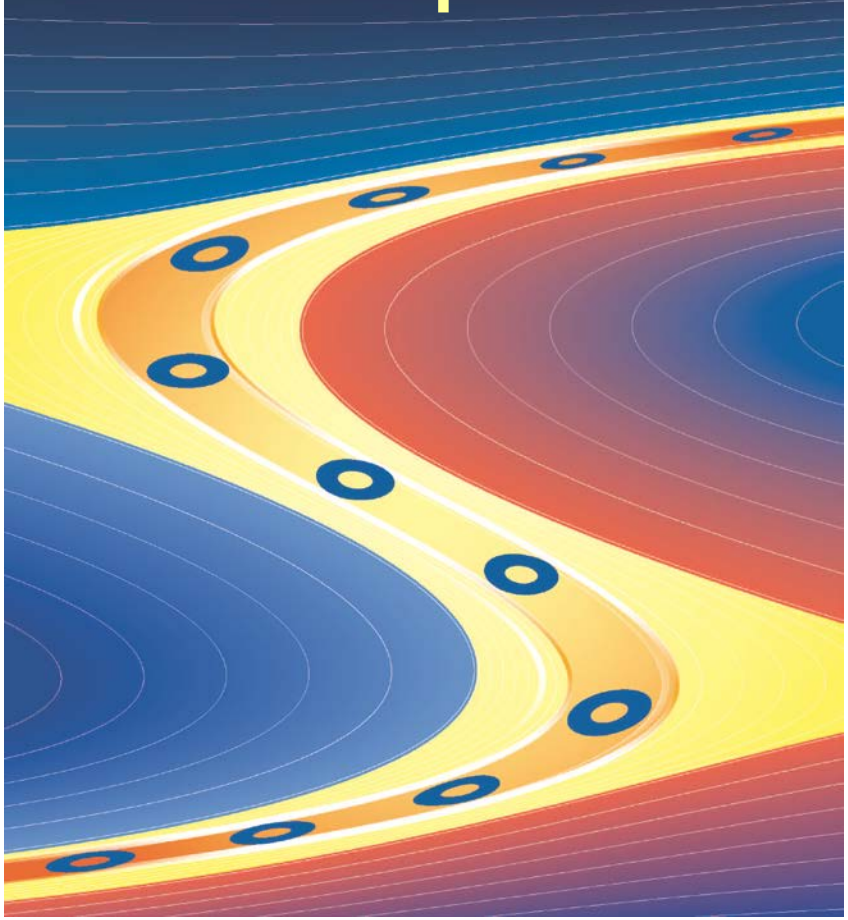
Science & Technology Facilities Council

BASROC CONFORM

New Results from the EMMA Experiment



Bruno Muratori

On behalf of the EMMA team

Science & Technology Facilities Council

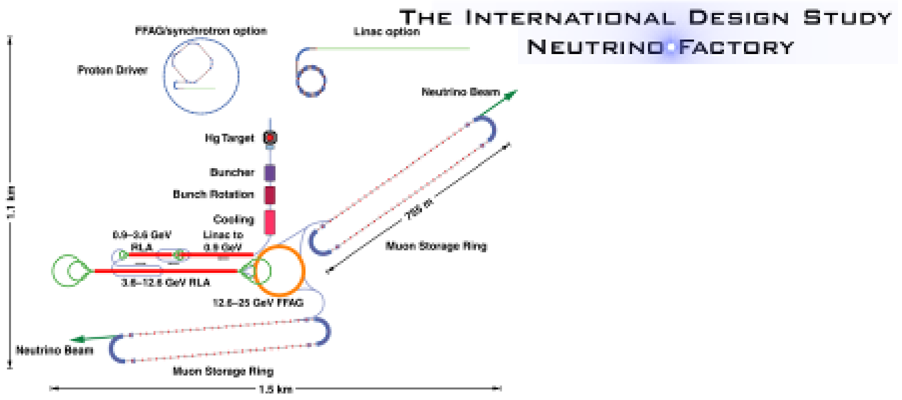
Daresbury Laboratory

IPAC12

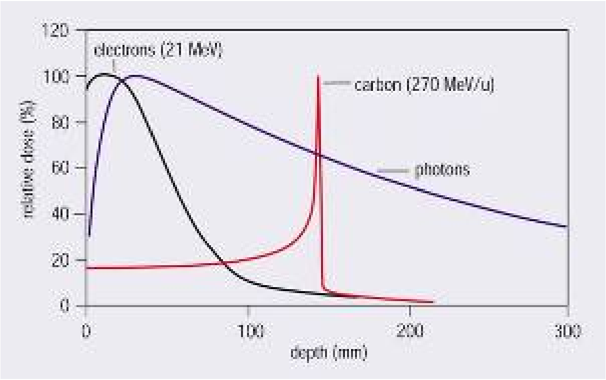
Contents

Applications of ns-FFAGs

Neutrino Factory

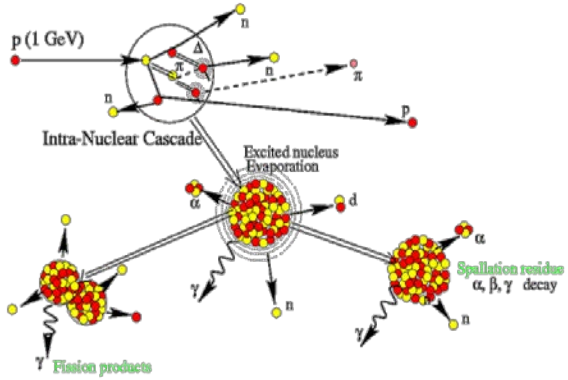


Proton & Carbon Therapy

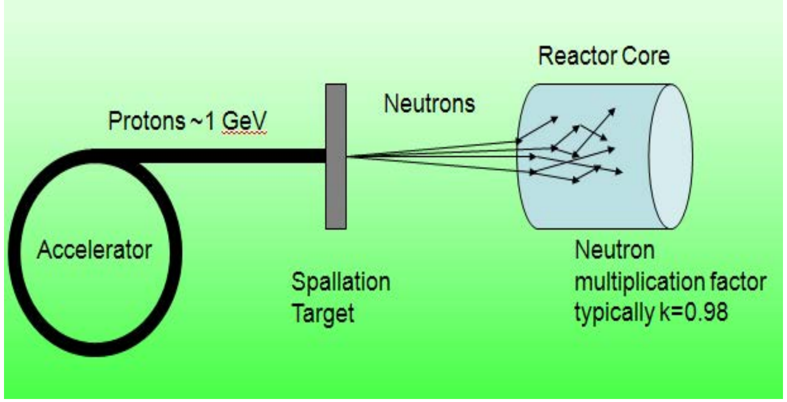


High power proton driver

Dedicated Muon Source

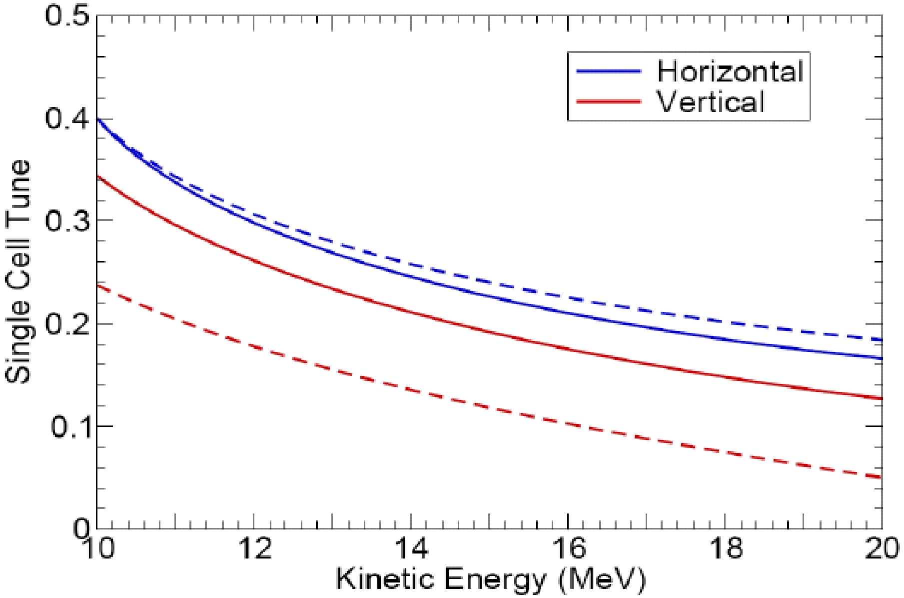


Accelerator driven reactor

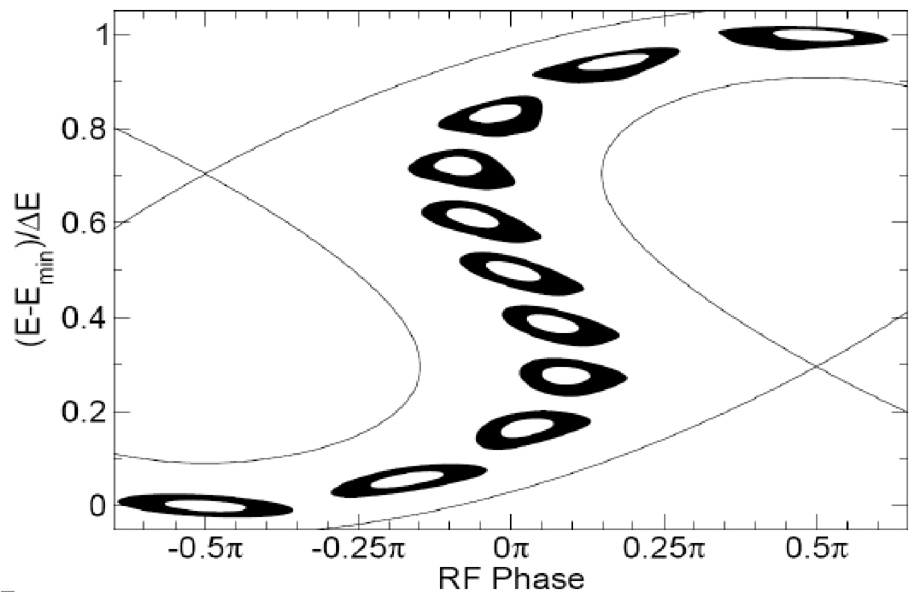


EMMA Goals

(1) Rapid acceleration with large tune variation (natural chromaticity)



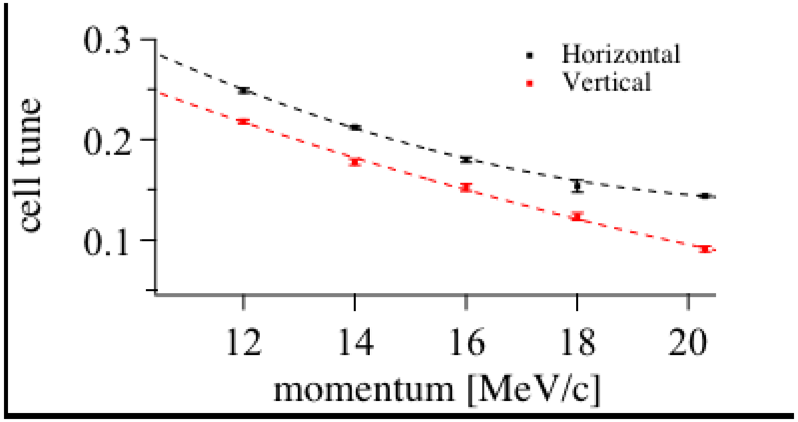
(2) Serpentine acceleration (results from parabolic ToF)

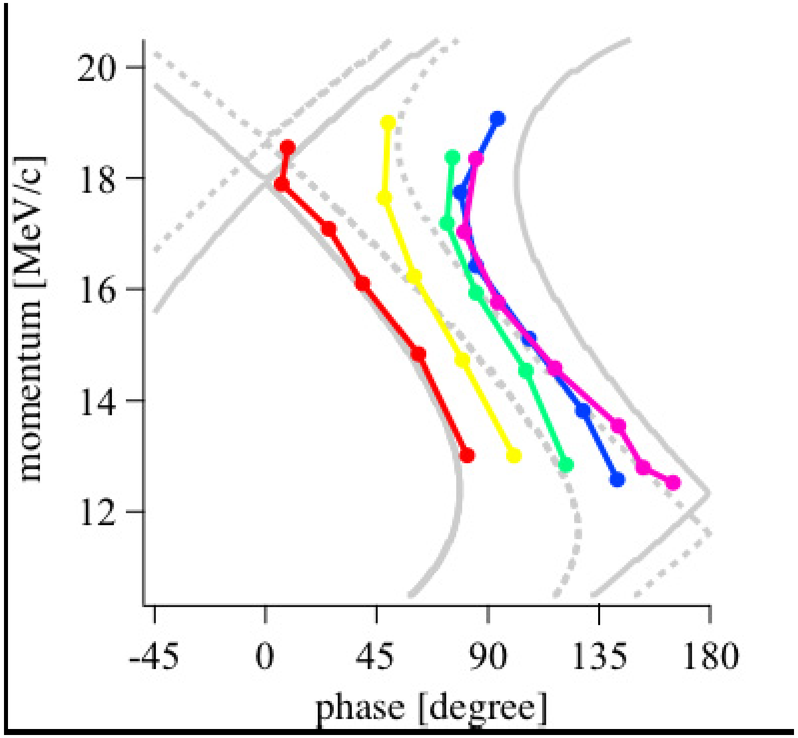


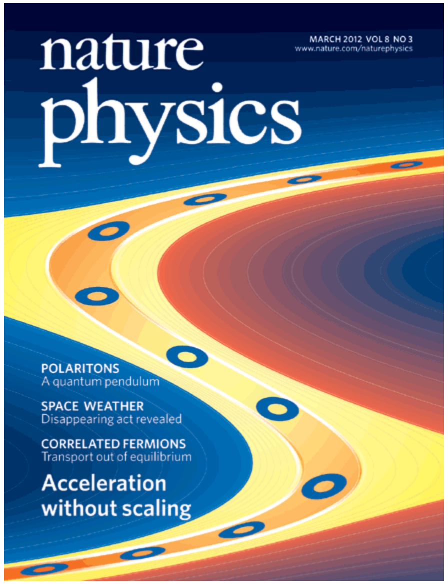
(3) Map the transverse and longitudinal acceptances.

Graphs courtesy of Scott Berg BNL

EMMA acceleration







- Measured

- Successfull acceleration in serpentine channel
- Published in Nature Physics (01/03/12)

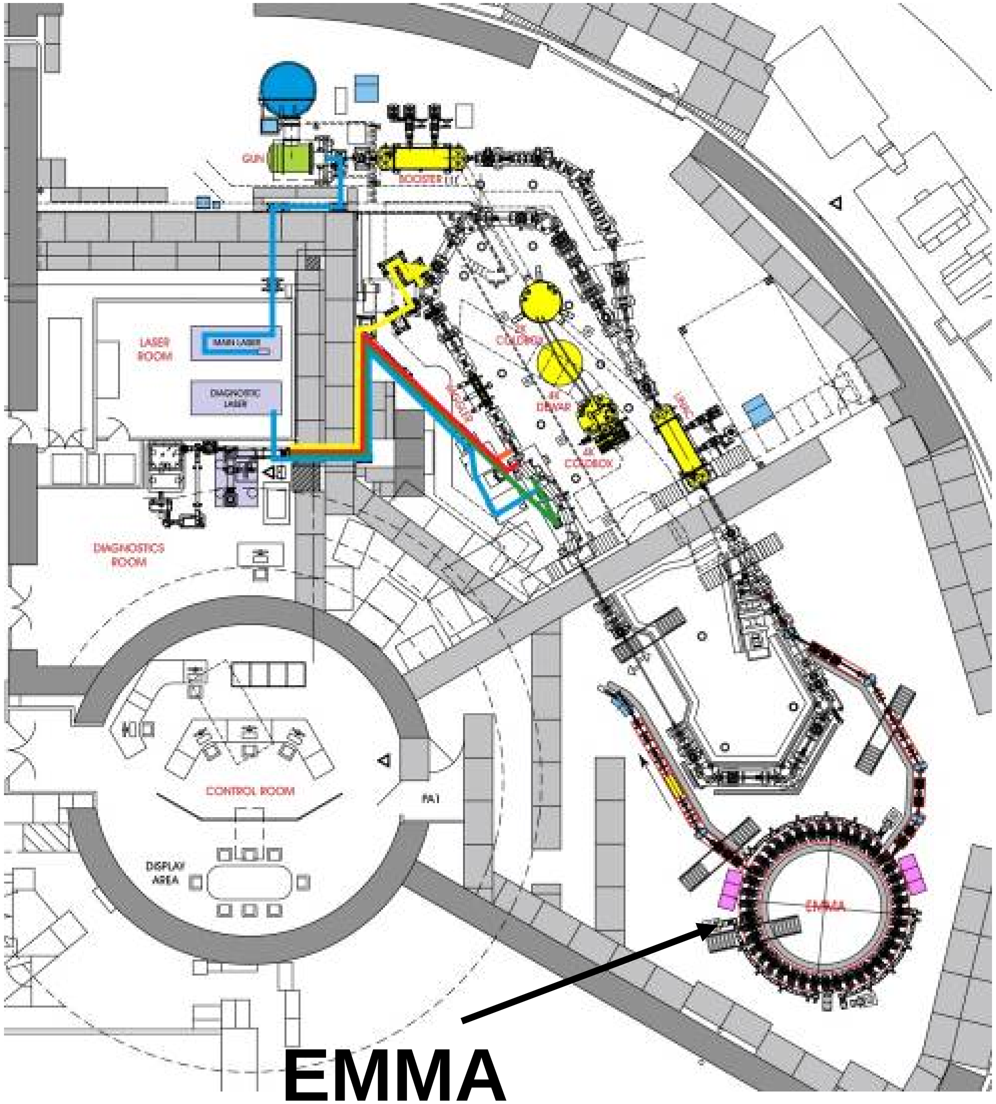
Accelerator Requirements

- Injection & extraction at all energies, 10 - 20 MeV
- Fixed energy operation to map closed orbits and tunes vs momentum
- Use equivalent momentum concept
- Many lattice configurations
  - Vary ratio of dipole to quadrupole fields
  - Vary frequency, amplitude and phase of RF cavities
- Map longitudinal and transverse acceptances with probe beam from ALICE
- EMMA is heavily instrumented with beam diagnostics

LAYOUT AND LATTICE

ALICE

Accelerators and Lasers In Combined Experiments



Energy range	10 – 20 MeV
Lattice	F/D Doublet
Circumference	16.57 m
No of cells	42
Normalised transverse acceptance	3π mm-rad

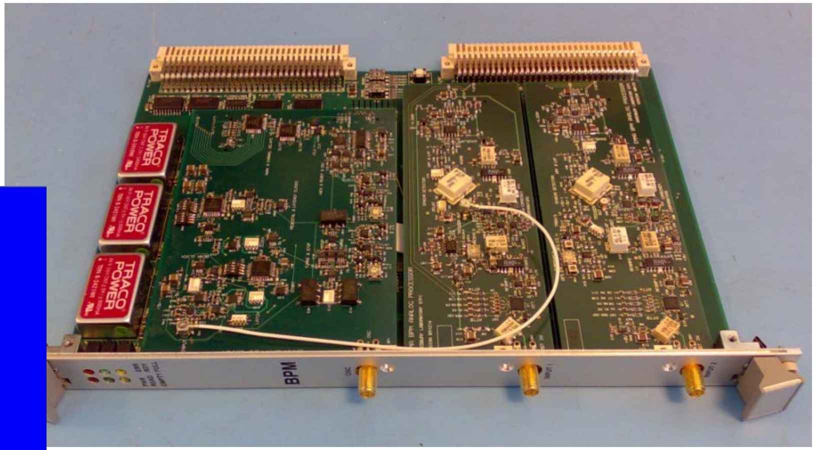
Frequency (nominal)	1.3 GHz
No of RF cavities	19
Repetition rate	1 - 10 Hz
Bunch charge	20-60 pC single bunch

DIAGNOSTICS

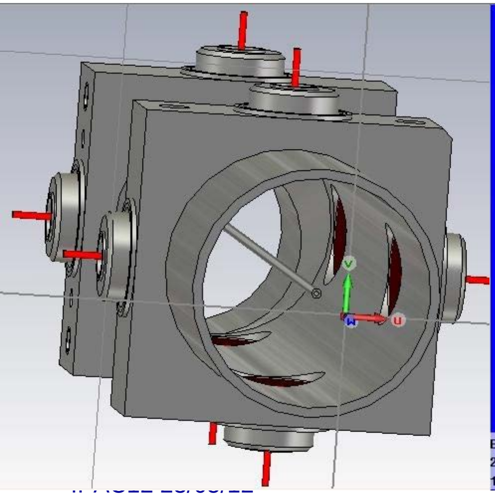
BPMs (MOPPR060 & MOPPR061)

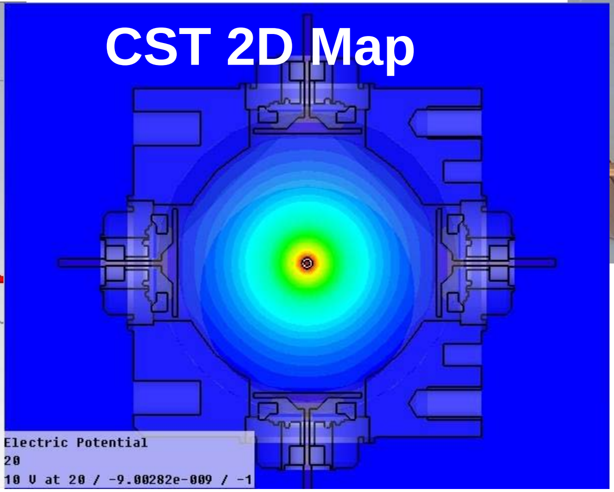
- 50 μm resolution or smaller over a large aperture
- Controlled via EPICS
- Giving turn by turn information
- Computing
  - Position
  - Charge

Coupler



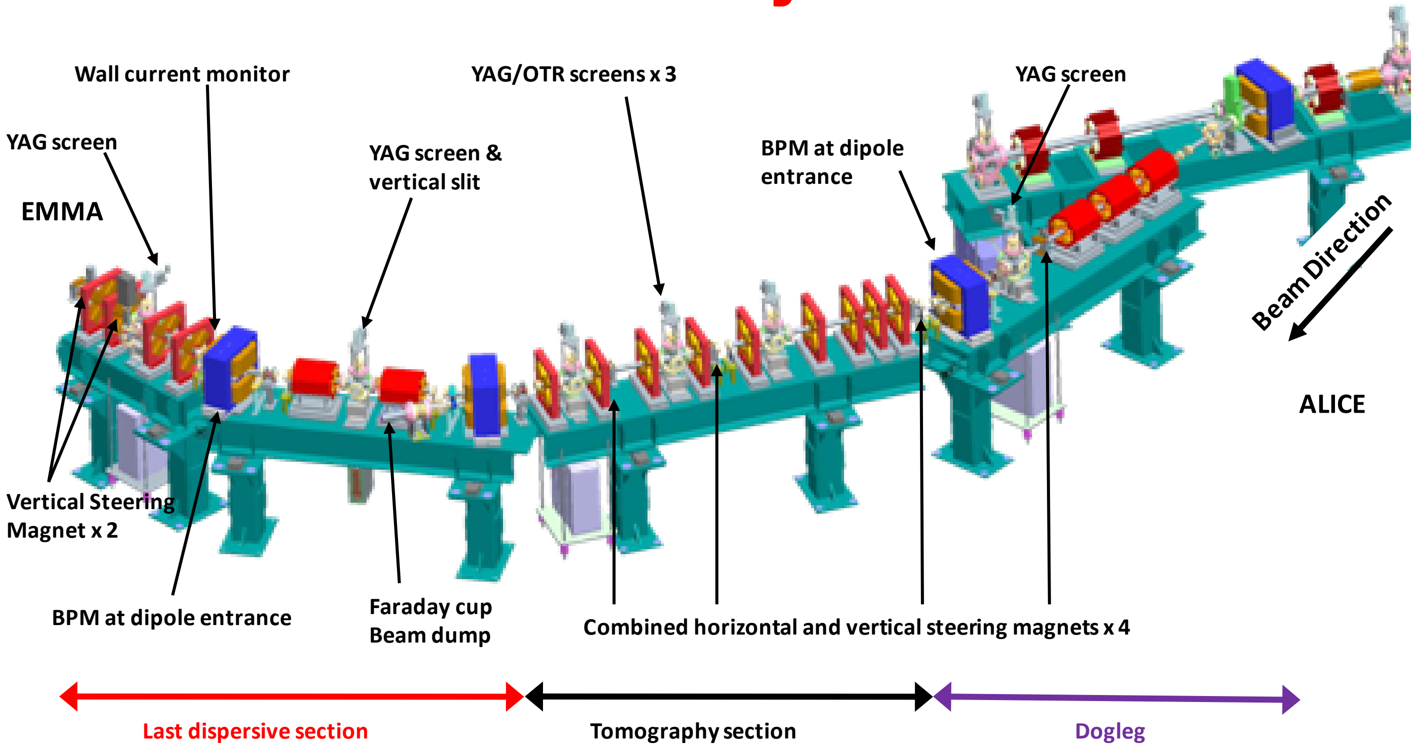
Detector card





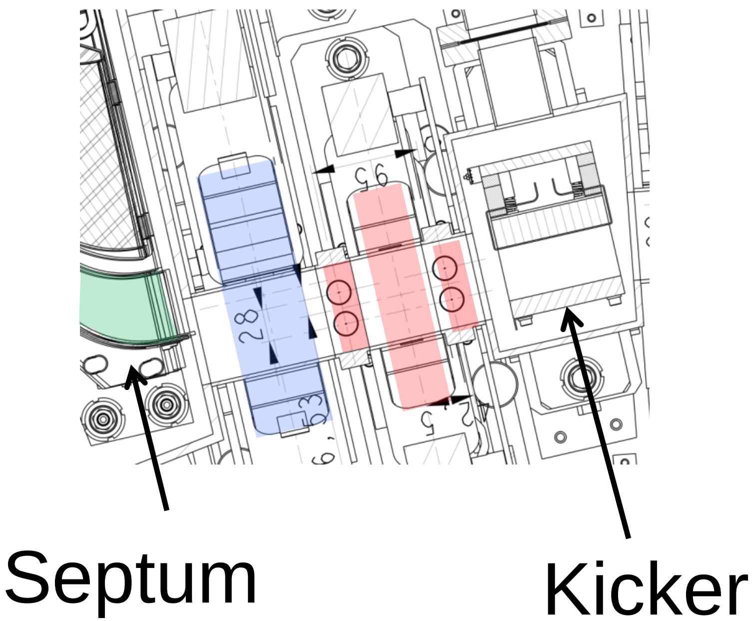
INJECTION

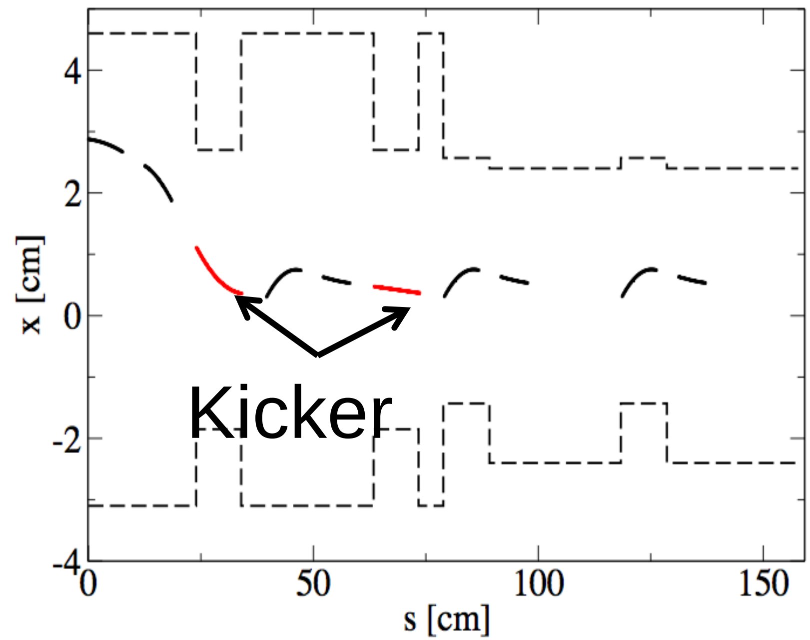
Injection line

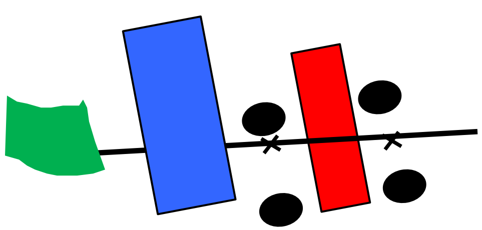


- Dogleg to extract beam from ALICE
- Tomography (dual purpose)
- Minimise energy spread (done & < 0.05 % at 15 MeV)

Optimisation of injection





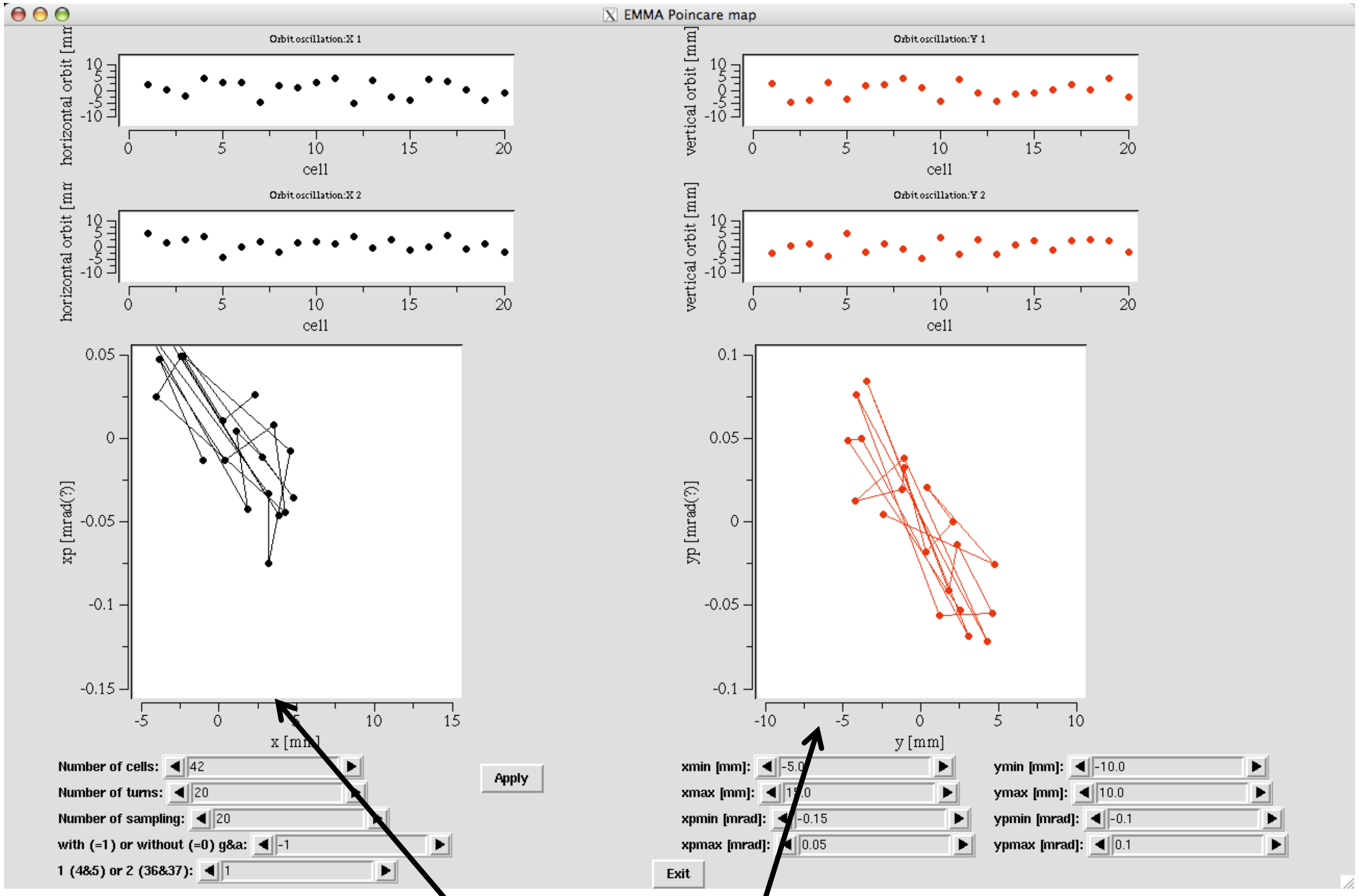


Angle at end of SEPT determined from BPM offsets with quads OFF

- Use code to determine kicker strengths relatively close to pragmatically found strengths
- Can generate Poincaré map from BPM readouts in real time

Real time Poincaré plot

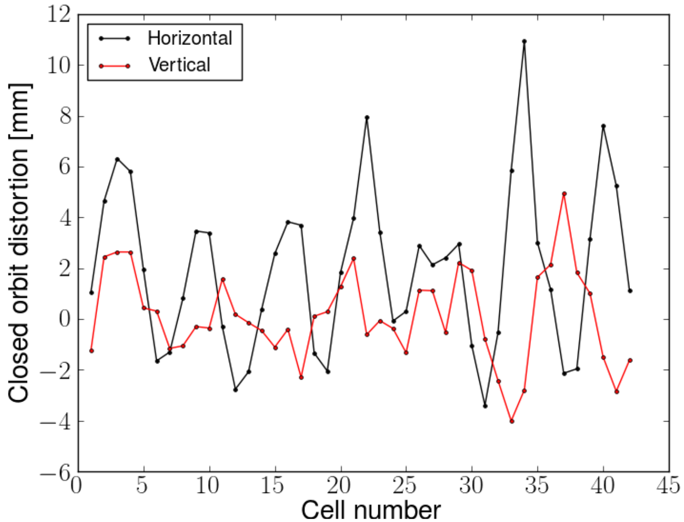
- Use 2 BPMs after septum
- Kickers off
- Updated every second
- Measure momentum in both planes

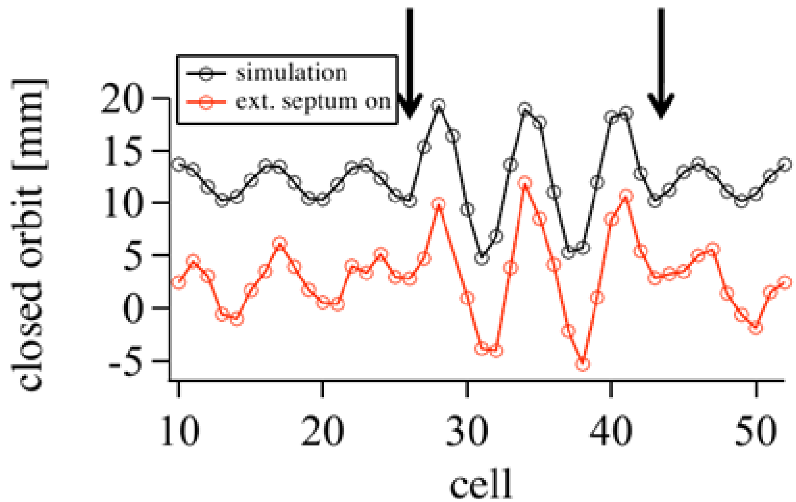


Orbit Correction (TUPPD021)

Error Sources

- Large closed orbit distorion in both horizontal and vertical planes (several mm). We would like to reduce this to increase the effective physical aperture.
- In the horizontal plane the stray field due to the septum is major source (0.5 mTm). Identified by checking the effect of the extraction septum on the orbit distoriton.
- In the vertical plane it is possible that stray fields in the vertical correctors are also a source.

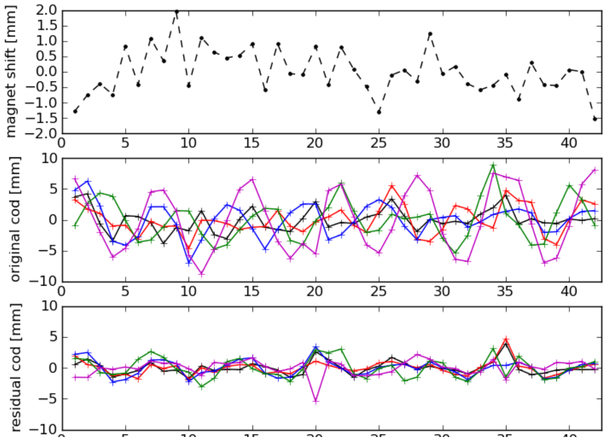




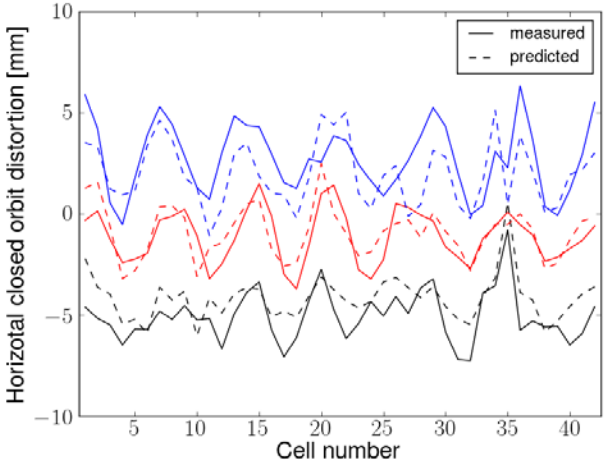
Effect of septum on orbit distortion (model)

Orbit Correction
multiple momenta

- No conventional closed orbit in ns-FFAGs so minimise measured deviation with respect to target deviation
- Tune & phase advance change with momentum so correction for one energy may not work for all
- Solve using least squares method
- Three energies shown (14.3, 16.4 & 18 MeV/c)
  - Shift in D quads, orbit before and after correction



Residual distortion after correction vs. model

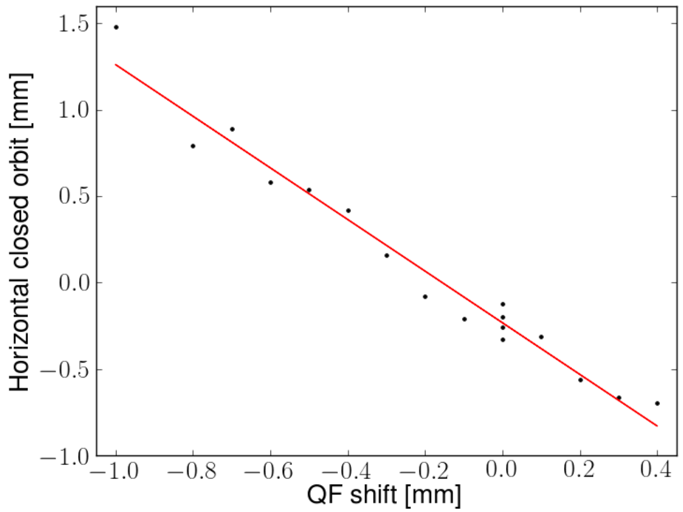


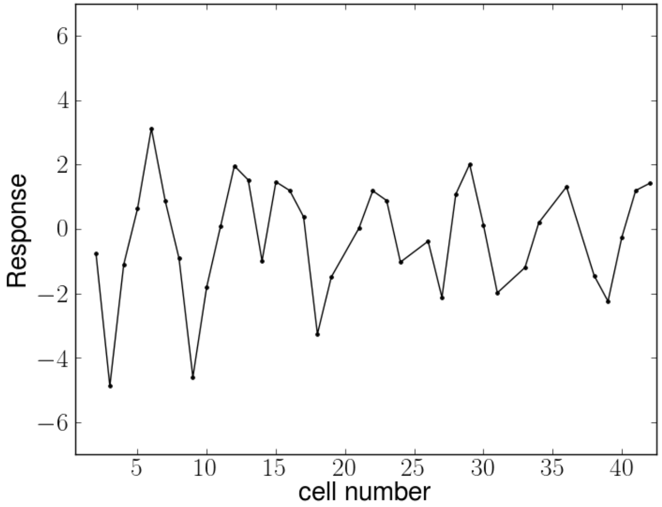
Bruno Muratori

Orbit Correction

Response matrix measurement

- Measuring the response matrix directly useful for correction.
- A single F quad was shifted in 0.1 mm steps and the closed orbit measured each time.
- Response given by slope of linear fit to data.
- Need to repeat for the other quadrupoles and vertical correctors to complete the response matrix.

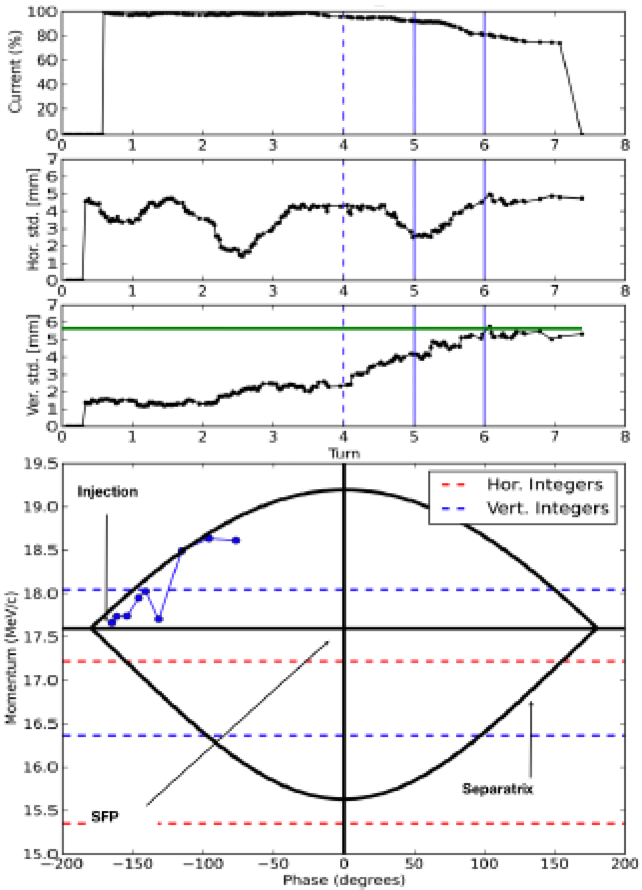




Slow Integer Tune Crossing (MOPPD021)

- Inject bunch into RF bucket and let it undergo synchrotron oscillations
- Arrange lattice such that horizontal and / or vertical integer tunes are crossed during synchrotron oscillation
- Regions of tune space crossed at 0.2 – 2 MV / turn
- Inject at 12.5 MeV/c and look at equivalent momenta for different energies
- Look at amplitude growth and longitudinal phase space taking different voltage and phase as parameters which change tune crossing speed
  - Near stable fixed point
  - Far away from stable fixed point

Slow Integer Tune Crossing (2)

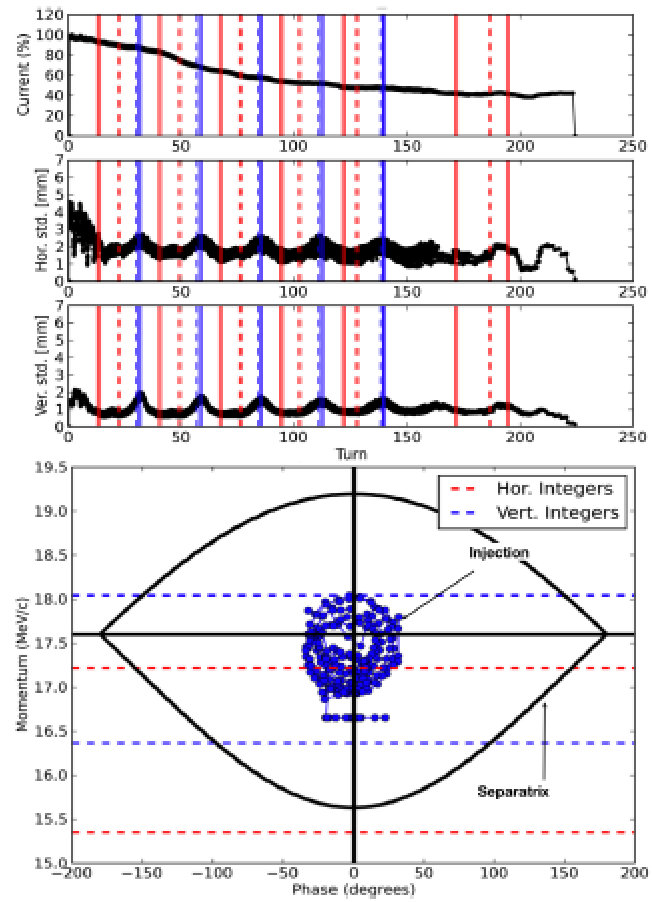


Current vs. Turn #

x pos. vs. Turn #

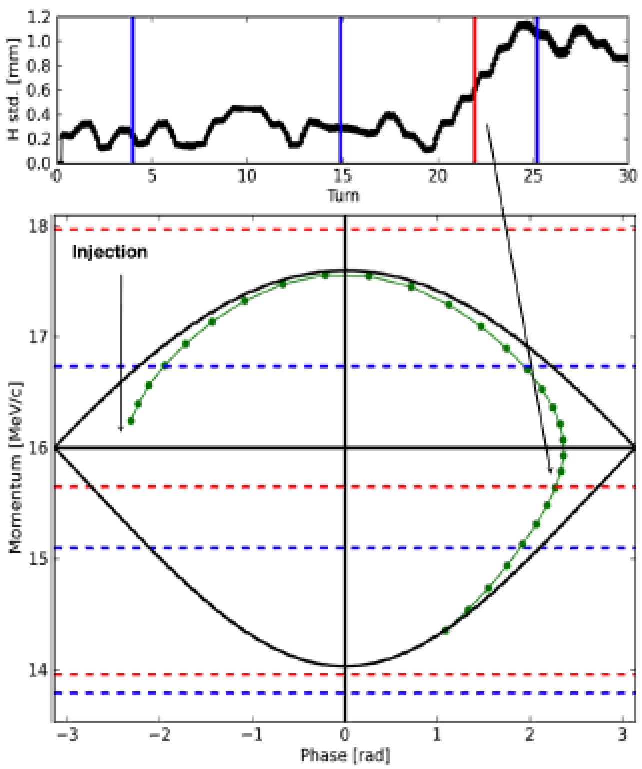
y pos. vs. Turn #

position in RF bucket for each turn #



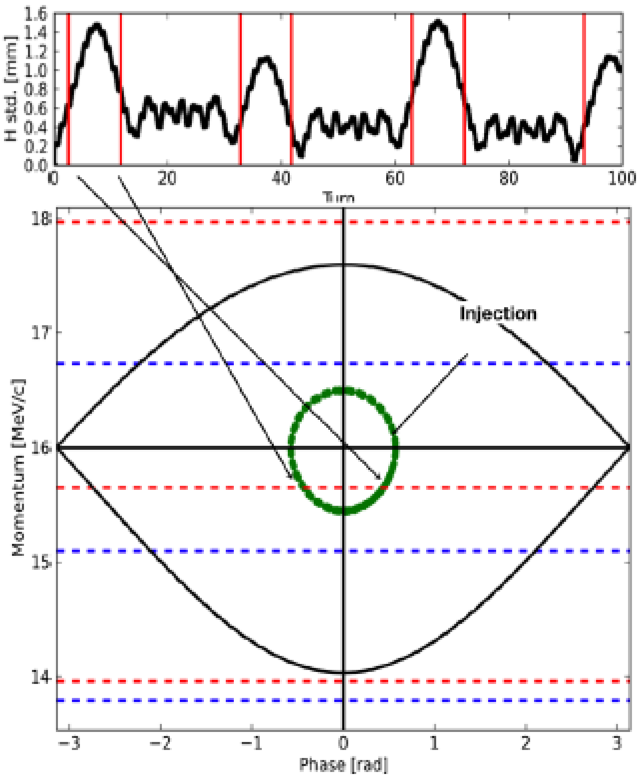
- Experimental results injecting beam near the stable fixed point and away from it

Slow Integer Tune Crossing (3)



x pos. vs. Turn #

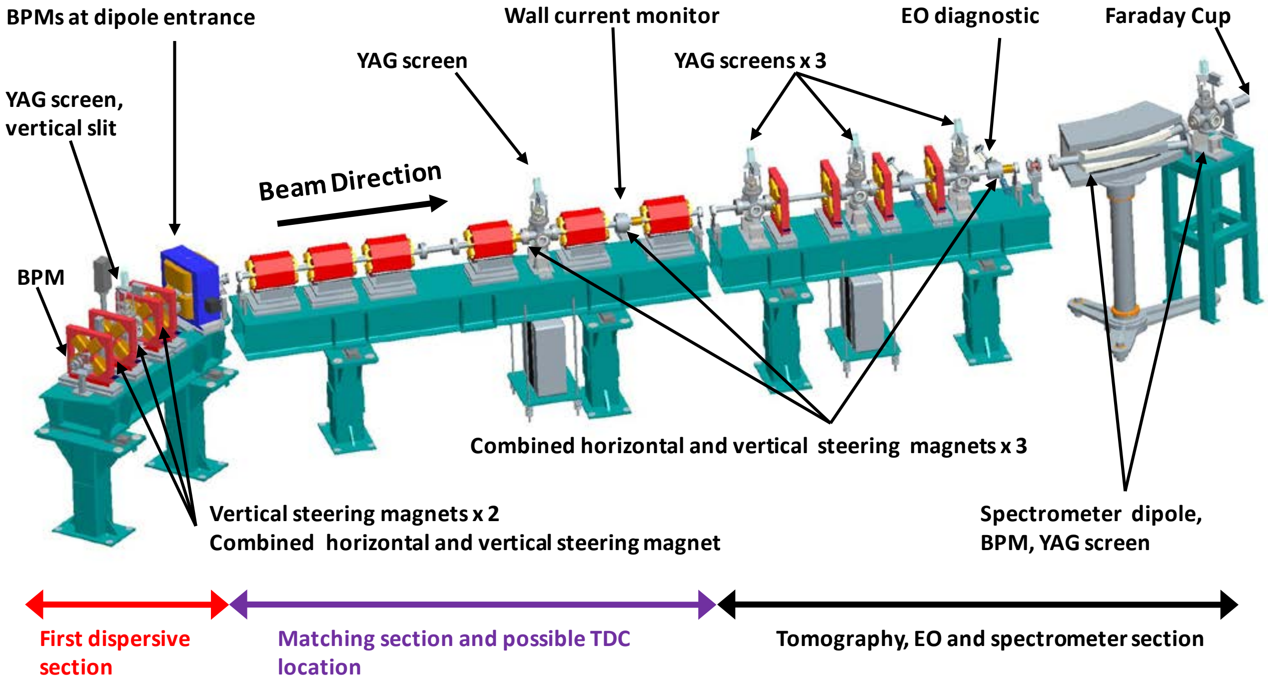
position in RF bucket for each turn #



- Simulation results injecting beam near the stable fixed point and away from it

EXTRACTION

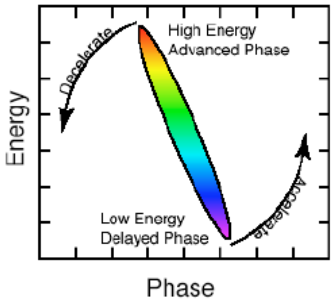
Extraction

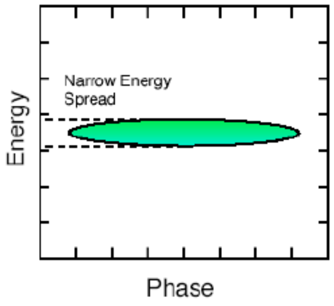


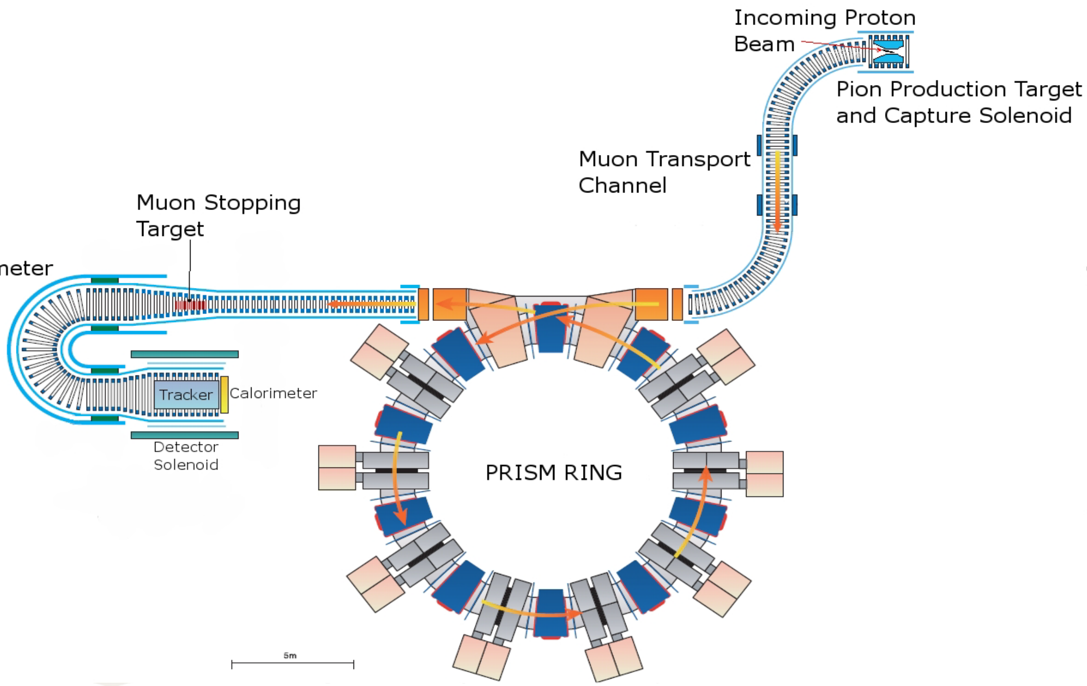
- Can routinely extract the beam - still very little charge
- Have plenty of diagnostics for further understanding the beam & what EMMA has done to it
- Projected emittance, slice emittance, bunch length, energy spread, slice energy spread

PRISM experiment on EMMA (TUPPD002)

- PRISM (Phase Rotated Intense Slow Muons) looks at muon to electron conversion (CLFV) as predicted by some unified theories
- Need a very small energy spread
- Want to use an FFAG (possibly non-scaling) to rotate the bunch in phase space



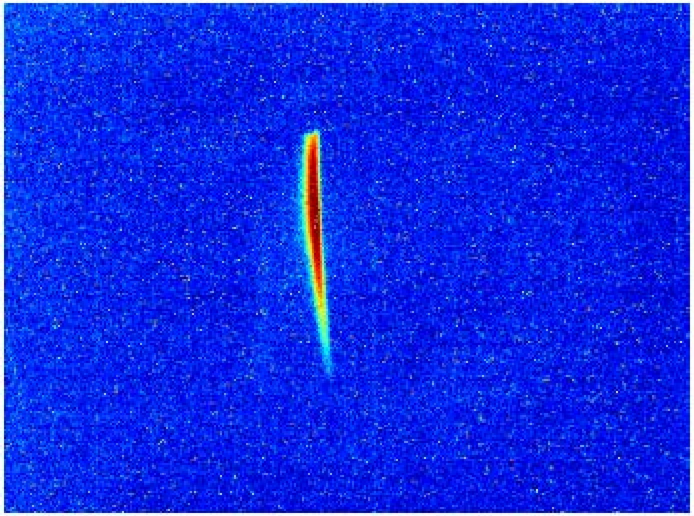




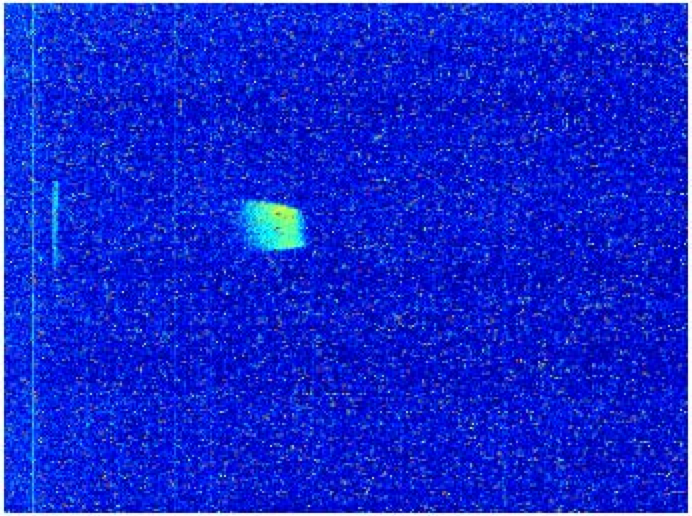
PRISM Experiment on EMMA

- Test Non-Scaling optics for PRISM
- ¼ of the synchrotron oscillation takes ~3 turns in EMMA and ~6 turns in PRISM.
- Experimental steps:
  - Inject into EMMA at fixed energy from ALICE with different transverse amplitudes with RF on (voltage and phase set to stationary bucket) *or* use different equivalent energies with transverse amplitudes & RF on.
- Extract after ¼ (3/4) of synchrotron oscillation and measure energy and ToF.
- Scale magnets in extraction line according to energy via a script
- Analyse the data and reproduce the longitudinal phase space as a function of the transverse amplitude

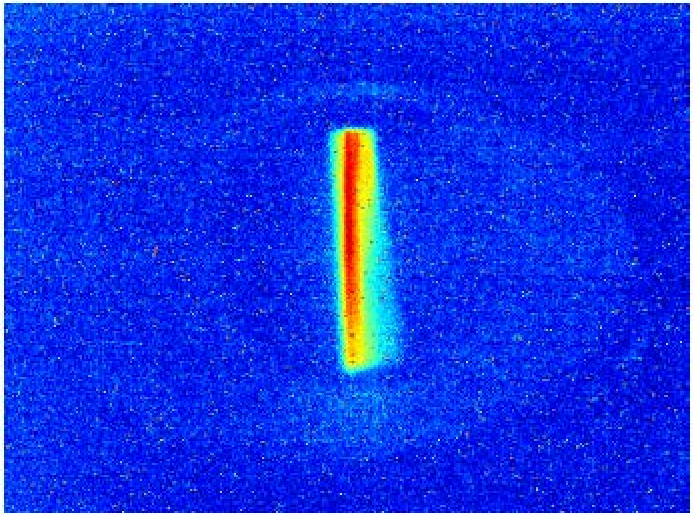
PRISM Experiment on EMMA

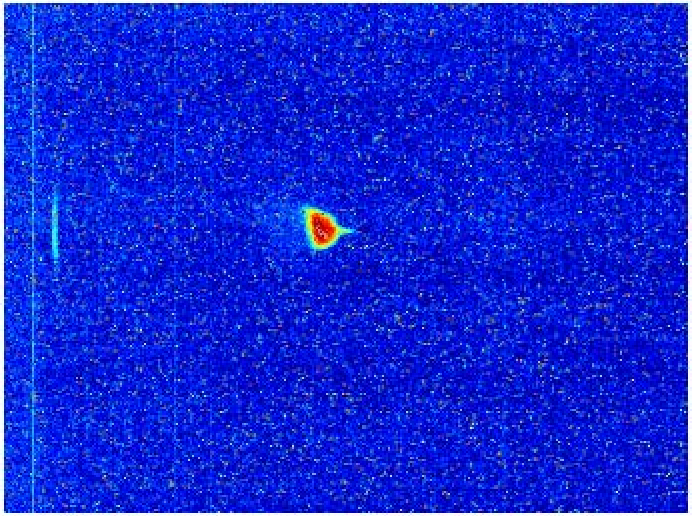


YAG01 – 3/2 (top), 5/2 turns, RF on, scaling



YAG03 – 3/2 (top), 5/2 turns, RF on, scaling





Summary

- **Design and construction phase of the project is complete**
- **Injection / extraction complicated but workable solution**
- **Have successfully accelerated !**
- **EMMA experiment still under way:**
    - Many 1000s of turns at fixed energy and for various energies
    - Time of flight measurements / tunes have been measured at various quadrupole settings and various equivalent energies
    - Full orbit correction under way
    - Started detailed characterisation of the accelerator
    - Aperture studies & PRISM experiment to be completed

Apply lessons learnt to new applications!

(MOEPPB003), (MOPPC032), (TUPPD020), (THPPD049)

Science & Technology Facilities Council

BASROC CONFORM

Acknowledgements

All the team

- STFC Daresbury & Rutherford Appleton Labs , Cockcroft Institute, John Adams Institute, Imperial College staff
- International Collaborators
- Commercial Suppliers

Funding from UK Basic Technology Programme

Thank you for your attention !