Muon Acceleration in Non-Scaling FFAG for the Neutrino Factory

J. Pasternak, Imperial College London / RAL STFC

Work in collaboration and with contributions from:
M. Aslaninejad (IC), J. Scott Berg (BNL),
N. Bliss (STFC/Technology/DL) C. Bontoiu (IC),
M. Cordwell (STFC/Technology/DL), D. Kelliher (ASTeC/STFC/RAL),
S. Machida (ASTeC/STFC/RAL), H. Witte (JAI-Oxford)

Outline

- Introduction.
- Layout and optics.
- Acceleration simulation.
- Injection/extraction.
- Effect of septum fields.
- Engineering layout.
- Preliminary solution for the large θ_{13} scenario.
- Conclusions and future plans.

Introduction

New IDS-NF baseline.	
Number of cells	67 m
Circumference	669 m
RF voltage	1.1956 GV
Max field in F magnet	4.4 T
Max field in D magnet	6.2 T
F magnet radius	16.1 cm
D magnet radius	13.1 cm
Muon decay	7.1 %
Injection energy	12.6 GeV
Extraction energy	25 GeV

Recent progress:

•Acceleration studies

•Effect of septum stray fields on the accelerated orbit

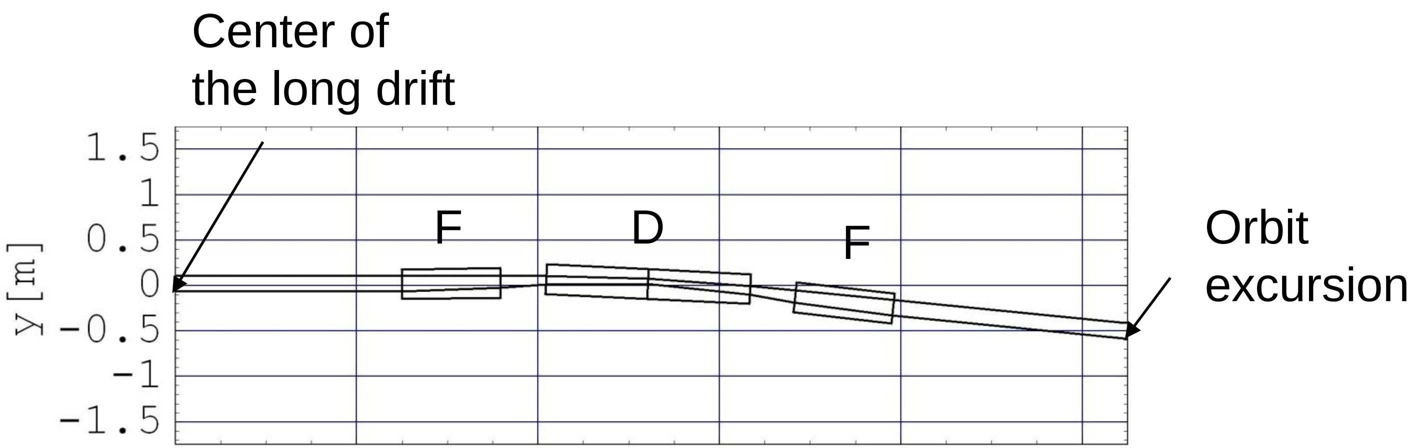
•Costing model

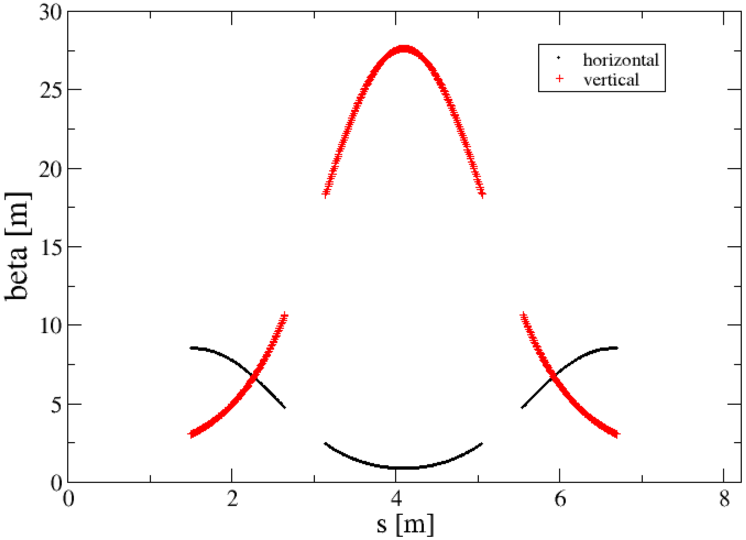
Non-scaling FFAG is selected for the final muon acceleration at the Neutrino Factory.

Advantages include:

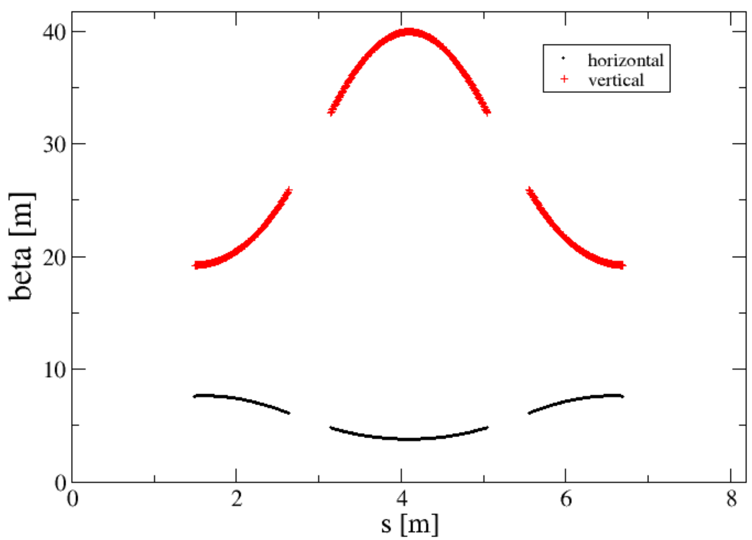
- Allows very fast acceleration (~12 turns).
- Large dynamic aperture due to linear magnets + high degree of symmetry.
- More turns than in RLA – more efficient use of RF – cost effective.
- Quasi-isochronous – allows fixed frequency RF system.
- Orbit excursion and hence magnet aperture smaller than in the case of a scaling FFAG – cost effective.
- Principles of NS-FFAG are now being tested during ongoing EMMA commissioning.

Layout and optics



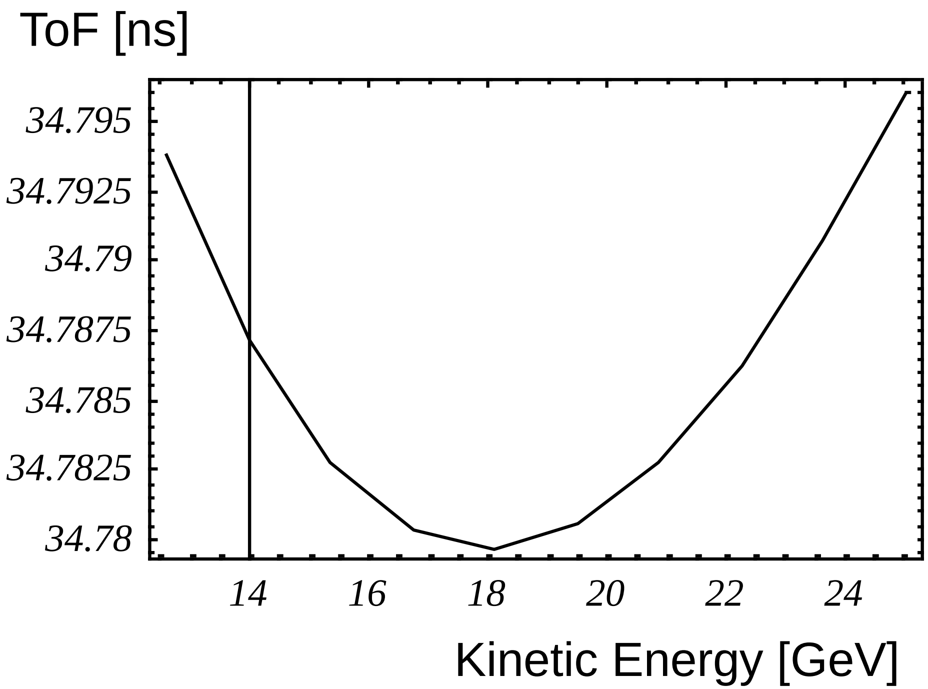


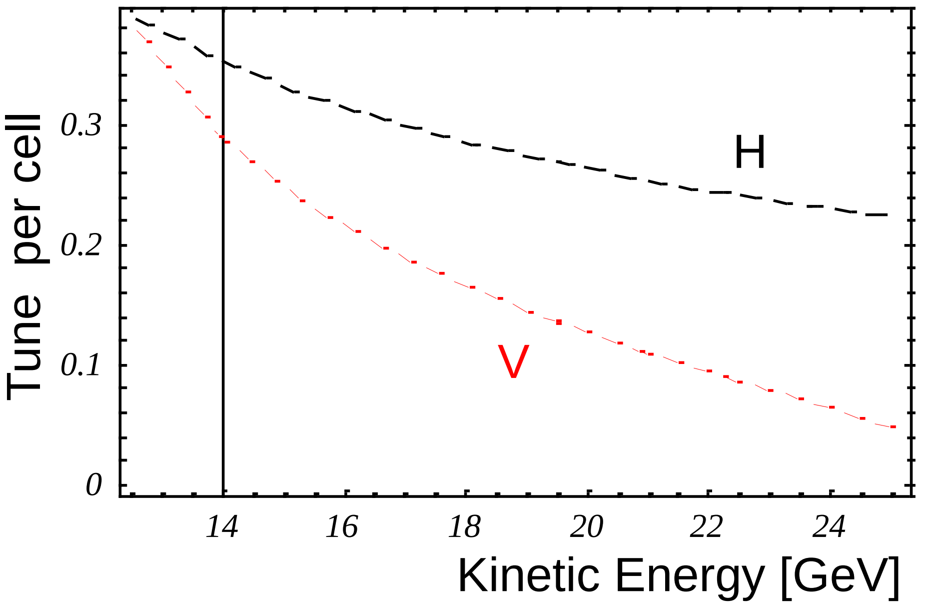
Beta functions at injection

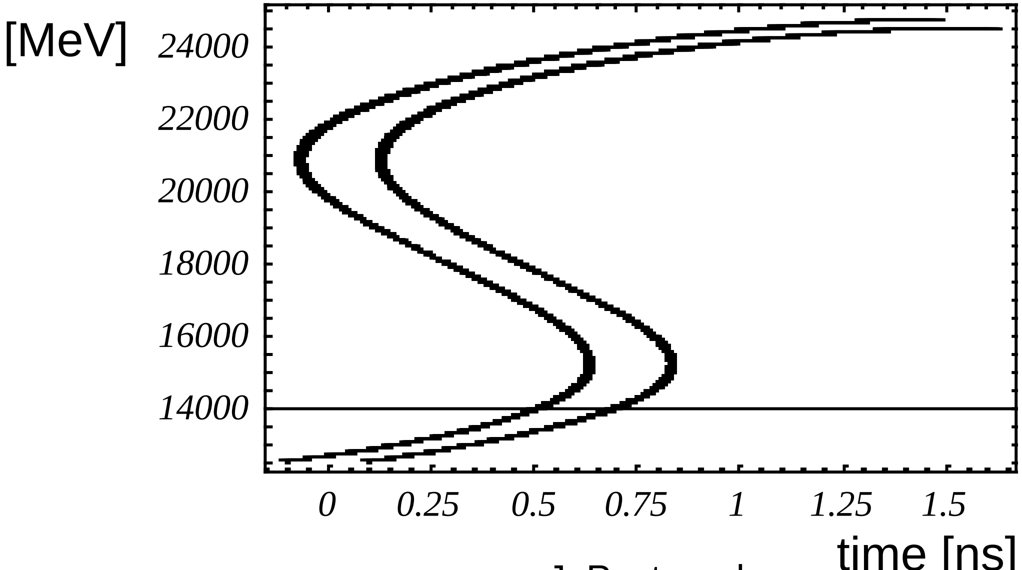


Beta functions at extraction

Beam Optics and Acceleration







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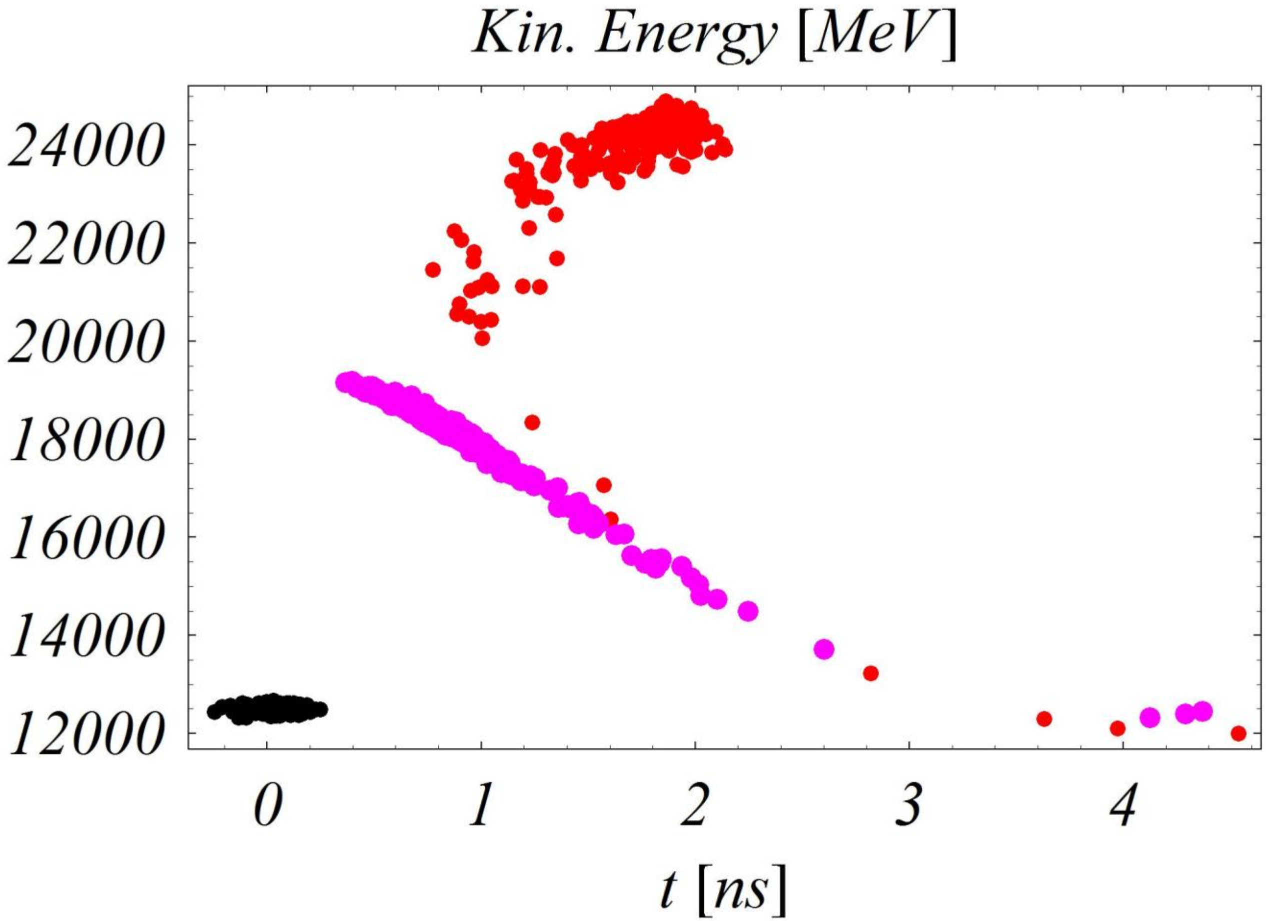
Acceleration studies:
6D tracking, full transverse emittance, Gaussian distribution, optimised RF synchronization

Muons with
a large momentun
spread!

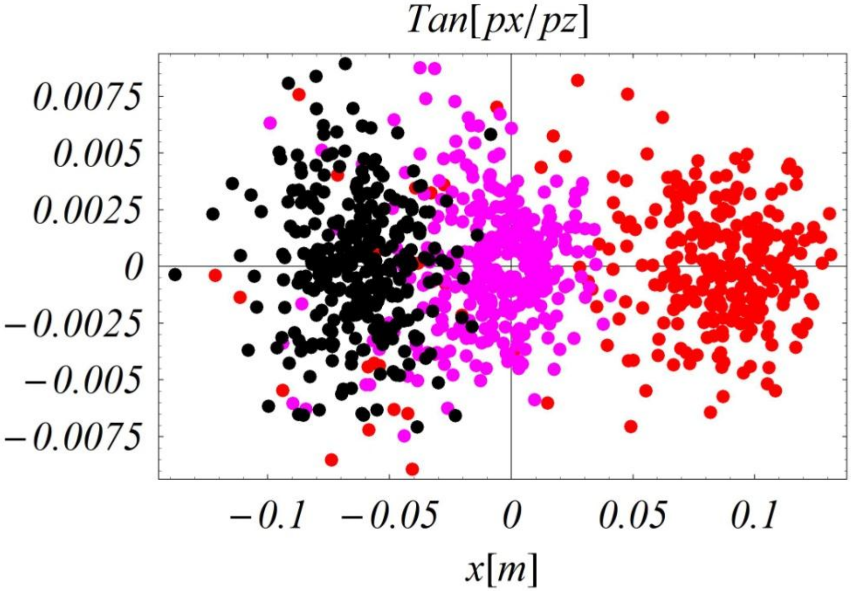
Potential problem
for the septum
operation!

To be fixed!

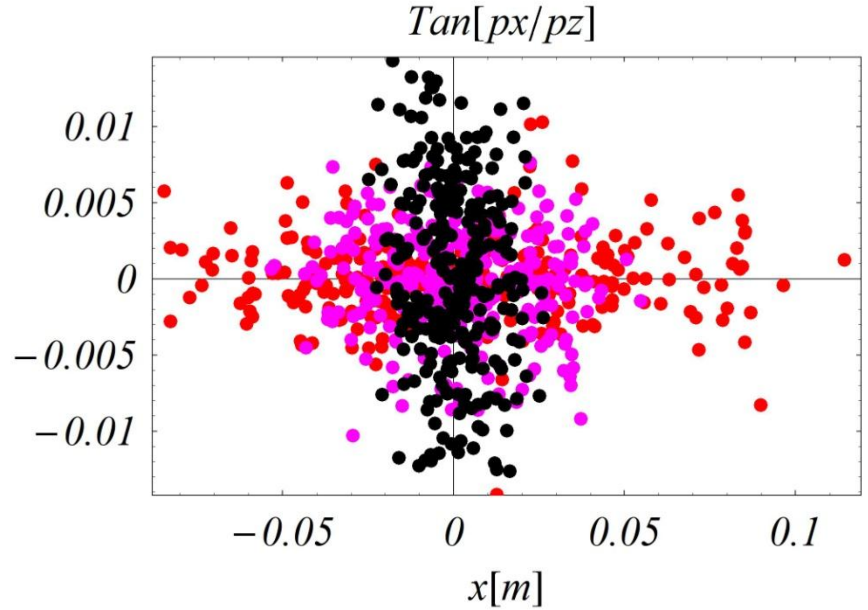


Acceleration studies (3):

6D tracking, full versus small transverse emittance, Gaussian distribution

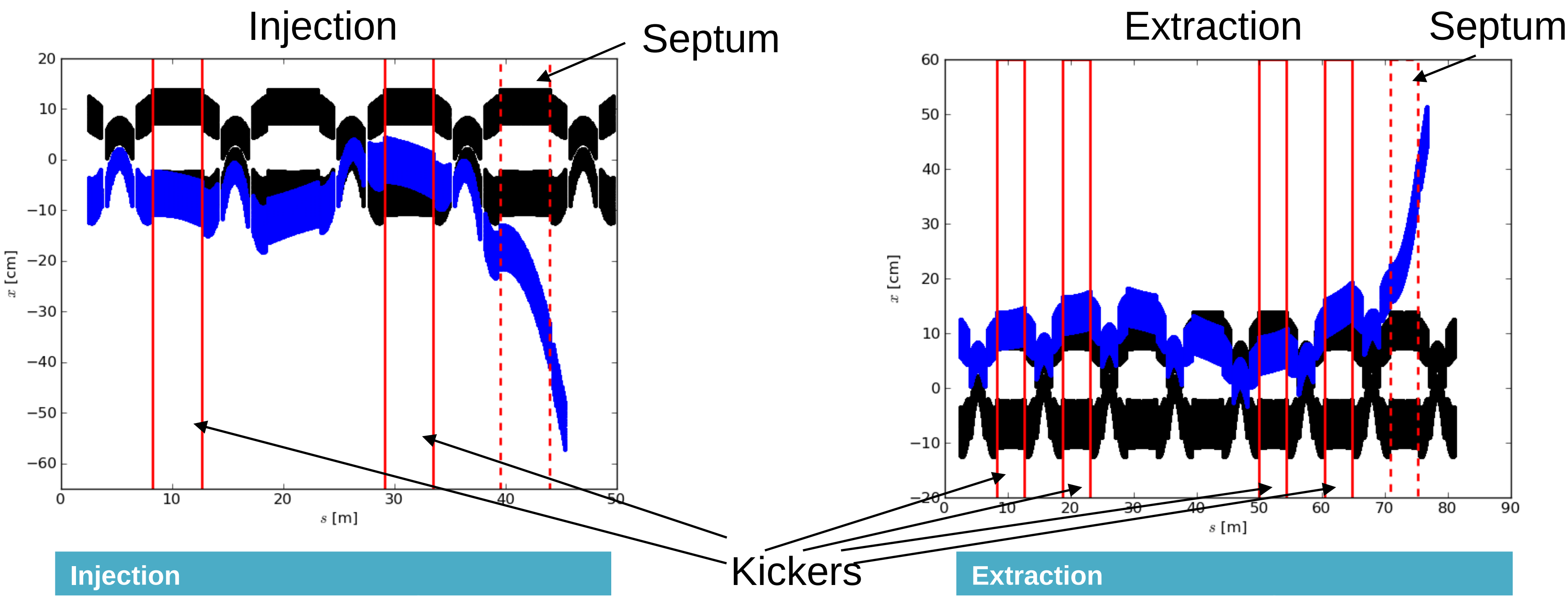


Horizontal plane



Vertical plane

Injection/Extraction geometries



Injection	
Plane	Horizontal
No. Kickers	2
Kicker field (T)	0.089
Kicker Polarity	**+0+**
Septum field (T)	0.92

Extraction	
Plane	Horizontal
No. Kickers	4
Kicker field (T)	0.067
Polarity	**++00++**
Septum field (T)	1.76

- Septum field was limited to 2 T by the stray fields studies (see next slides).
- Both injection and extraction are in the horizontal plane (minimal additional magnet aperture needed and no generation of the vertical dispersion).
- Larger apertures in the special magnets witch are needed have been calculated.

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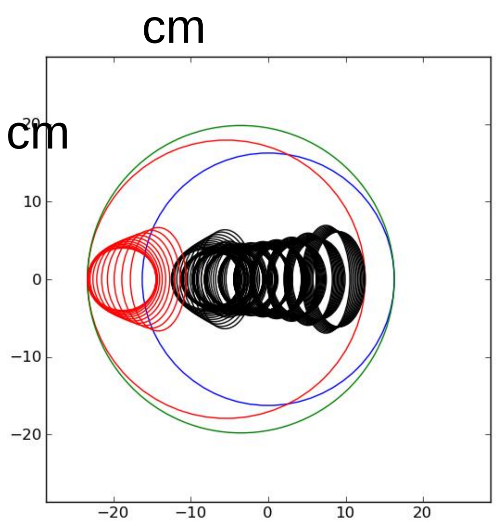
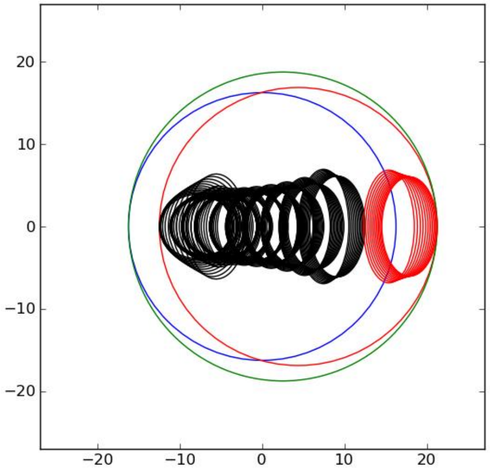
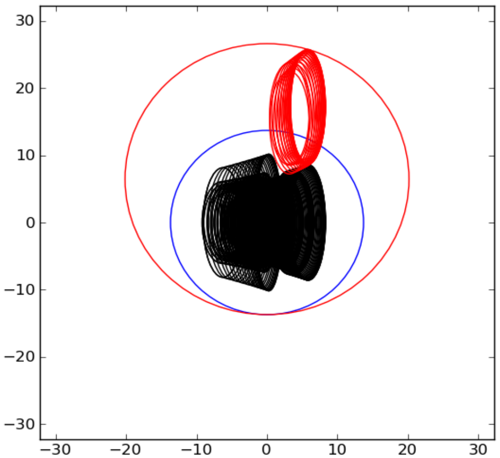
Magnet aperture studies



Magnet aperture in F magnet near the injection septum. Blue is the requirement for the circulating beam, red for kicked beam and green is the final special magnet aperture.



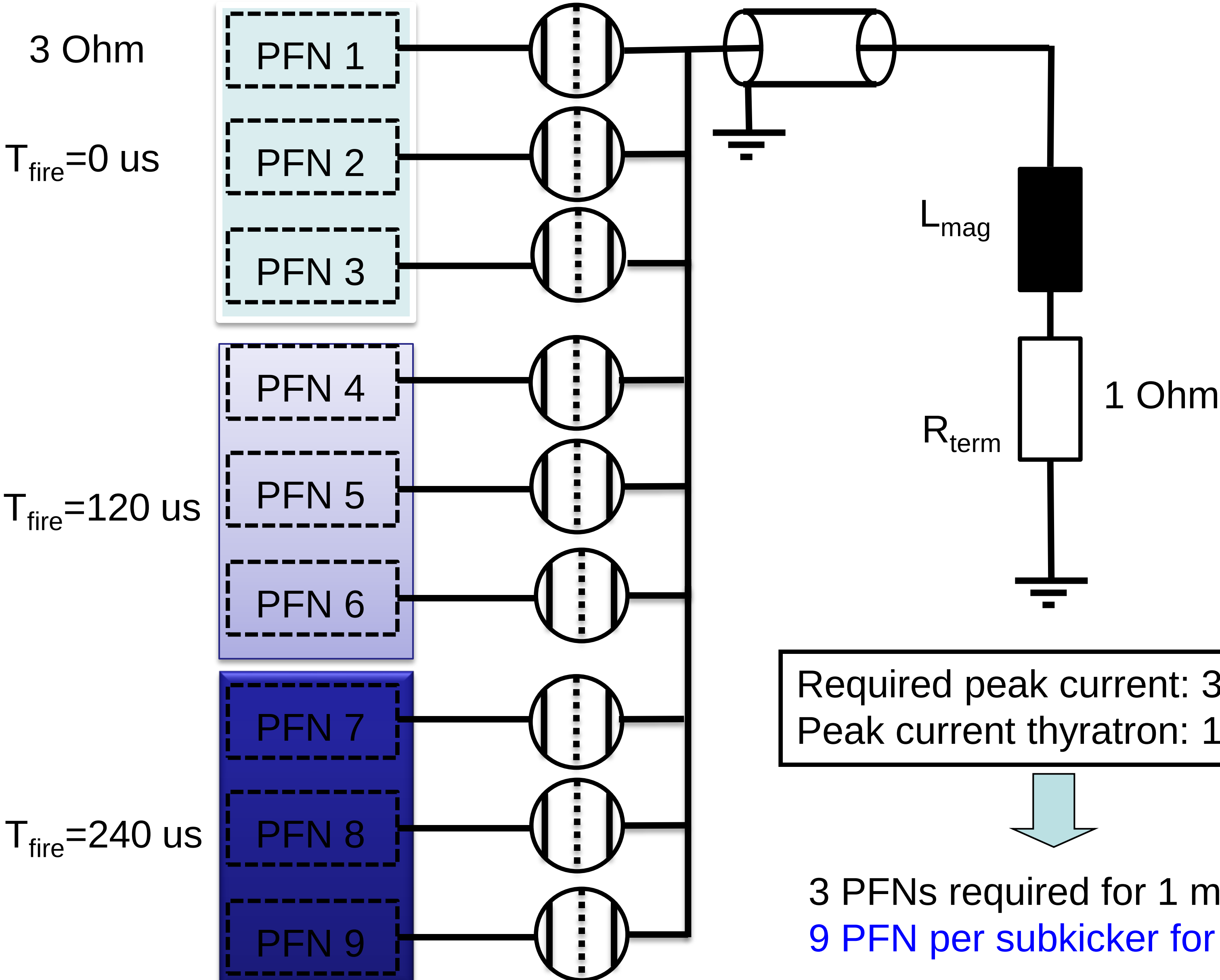
Magnet aperture in F magnet before the extraction septum.



Magnet aperture in D magnet rules out the vertical extraction.

Magnet type	Number of magnets	Radius (cm)
Normal F	116	16.3
Normal D	58	13.7
Injection F	4	20.8
Injection D	4	16.1
Extraction F	8	19.8
Extraction D	2	15.5

IDS Kicker System



Required peak current: 30 kA
Peak current thyratron: 10 kA

3 PFNs required for 1 muon bunch train.
9 PFN per subkicker for 3 trains!

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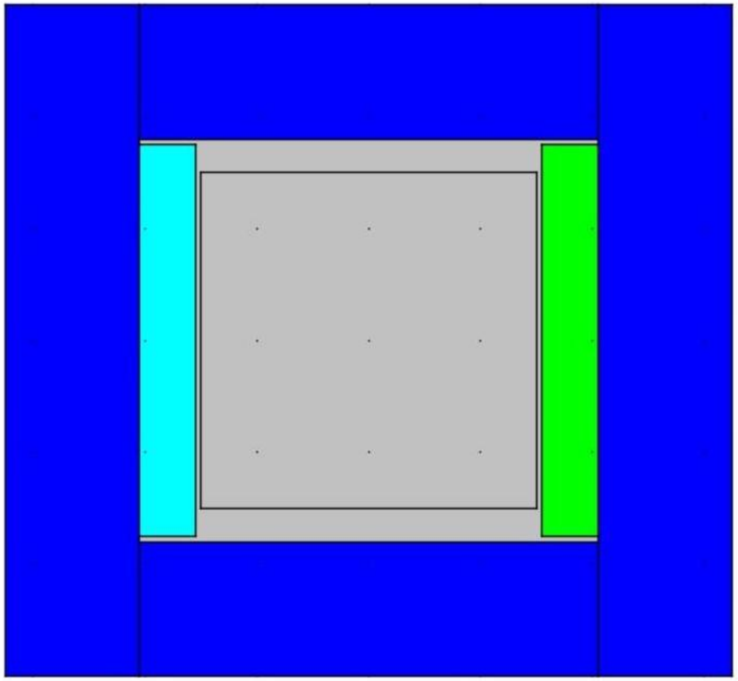
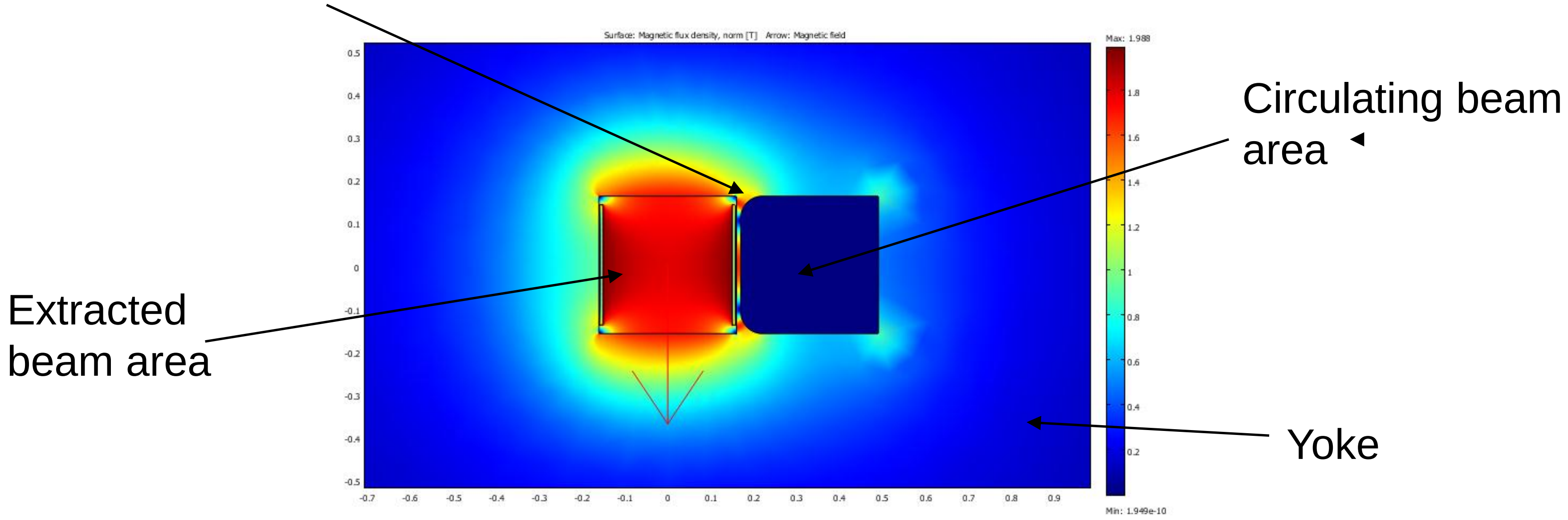
Kicker magnet

- Travelling wave type.
- Geometry
  - Aperture: 0.3x0.3 m^2 (recent update ~0.32x0.22)
  - Yoke: 120 mm
  - Length: 4.4 m
- Field: 100 mT (to add margins)
- Current: 29 kA
- Voltage 60 kV
- Magnetic energy: 1700 J
- Inductance (single turn): 5.1 uH
- Subdivided into 4 smaller kickers (36=9x4 PFNs and switches per magnet).
- Rise/fall time 2.2 us.
- Impedance matching
  - Add capacitors

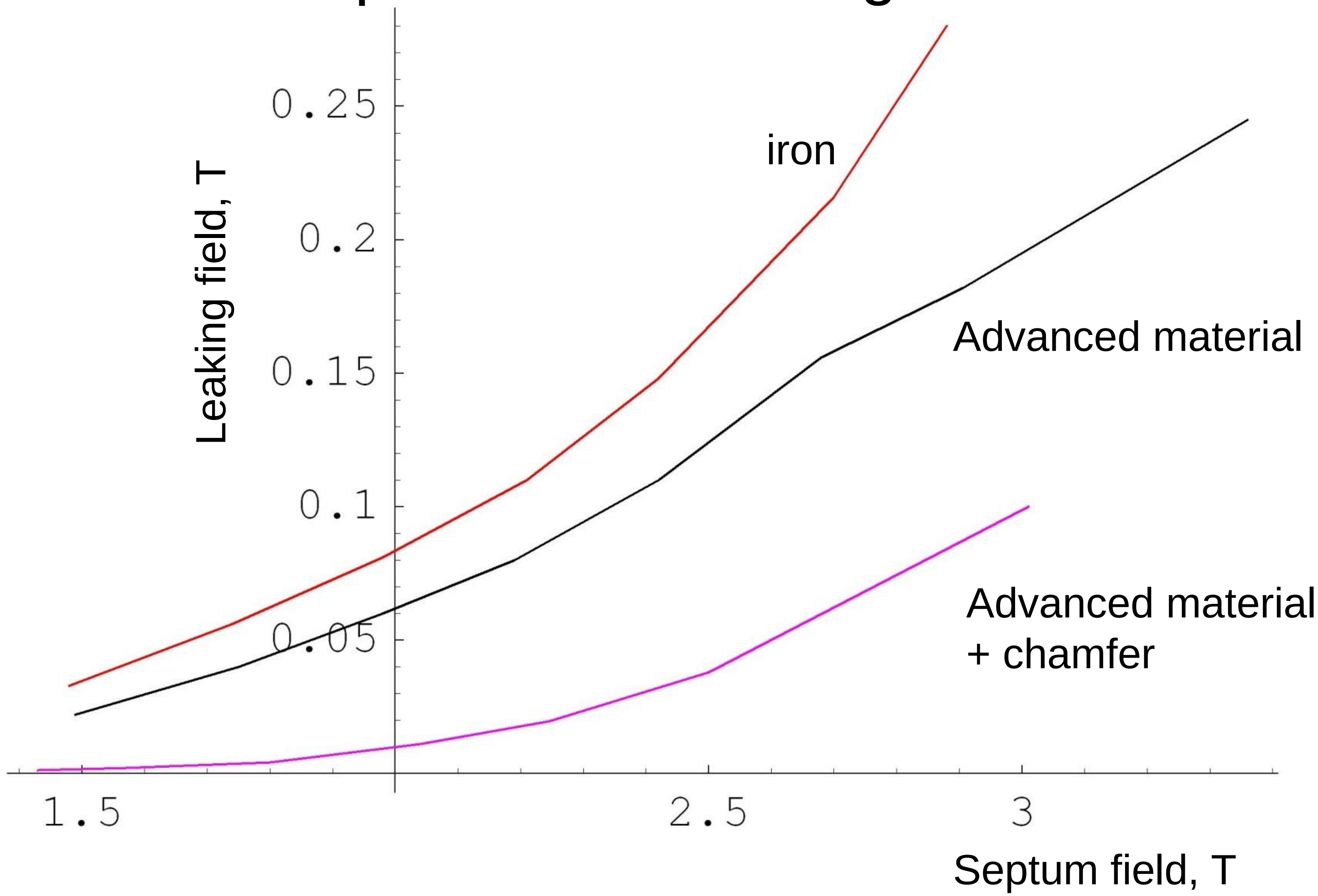


Septum geometry

- The goal of the study was to limit the field leakage from the septum to the circulating beam region.
- We were using COMSOL and performed 2D simulations.
- Starting point was a basic „C-shape" septum magnet.
- Iron was introduced all around the circulating beam.
- Iron was replaced by the soft magnetic cobalt-iron-alloy with high saturation limit.
- Chamfer was introduced.



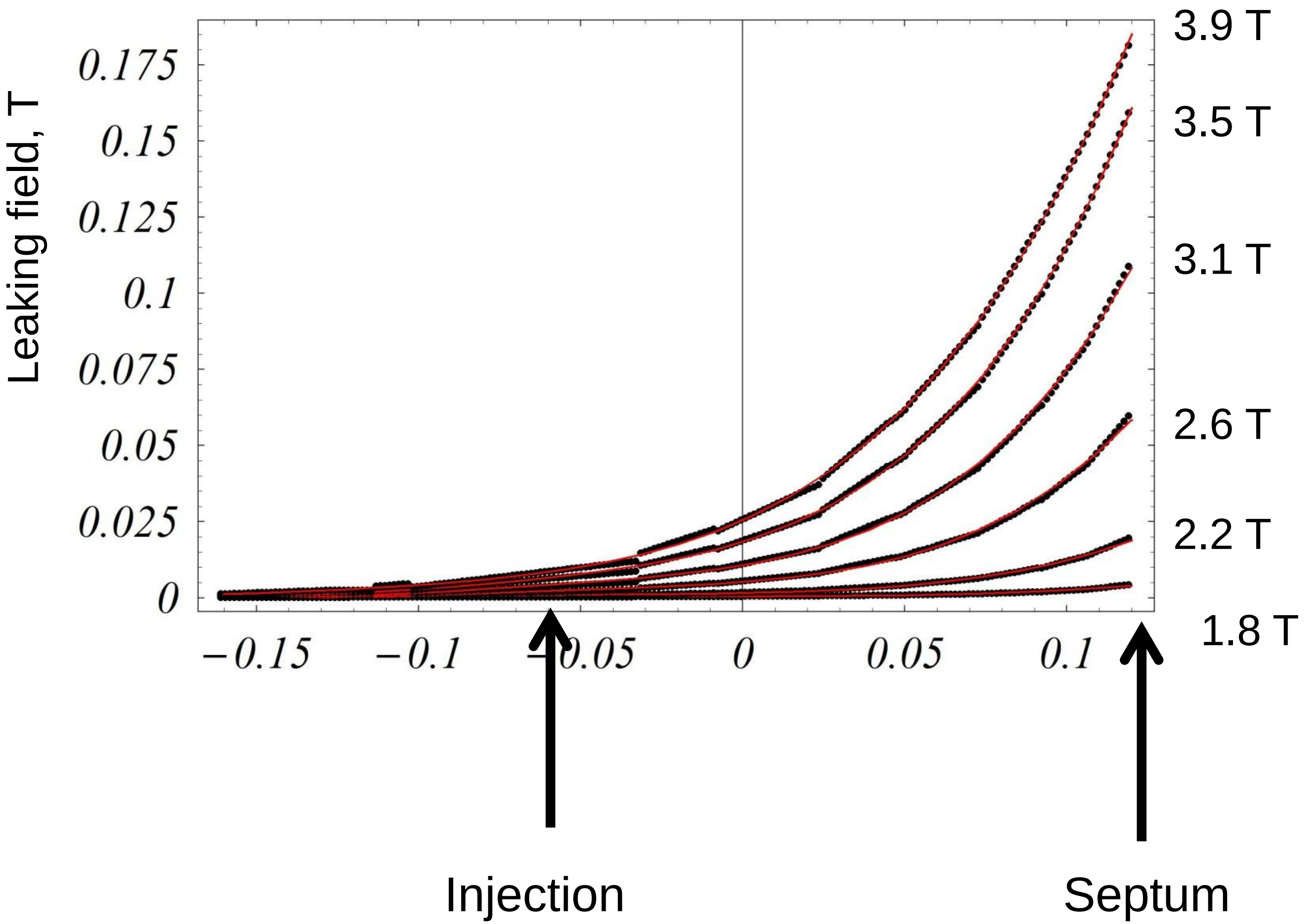
Septum Field Leakage



- The advanced material is the soft magnetic cobalt-iron-alloy (VACOFLUX 50 from www.vacuumschmelze.de)
- We may still look for more advanced materials.

Effect of Septum Field Leakage

- Stray fields have been generated using COMSOL
- Multipoles have been fitted to the numerical points up to the decapole.



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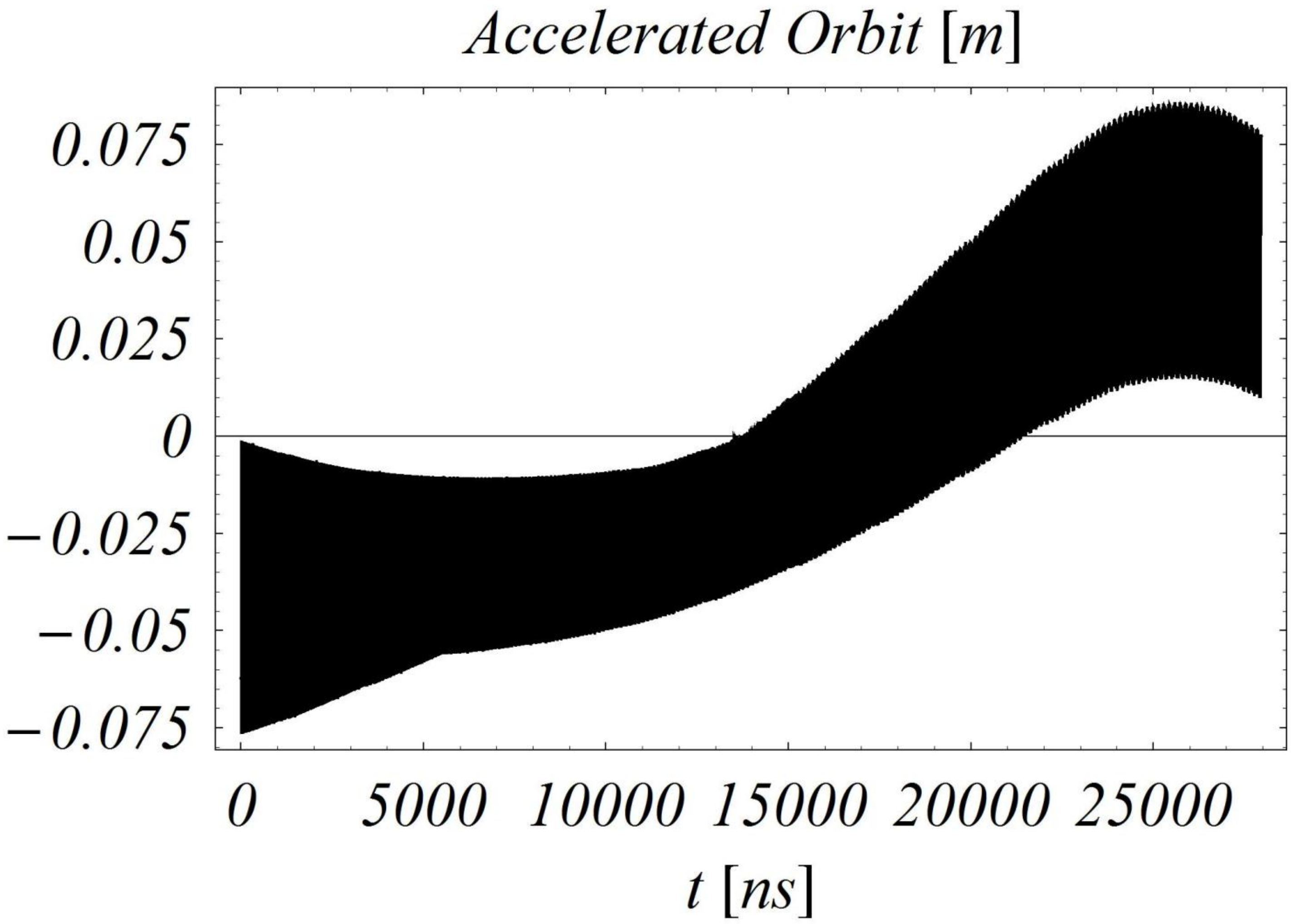
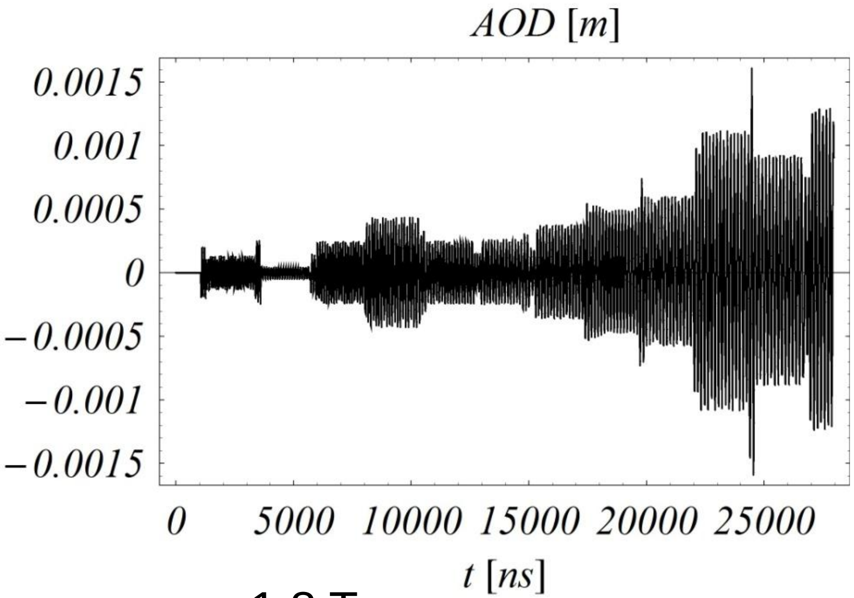
Effect of Septum Field Leakage (2)



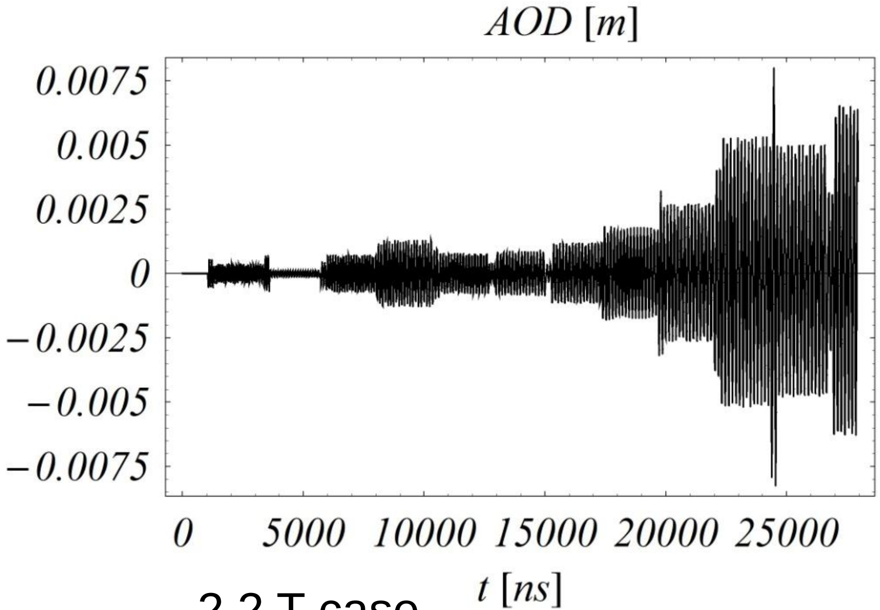
Septum field zero, no leakage.

Effect of Septum Field Leakage (3)

AOD – Accelerated Orbit Distortion



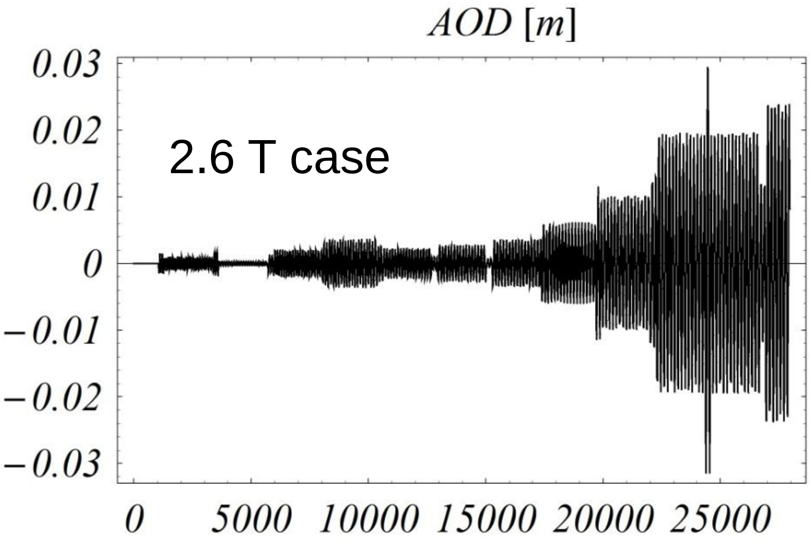
1.8 T case

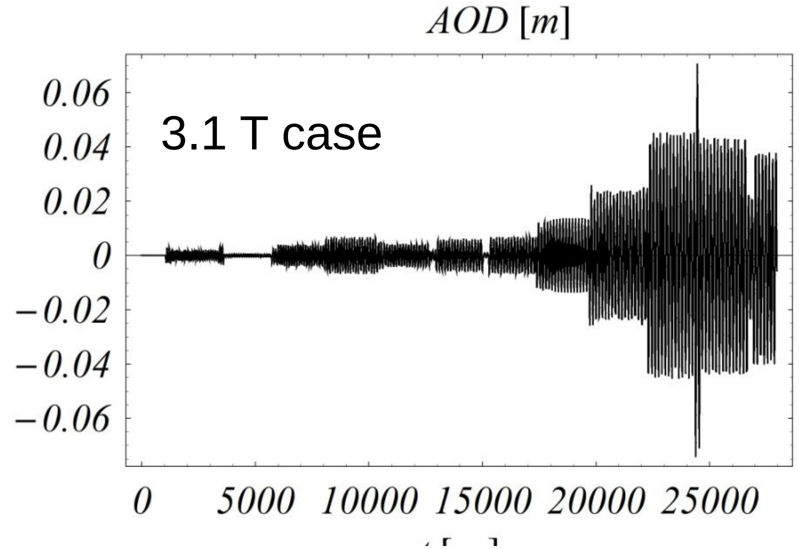


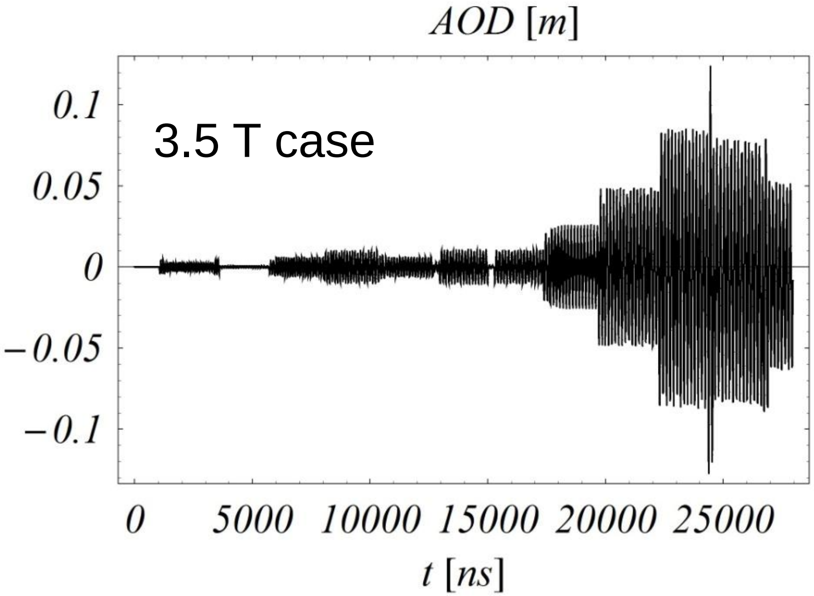
2.2 T case

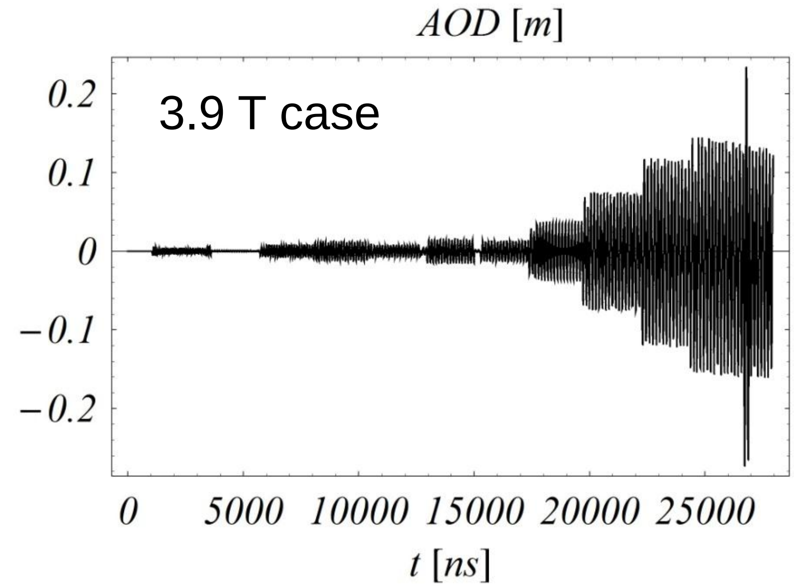
- With the model of the leaking field described by the magnet with the fitted multipole expansion.
- No other errors included.
- Acceleration shifted to 24 GeV (?).

Effect of Septum Field Leakage (4)









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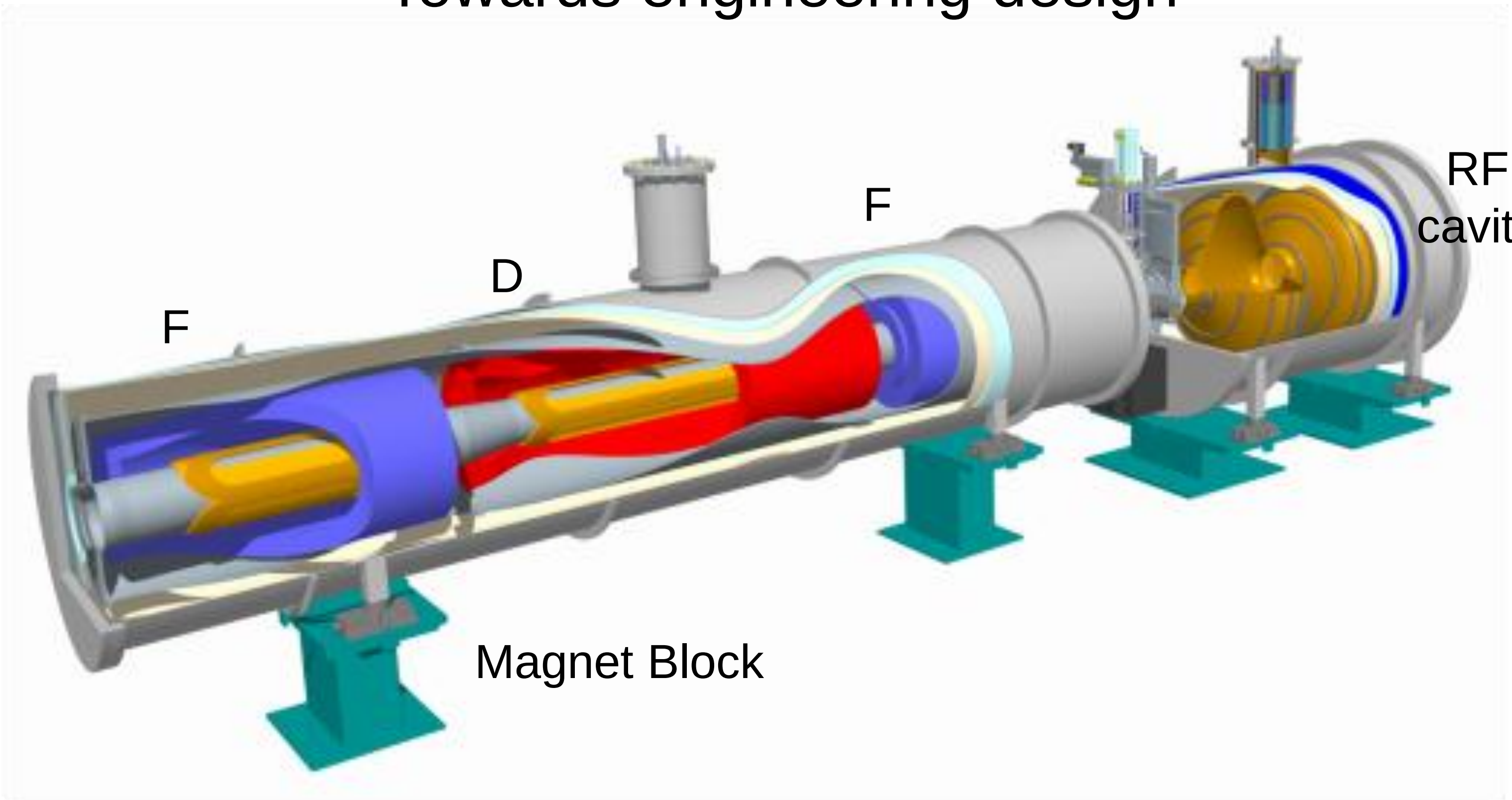
Towards engineering design



•Engineering layout of the machine has been created!
•Effective drift length reduced to 4m
(due to space for the cryostat and flanges).
• Kicker field increased 0.106 T
• Extraction septum field to 1.94 T.
•Injection/extraction still feasible!
•Configuration for RF power sources and distribution has been created.

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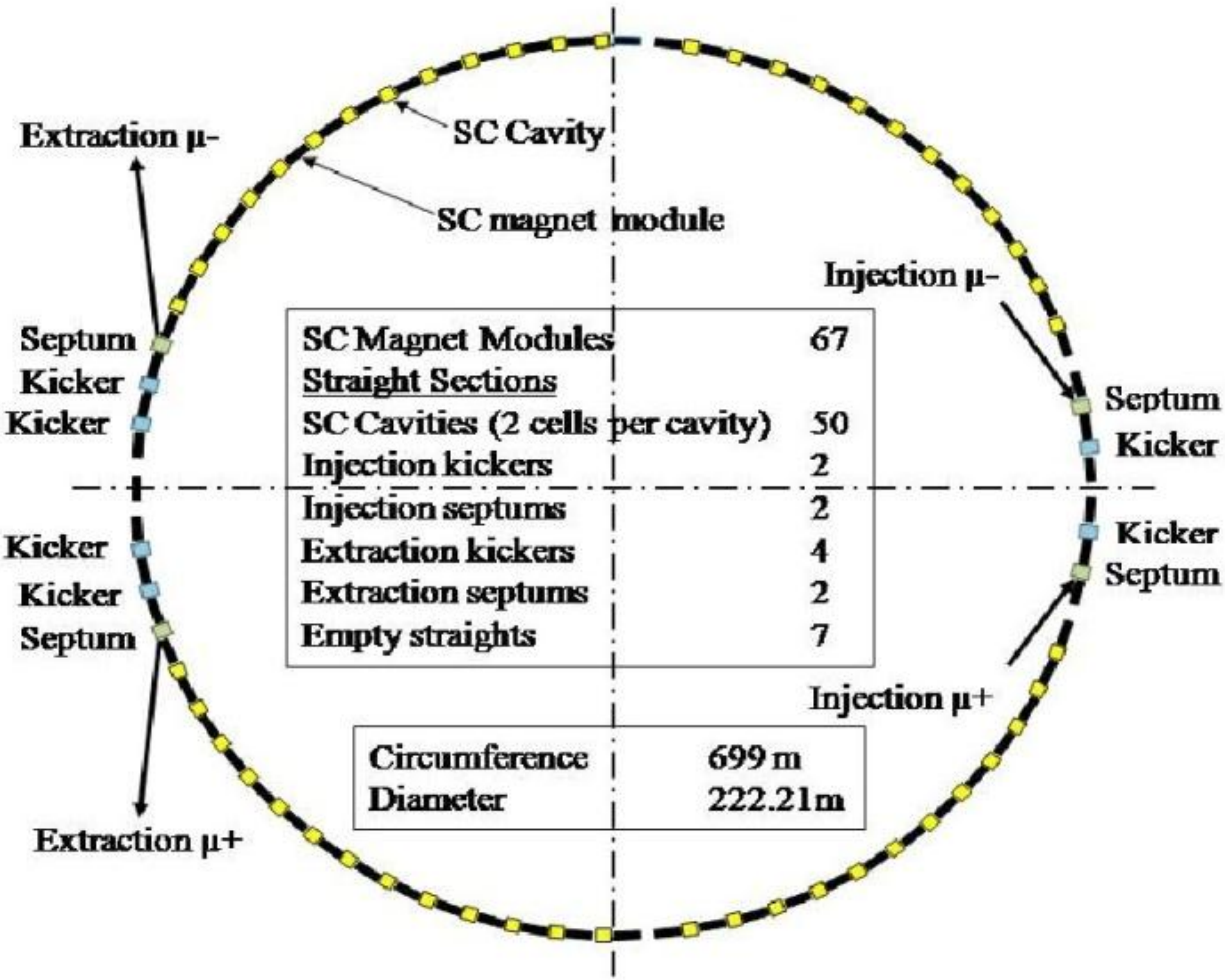
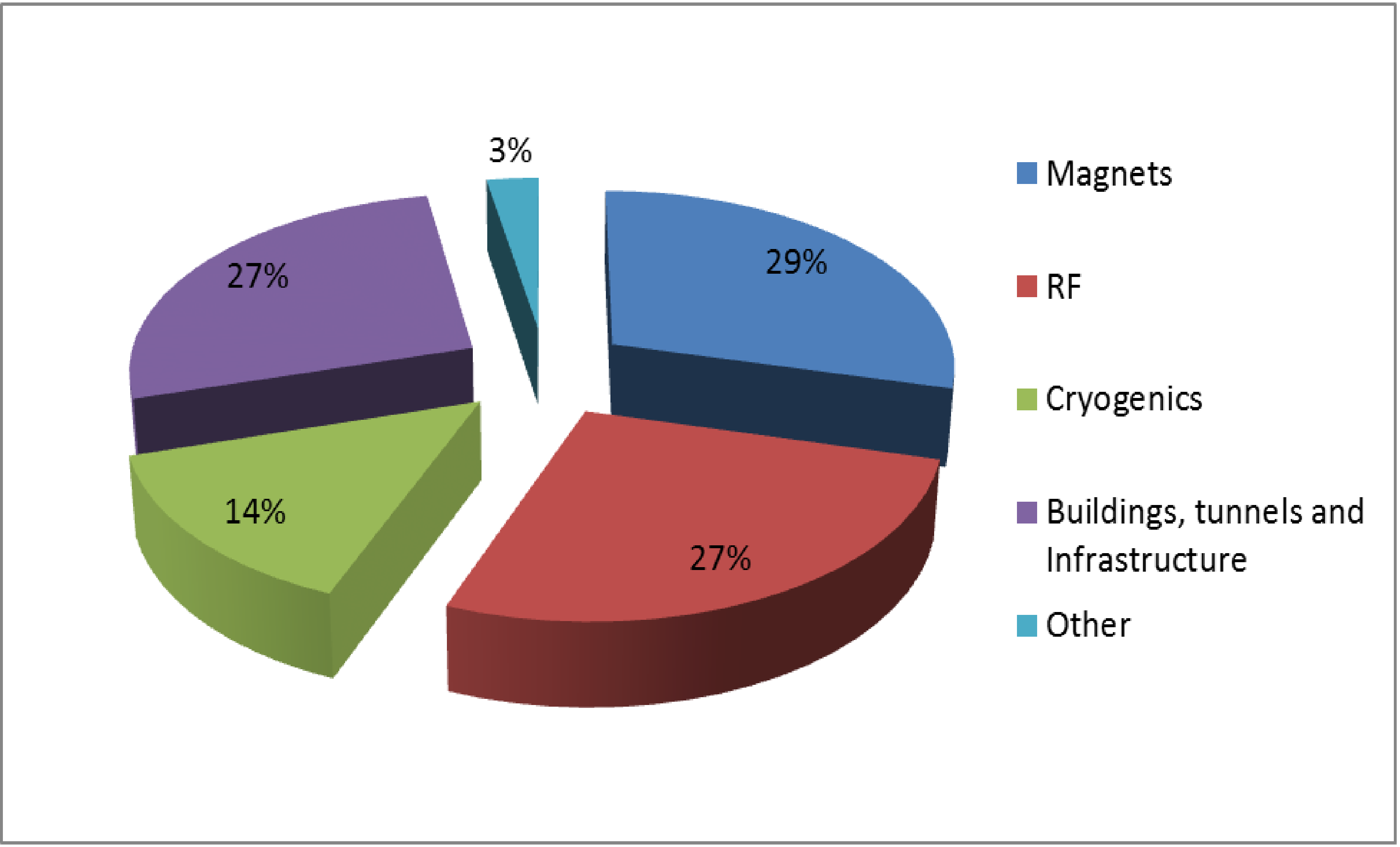
Ring Layout (12.6 -25 GeV NS-FFAG)



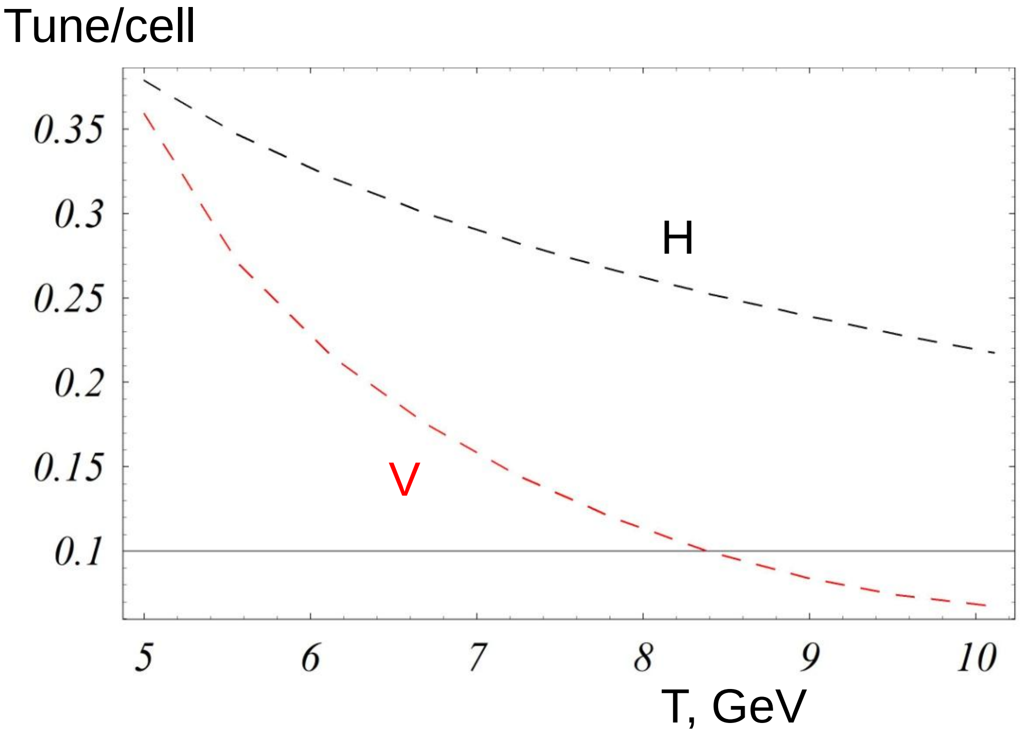
Costing of Muon NS-FFAG, A.Kurup, N. Bliss



The large θ_{13} scenario, NS-FFAG 5-10 GeV (preliminary)

- Assumption:

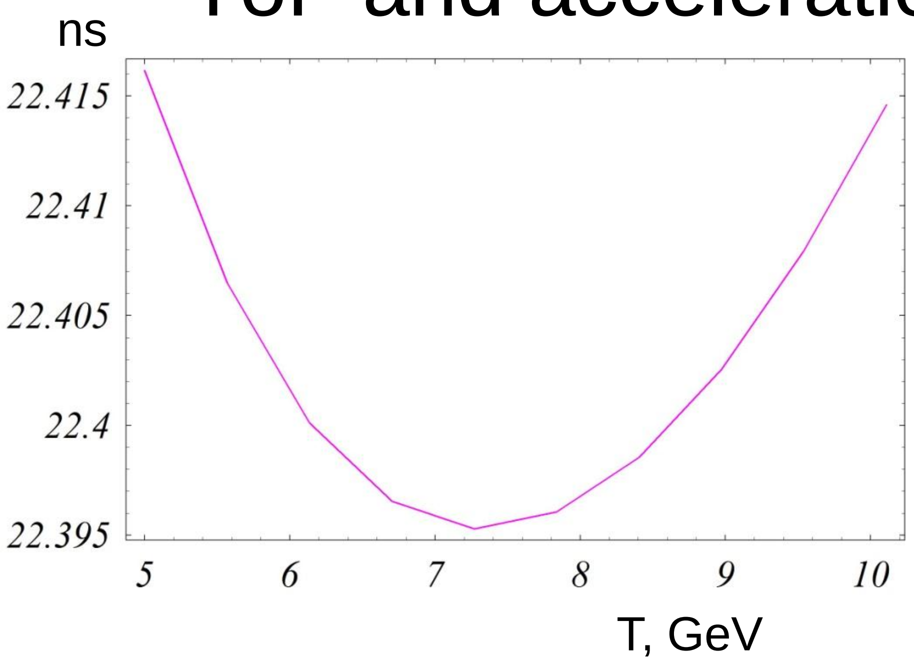
  Use the same technology as in 25 GeV machine (B field levels, RF, apertures, etc.).

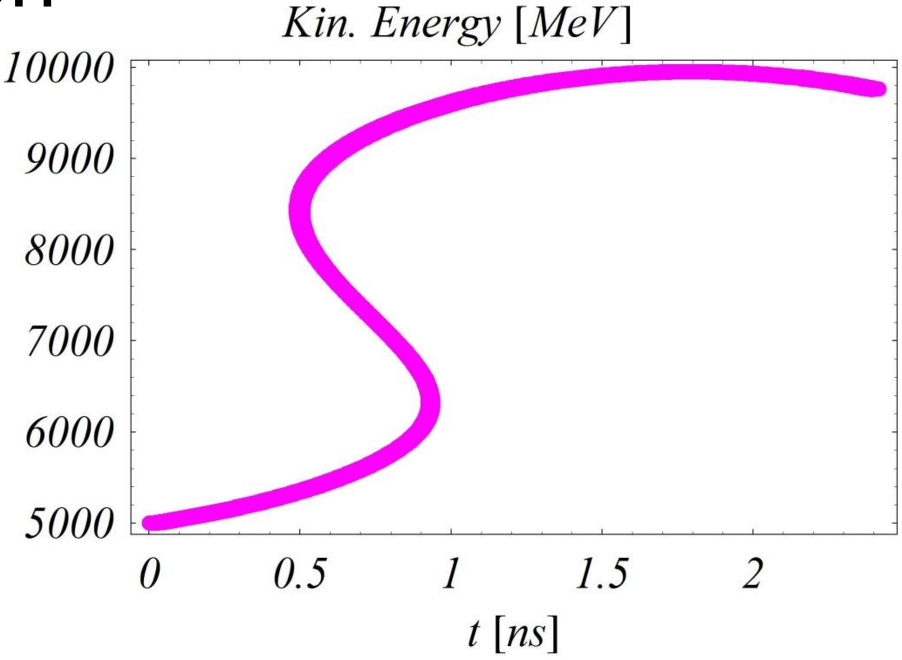


•FDF triplet
•Drift length 3.5 m
•Assumed single 201 MHz cavity in a drift.
•B max 6.3 T
•N cells 49
•Small level of chromaticity correction assumed (to improve the off-momentum stability and partially improve the ToF problem).
•Machine seems to have a sufficient DA.

The large θ_{13} scenario, NS-FFAG 5-10 GeV (preliminary) -2

- ToF and acceleration





Acceleration in ~10 turns using 550 MV/turn

The large θ_{13} scenario, NS-FFAG 5-10 GeV (preliminary) -3

- 25 GeV and 10 GeV machines (comparison)

	25 GeV machine	**10 GeV machine (preliminary)**
Circumference [m]	669	328.8
RF voltage [MV]	1196	550
Number of cells/magnets	67/201	49/147
Magnetised length [m]	~263	~108.3

This can be used to scale costing!

Summary

- The acceleration studies proof that the machine can accelerate the beam to the 25 GeV, but more longitudinal dynamics re-optimisation is needed to reduce the momentum spread. In particular this effect may be an issue for the superconducting septum operation.

- Effect of septum stray fields on the accelerated orbit have been evaluated. The expected distortion is of the order of a few mm for the baseline septum field. Options with higher septum fields are ruled-out, unless stray fields could be better controlled. This confirms our previous change of baseline!

- The preliminary conceptual designs of machine subsystems were produced.

- Real engineering effort has been started!
  Costing model has been created!

...but θ_{13} is large -> next slide!

Future plans

- The discovery of the large θ_{13} changed the NF baseline energy to 10 GeV.

- The technology established during the 25 GeV machine study (EUROnu) can now be used for the low energy FFAG.

- In particular the acceleration scenario of Linac+RLA to 5 GeV followed by FFAG (5-10 GeV) needs to be addressed and compared with alternative scenarios based on linac-RLA(s) only options with respect to cost and performance.

- Preliminary parameter list looks promising, but more studies are required.

- FFAG technology development must be continued for future applications (PRISM, ADS, PBT, Muon Collider, etc.).