Imperial College London

Science & Technology Facilities Council ISIS

FFAG Designs for the Neutrino Factory

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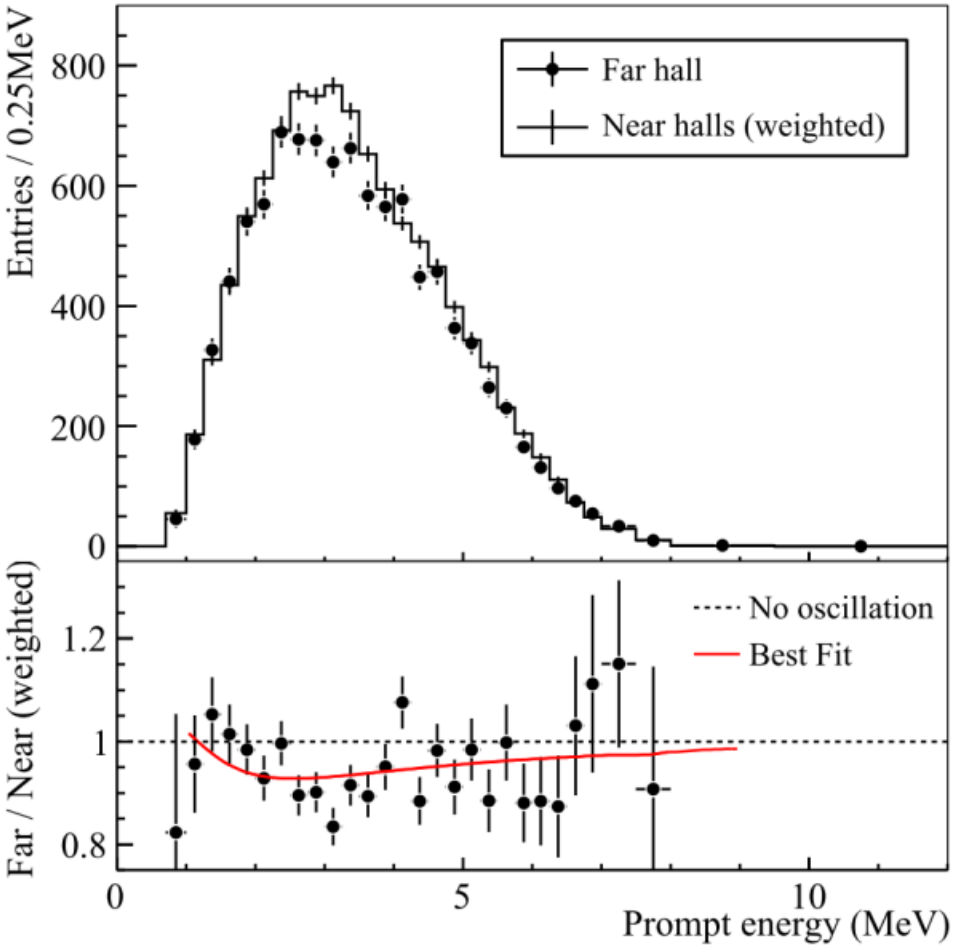
Outline

- Implications of large θ_{13} on the IDS-NF baseline.
- Physics and technology of NS-FFAG.
- Preliminary solutions for the large θ_{13} scenario.
- Cost versus performance?
- Summary

Discovery of the large θ_{13} in reactor experiments

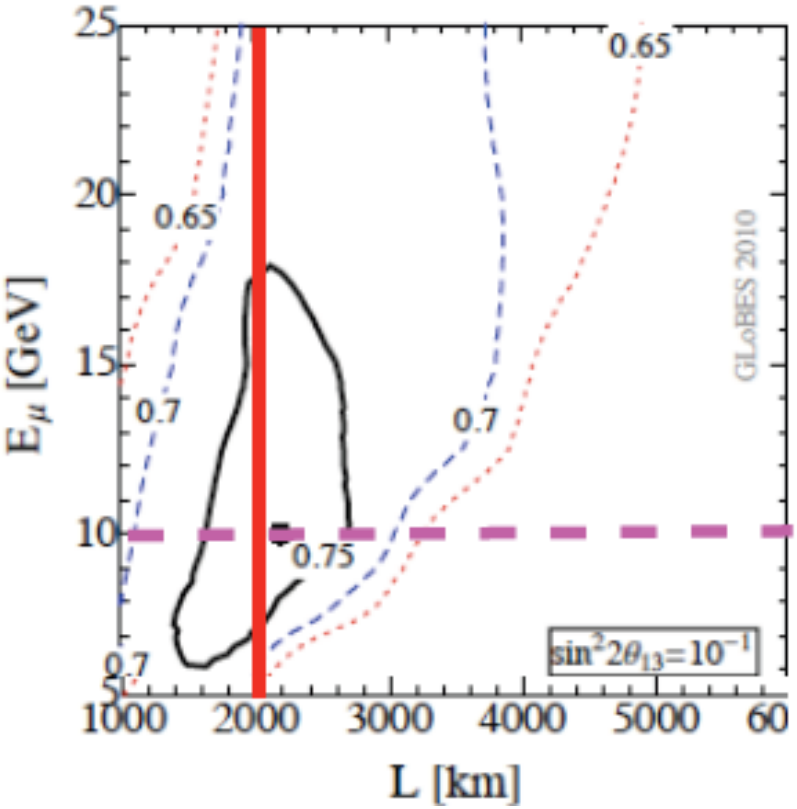


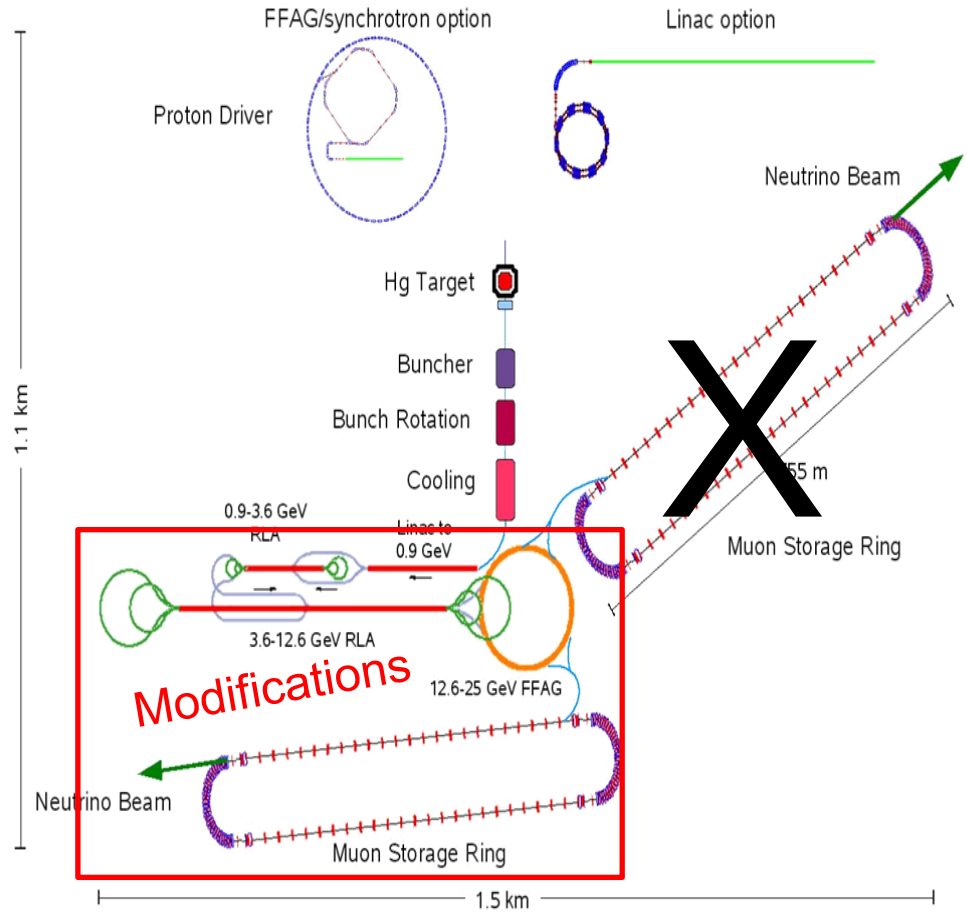
Daya Bay oscillation result, from arXiv: 1203.1669v2 [hep-ex] 2 April 2012

PMTs in the Daya Bay detector, (from Nature News)

	$\sin^2 2\theta_{13}$		
	Value	Statistical	Systematic
D-Chooz	0.086	0.041	0.030
Daya Bay	0.092	0.016	0.005
RENO	0.113	0.013	0.019
Mean	***0.098***	***0.013***	

Baseline modifications due to the large θ_{13}



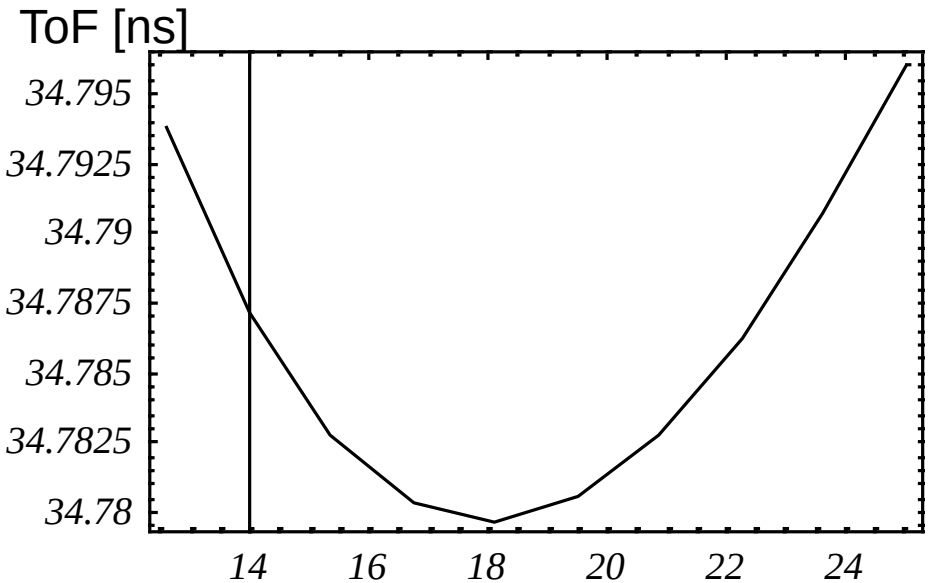


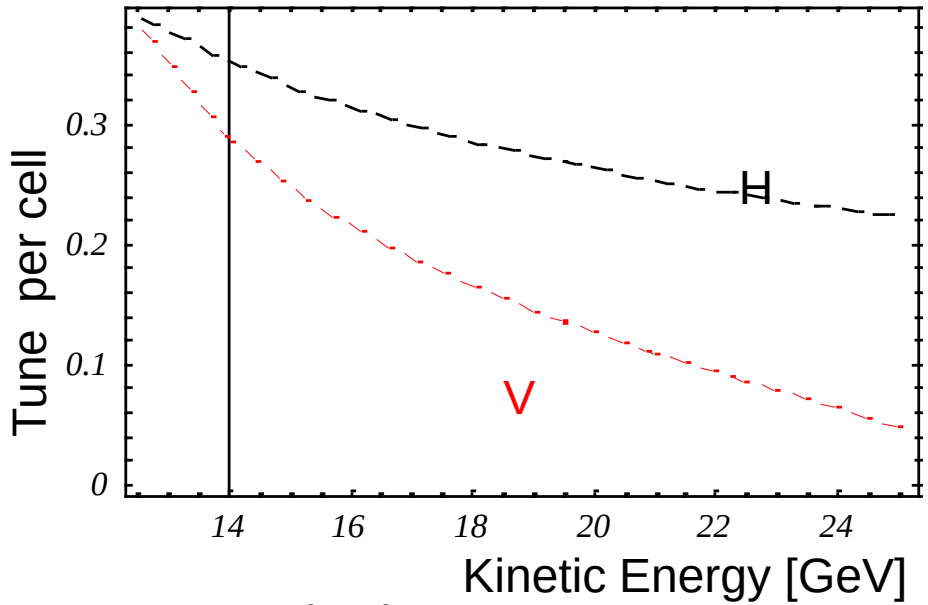
Detectable CP-violation fractions as a function of muon energy in the storage ring and a baseline length, from S. Pascoli's talk at IDS-NF meeting in Glasgow

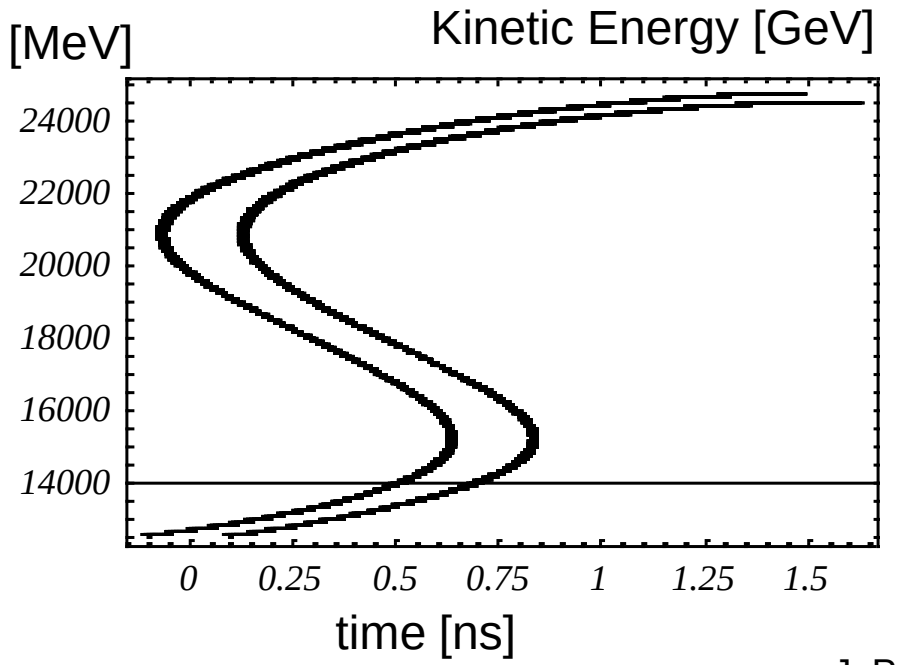
Effects of large θ_{13} on the baseline:

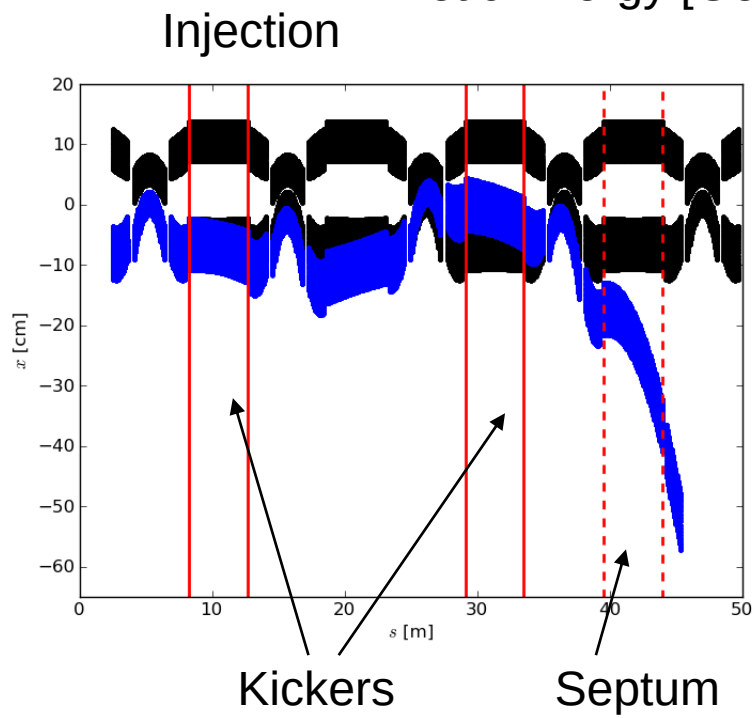
- Only one decay ring needed with reduced energy/circumference/cost (see David's talk).
- Modifications in the muon acceleration scheme (only 10 GeV needed).

Beam Physics in 25 GeV NS-FFAG









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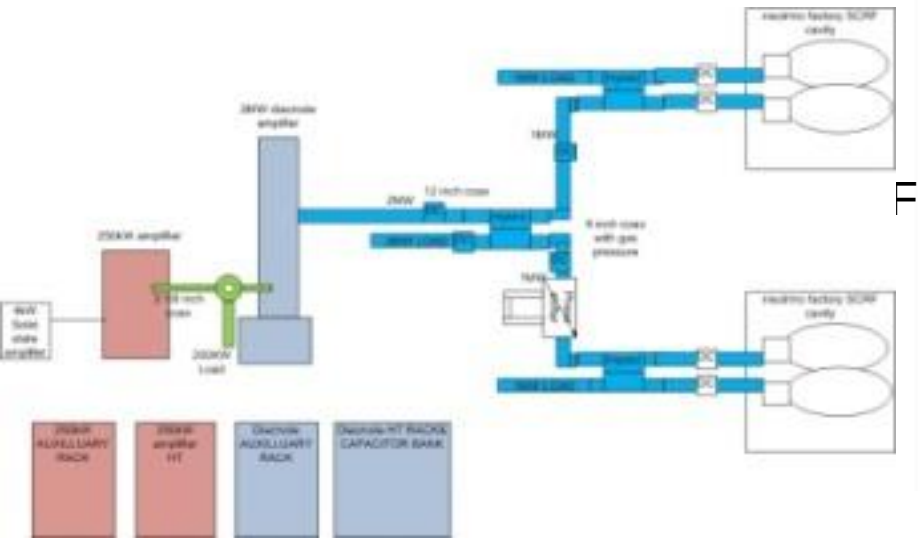
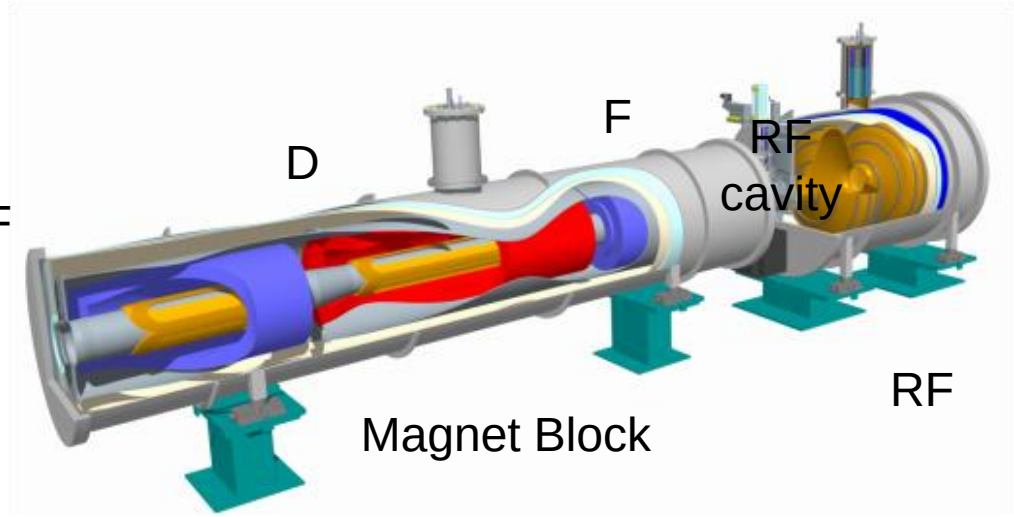
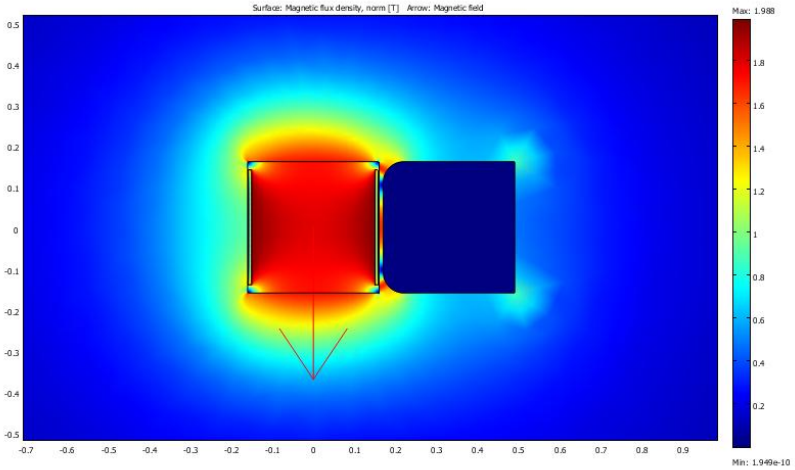
Engineering studies for 25 GeV NS-FFAG

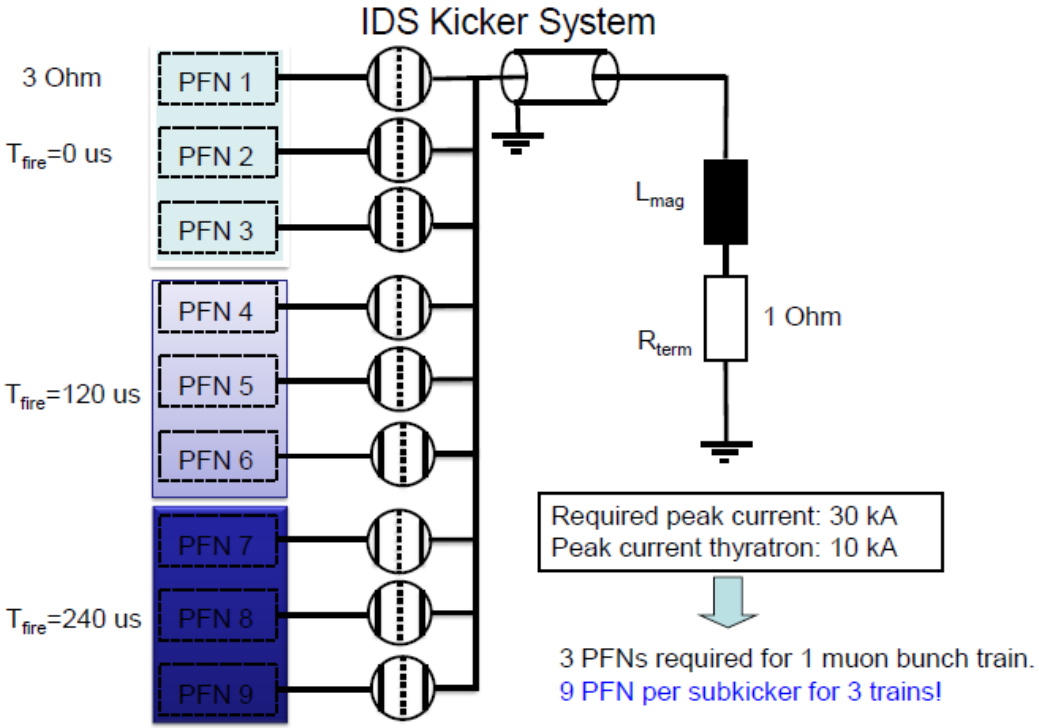


RF source and distribution





Septum simulations



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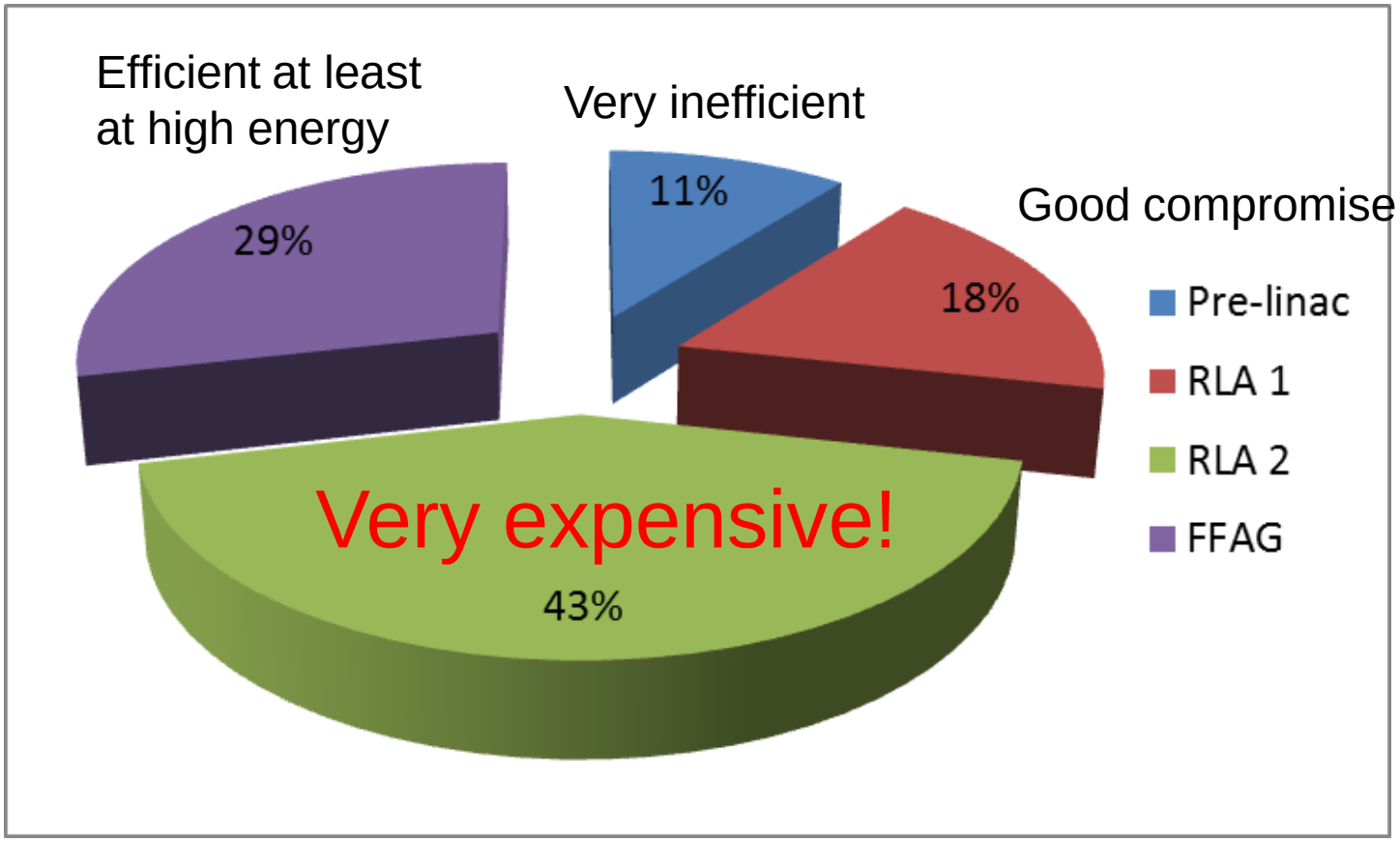
Lessons from the costing exercise

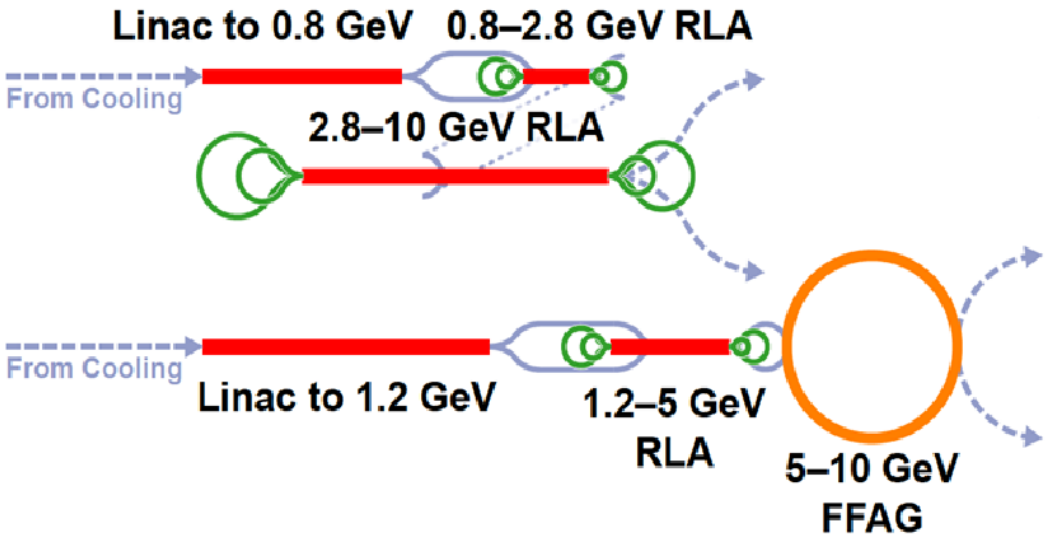


We still need to keep in mind that the error bars are large!

10 GeV acceleration scenarios due to large θ_{13}

Option I

Option II



For 10 GeV muon acceleration two options have been proposed:

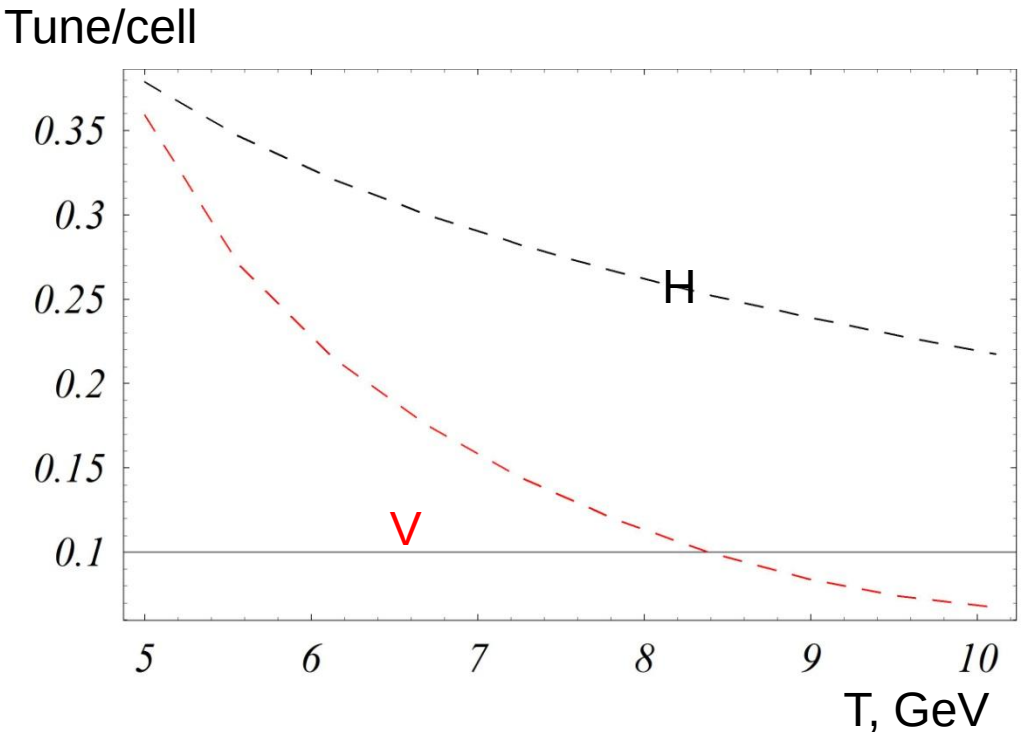
- **Option I:** using linac and two Recirculating Linear Accelerators (RLAs) – it is very similar to the previous baseline part up to 12.6 GeV
  This option is not good, if you want a staging scenario, as 2.8 GeV is not high enough for detectors!

- **Option II:** using linac+RLA+ Nonscaling Fixed Field Alternating Gradient (NS-FFAG) ring – NS-FFAG could use the same technology developed for 12.6-25 GeV ring.

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.

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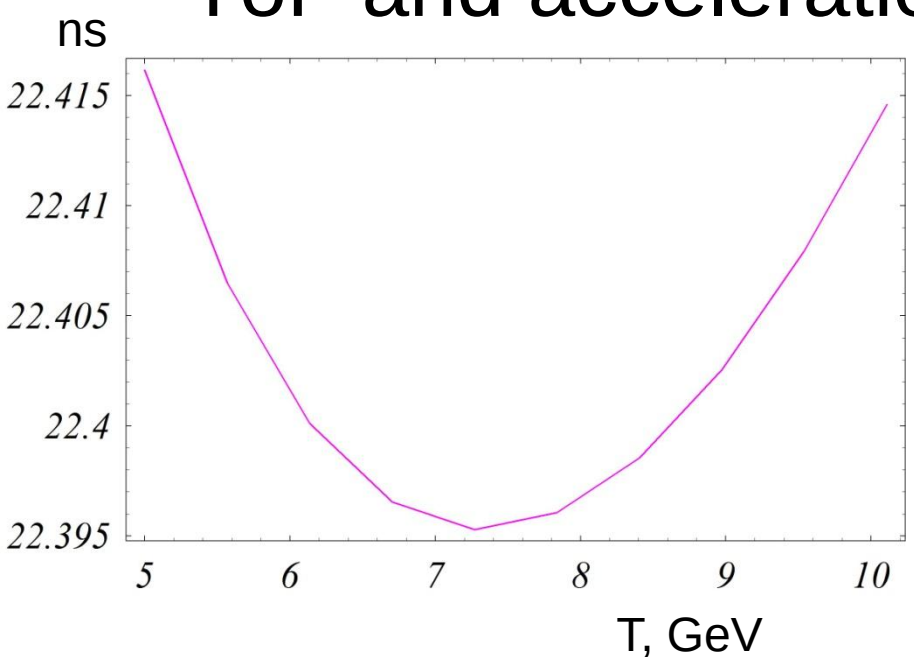
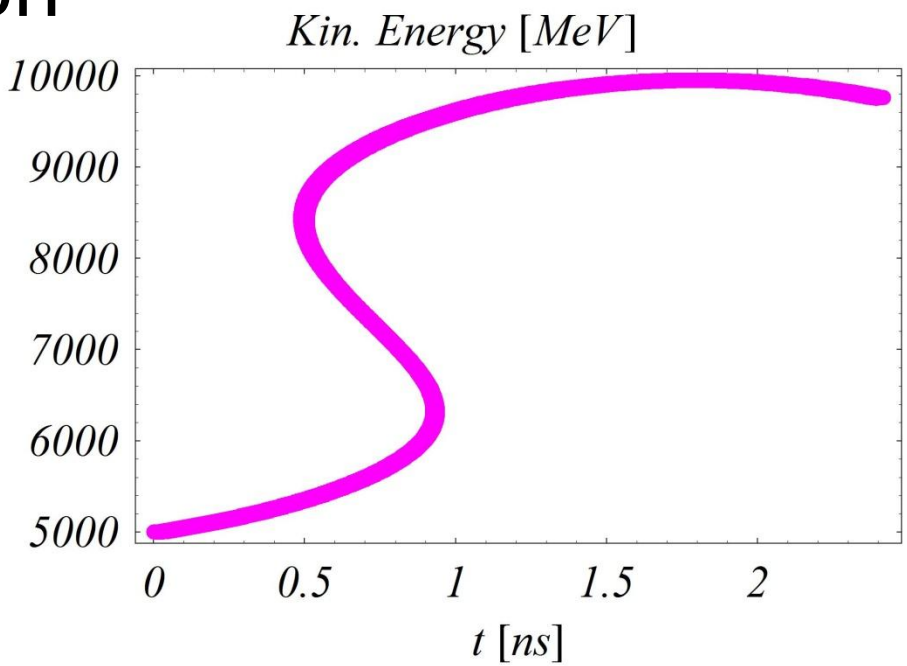
There exists an alternative set of parameters from J. Scott Berg

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

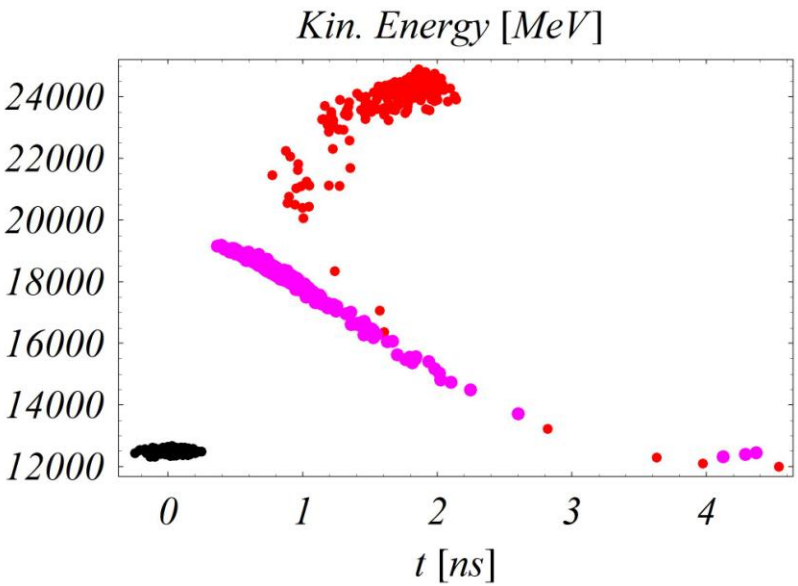
- 25 GeV and 10 GeV machines (comparison)

	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

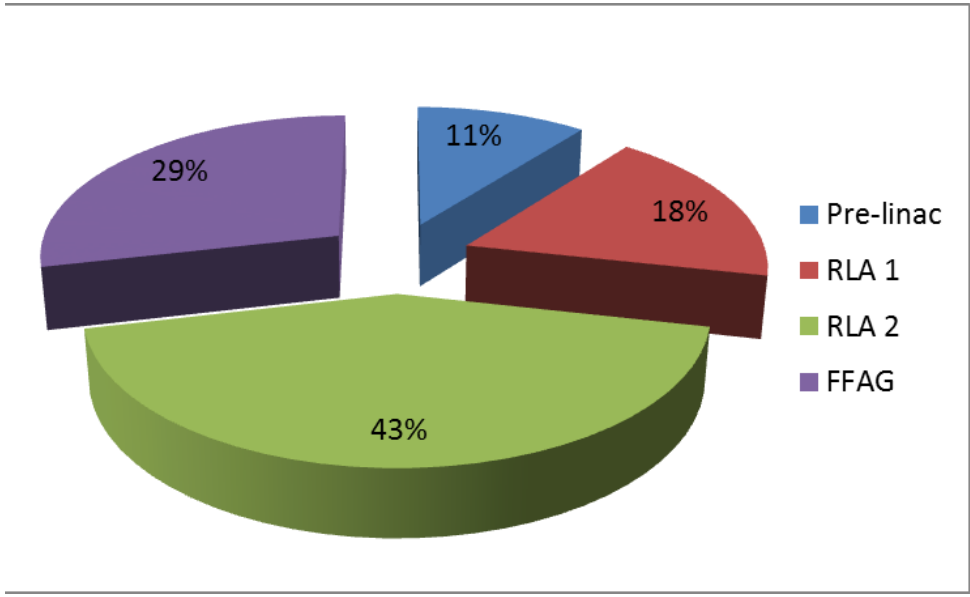
This can be used to scale costing!

Which option to choose?

The decision-making process should be based on the cost and performance evaluation



Acceleration in 25 GeV NS-FFAG



Cost breakdown for 25 GeV acceleration

The important performance and cost figures need to re-evaluated (scaled down) from the 25 GeV scenario – work in progress!

RF budget for muon acceleration in the NF

Back of envelope calculations (very crude)

Efficiency Factors

•Old 25 GeV scenario:

(0.9-0.15)/1 + (12.6-0.9)/4.5 + (25-12.6)/10.3 [GeV/e] = ~4.5 GV
LINAC RLAs FFAG

•New 10 GeV scenario, Option I (difficult for staging):

(0.8-0.15) + (10-0.8)/4.5 [GeV/e] = ~2.7 GV
LINAC RLAs

Both equal up to error bars

•New 10 GeV scenario, Option II (inefficient use of FFAG):

(1.2-0.15) + (5-1.2)/4.5 + (10-5)/9 [GeV/e] = ~2.5 GV
LINAC RLAs FFAG

Conclusion:

- both scenarios have approximately the same cost,
- both are not ideal!

RF budget for muon acceleration in the NF

Back of envelope calculations (very crude)

•New 10 GeV scenario, Option I (difficult for staging):

(0.8-0.15) + (10-0.8)/4.5 [GeV/e] = ~2.7 GV
LINAC RLAs

•New 10 GeV scenario, Option II (inefficient use of FFAG):

(1.2-0.15) + (5-1.2)/4.5 + (10-5)/9 [GeV/e] = ~2.5 GV
LINAC RLA FFAG

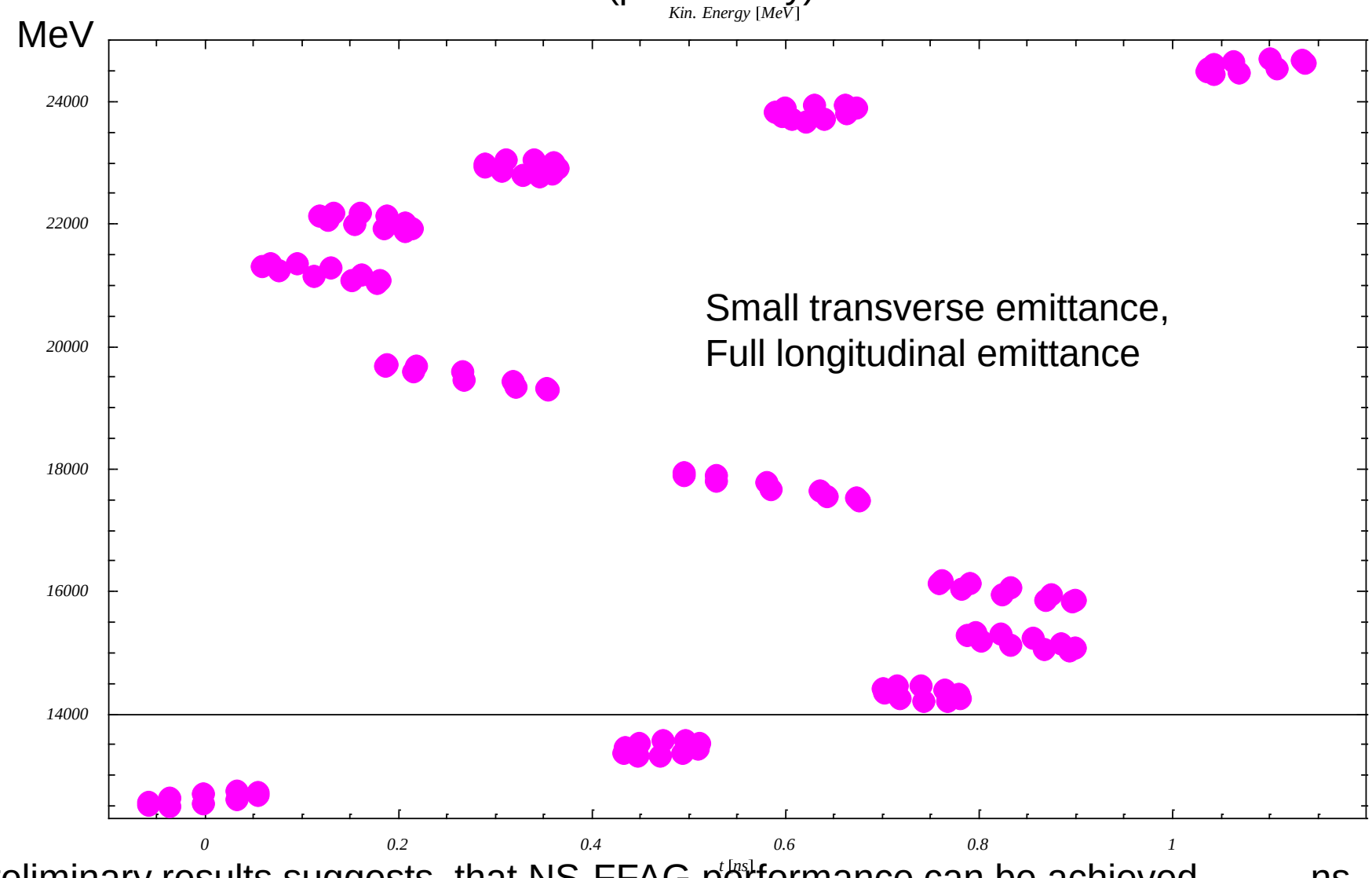
•Yet another10 GeV scenario (better for staging, may save 0.5 GV)

(1.-0.15) + (4.-1.)/4.5 + (10-4.)/7.3[GeV/e] = ~2.3 GV
LINAC RLA FFAG ?

Conclusion:

-Must accelerate in FFAG by more than a factor of 2 (2.5?)!

Acceleration with matched initial distribution in 25 GeV ring (preliminary)



Preliminary results suggests, that NS-FFAG performance can be achieved. ns
More studies are needed!

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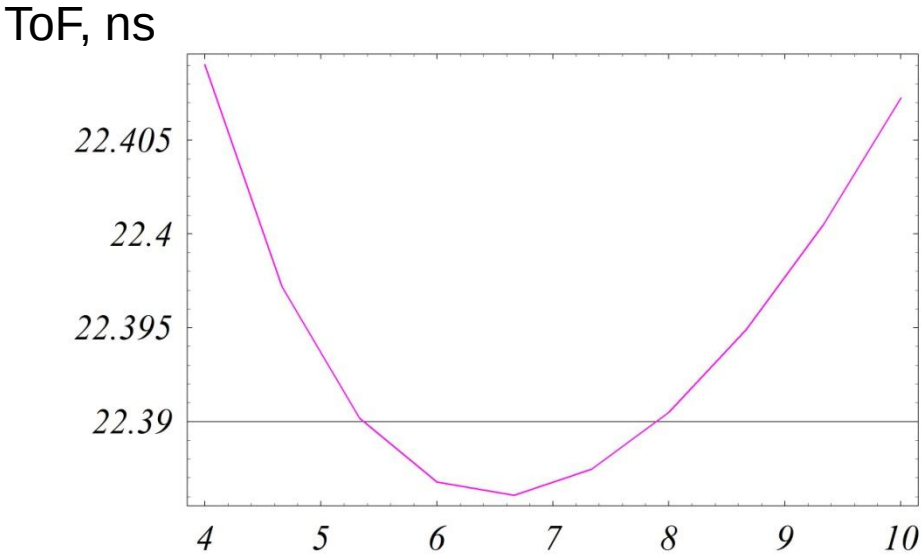
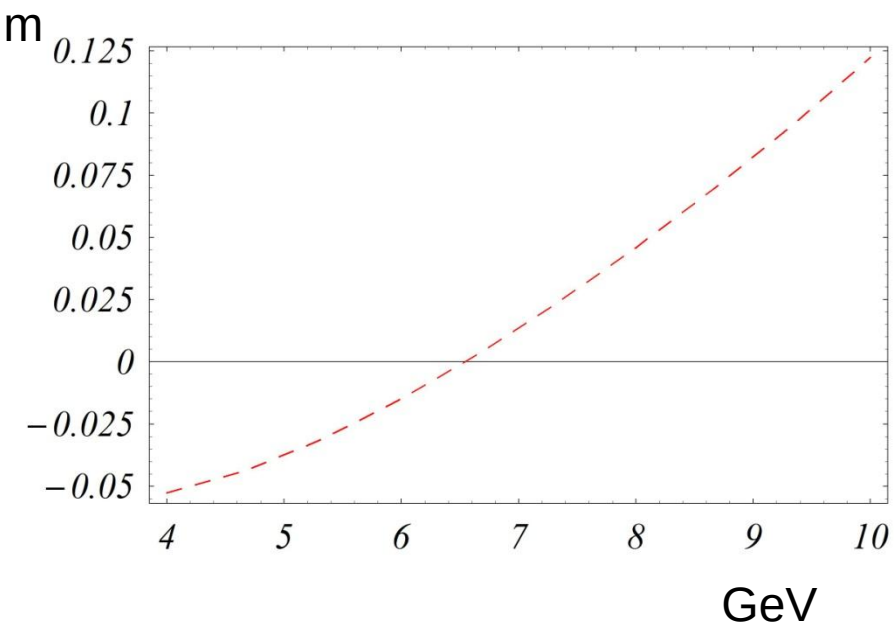
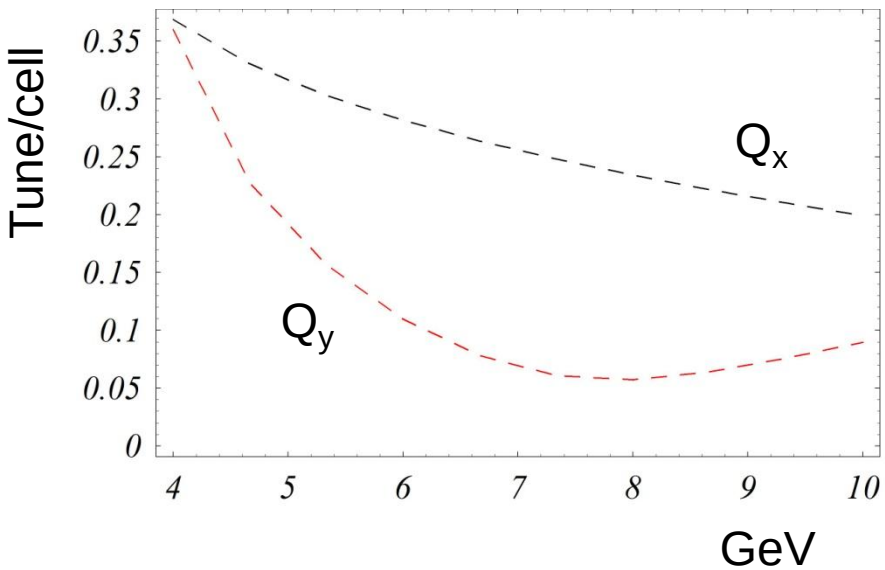
Preliminary results for 4-10 GeV machine (factor 2.5 in acceleration)







- 63 cells
- 423 m in circumference
- Orbit excursion close to the 25 GeV machine
- Short cells
- Drift length of 3.5 m
- 15 % chromaticity correction to improve the tune behaviour and ToF
- Please mind machine is non-linear.

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Summary

- The discovery of the large θ_{13} changed the NF baseline length to 2000 km and energy to 10 GeV.
- Two options for 10 GeV acceleration have been identified with particular breaking points: Option I - Linac+ RLAI+RLAII and Option II - Linac+RLA +NS-FFAG.
- Preliminary cost estimate suggests: both options cost approximately the same, but both are not optimal due to the choice of the breaking points !
- Option I is not good as a staging scenario due to a low breaking point at 2.8 GeV.
- Option II uses FFAG in inefficient way.
- Another scenario with the breaking point of ~4 GeV is needed, but in order to use FFAG efficiently its acceleration range needs to be increased (2.5?).
- Preliminary parameter list for 4-10 GeV NS-FFAG looks promising, but more studies are required.
- FFAGs are important for muon accelerators (nu-STORM, PRISM, NF, Muon Collider) so we need to keep studying them!