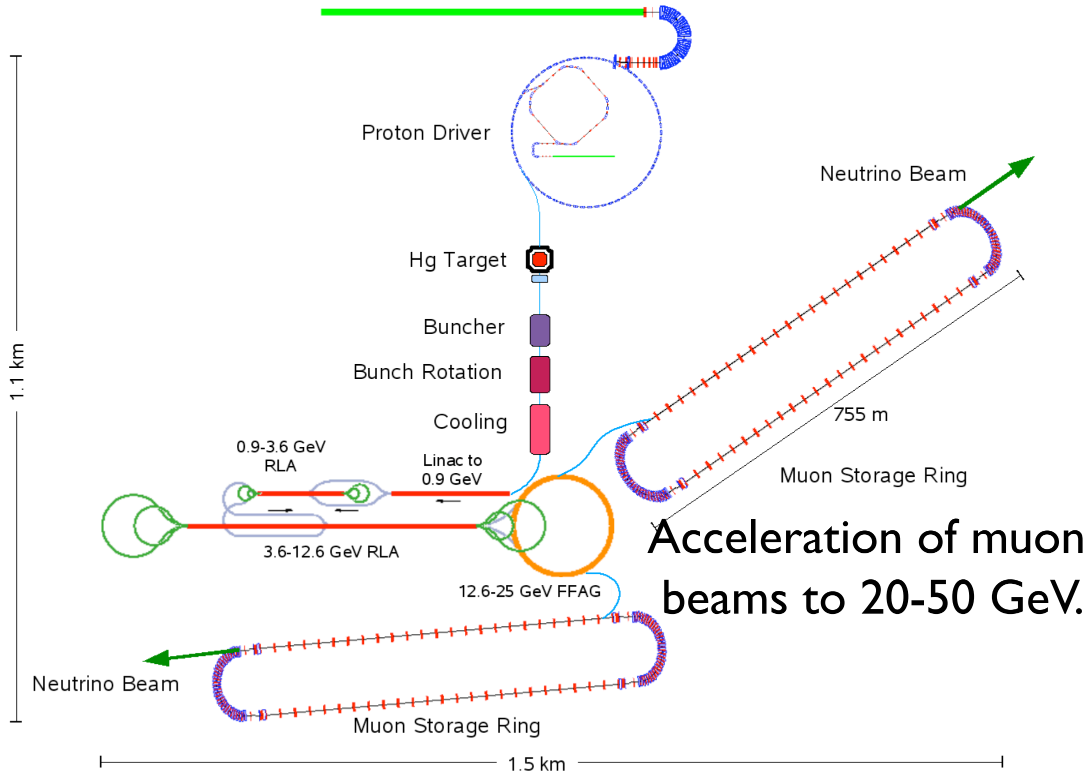
  Acceleration of space charge dominated beam in FFAG is not demonstrated in EMMA

- Proton accelerator for medical and security

  Compact and inexpensive machine

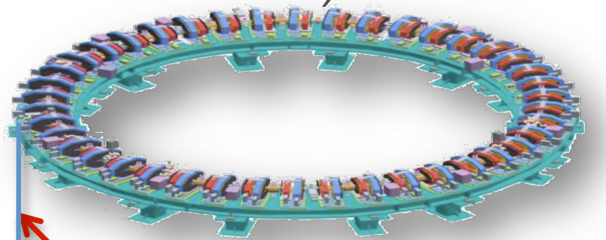
Demands for new accelerator

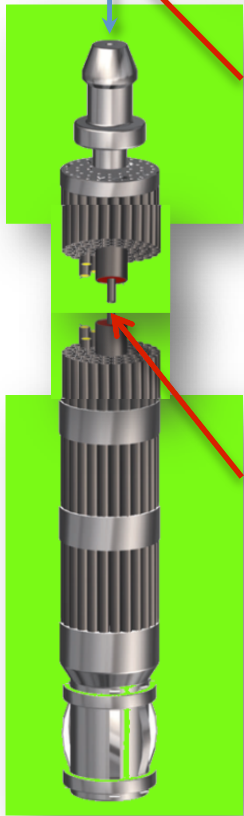
Neutrino Factory



Acceleration of muon beams to 20-50 GeV.

ADSR (accelerator driven subcritical reactor)

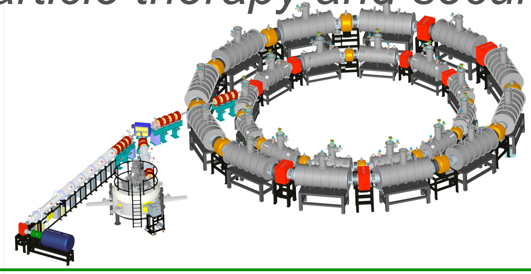




High power (MW) proton beam

Miniature spallation target in central bore of fuel element assembly

Particle therapy and security application



Compact and flexible accelerator.

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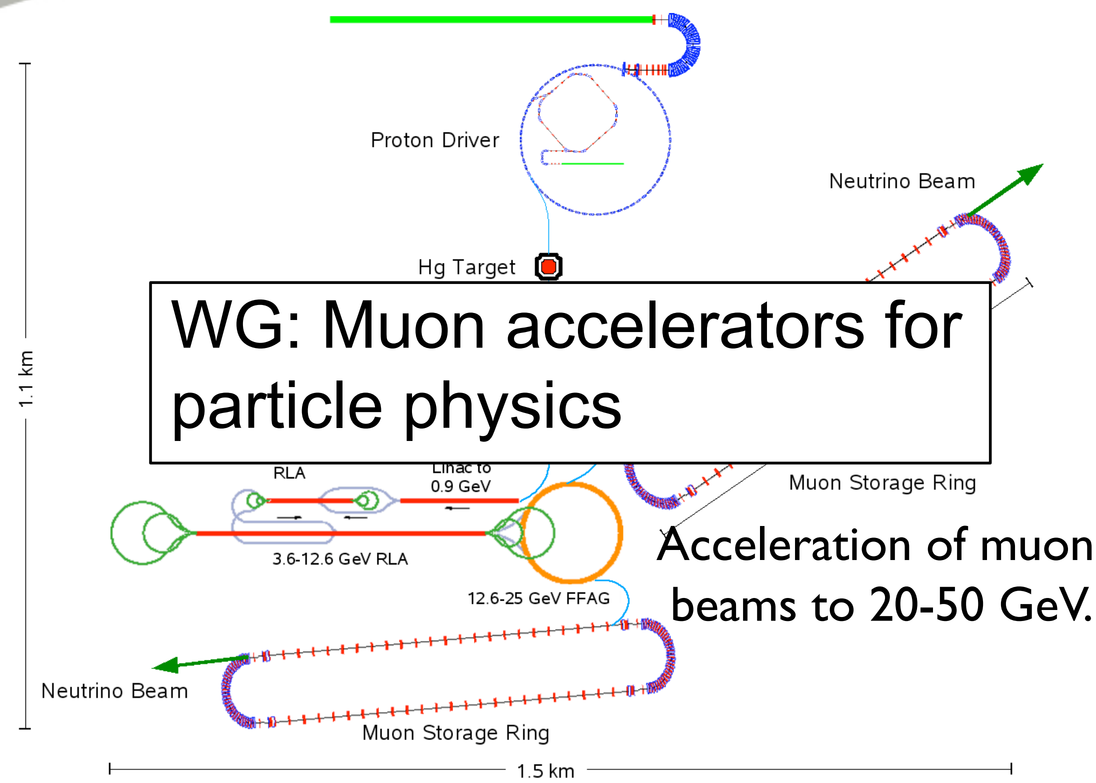
Demands for new accelerator

Neutrino Factory



WG: Muon accelerators for particle physics

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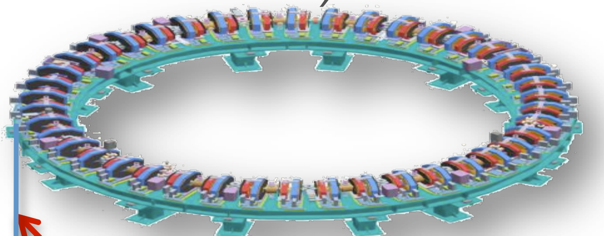

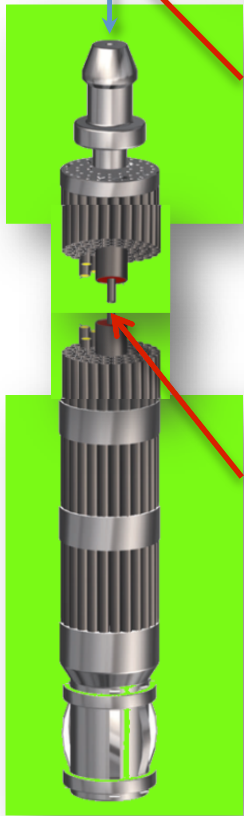

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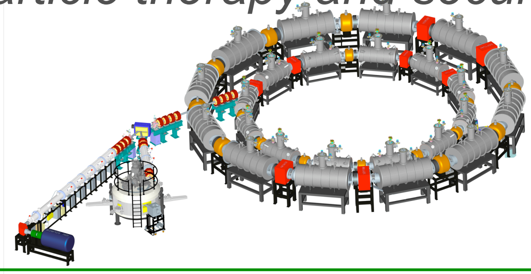

Compact and flexible accelerator.

Science & Technology Facilities Council

Demands for new accelerator

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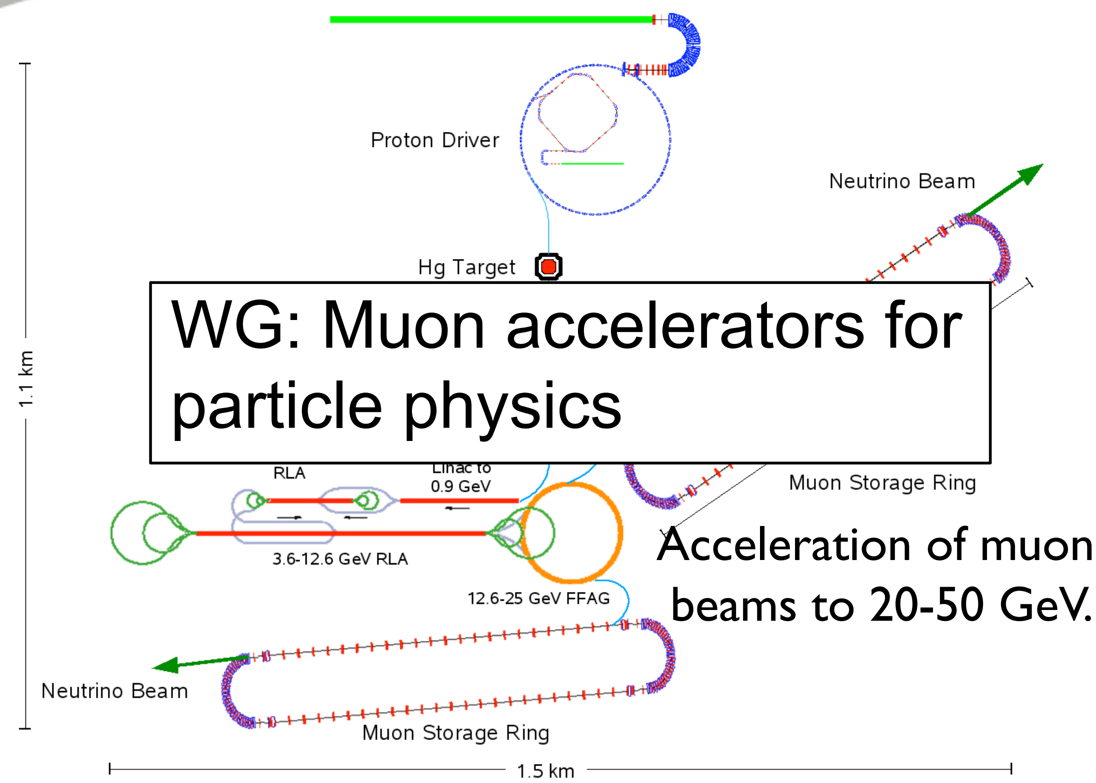

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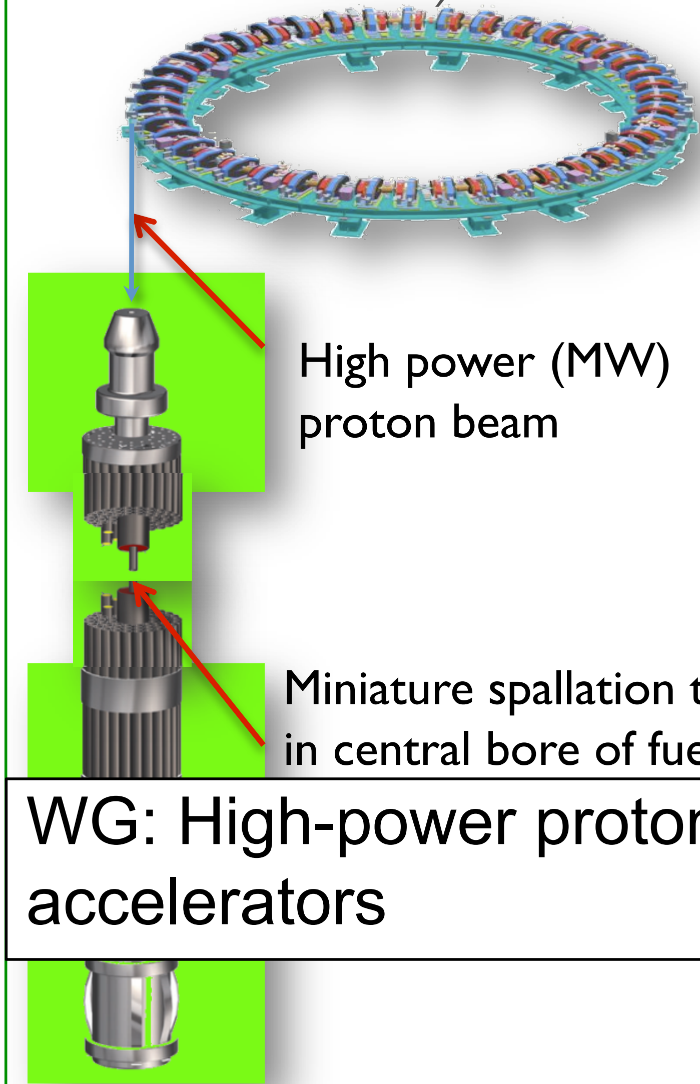
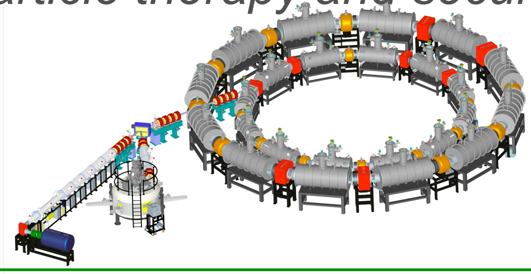


High power (MW) proton beam

Miniature spallation target in central bore of fuel

WG: High-power proton accelerators

Particle therapy and security application

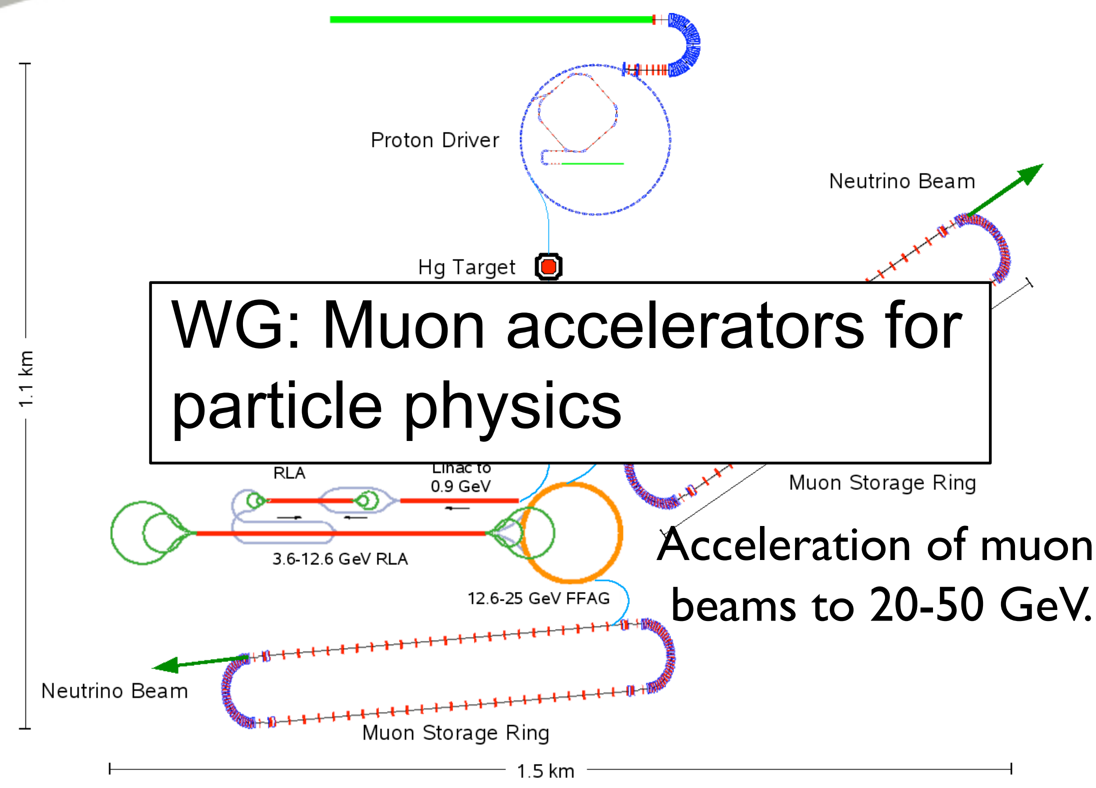


Compact and flexible accelerator.

Science & Technology Facilities Council

Demands for new accelerator

Neutrino Factory



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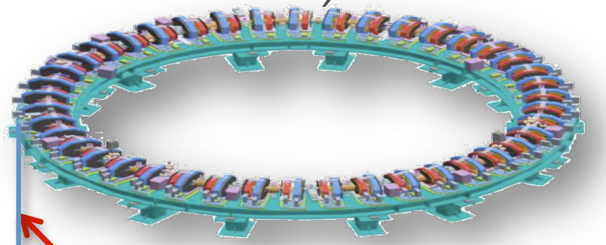

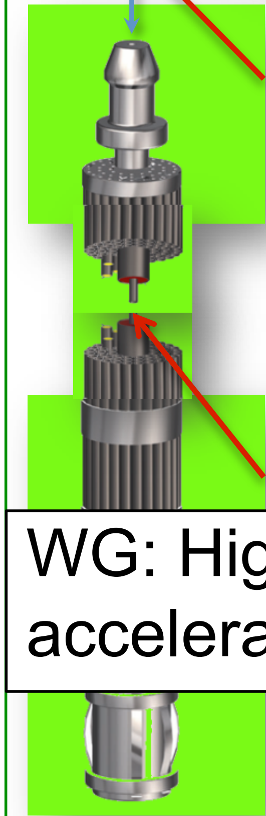

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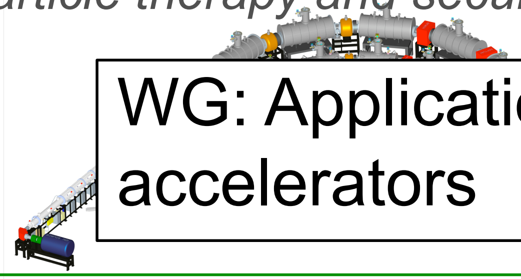
Miniature spallation target in central bore of fuel

WG: High-power proton accelerators

Particle therapy and security application



WG: Applications of proton accelerators

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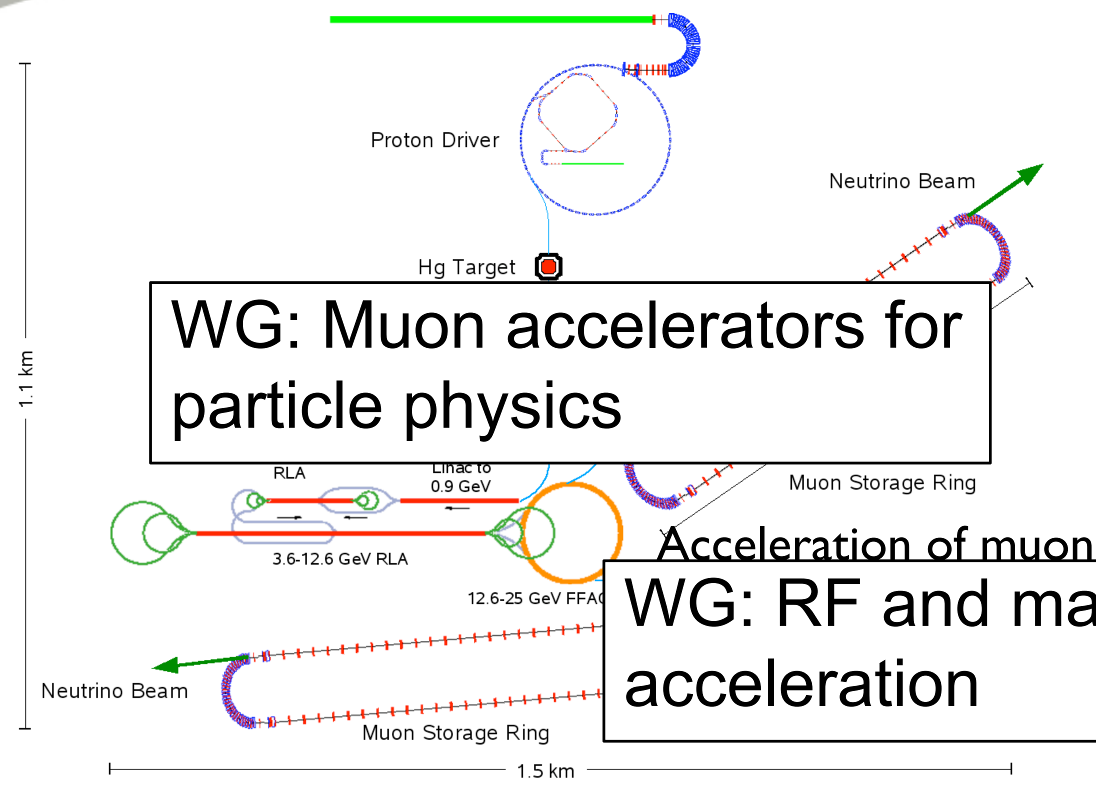
Demands for new accelerator

Neutrino Factory

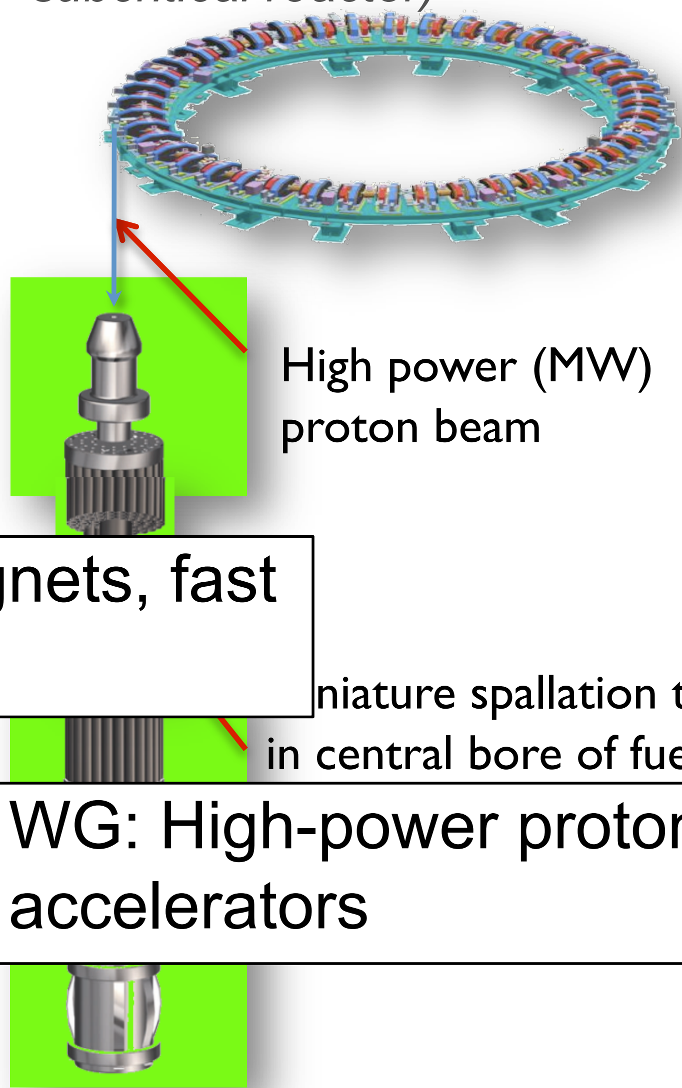


WG: Muon accelerators for particle physics

Acceleration of muon

WG: RF and magnets, fast acceleration

ADSR (accelerator driven subcritical reactor)

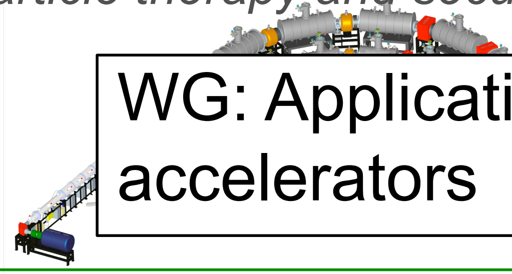


High power (MW) proton beam

niature spallation target in central bore of fuel

WG: High-power proton accelerators

Particle therapy and security application



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WG: Applications of proton accelerators

Thank you for your attention.