Neutrino Factory:

Cost Structure

and

Cost Driving Elements

J. Pozimski, Imperial College @ 2nd annual Euroν meeting 1-4 June 2010, Strasbourg

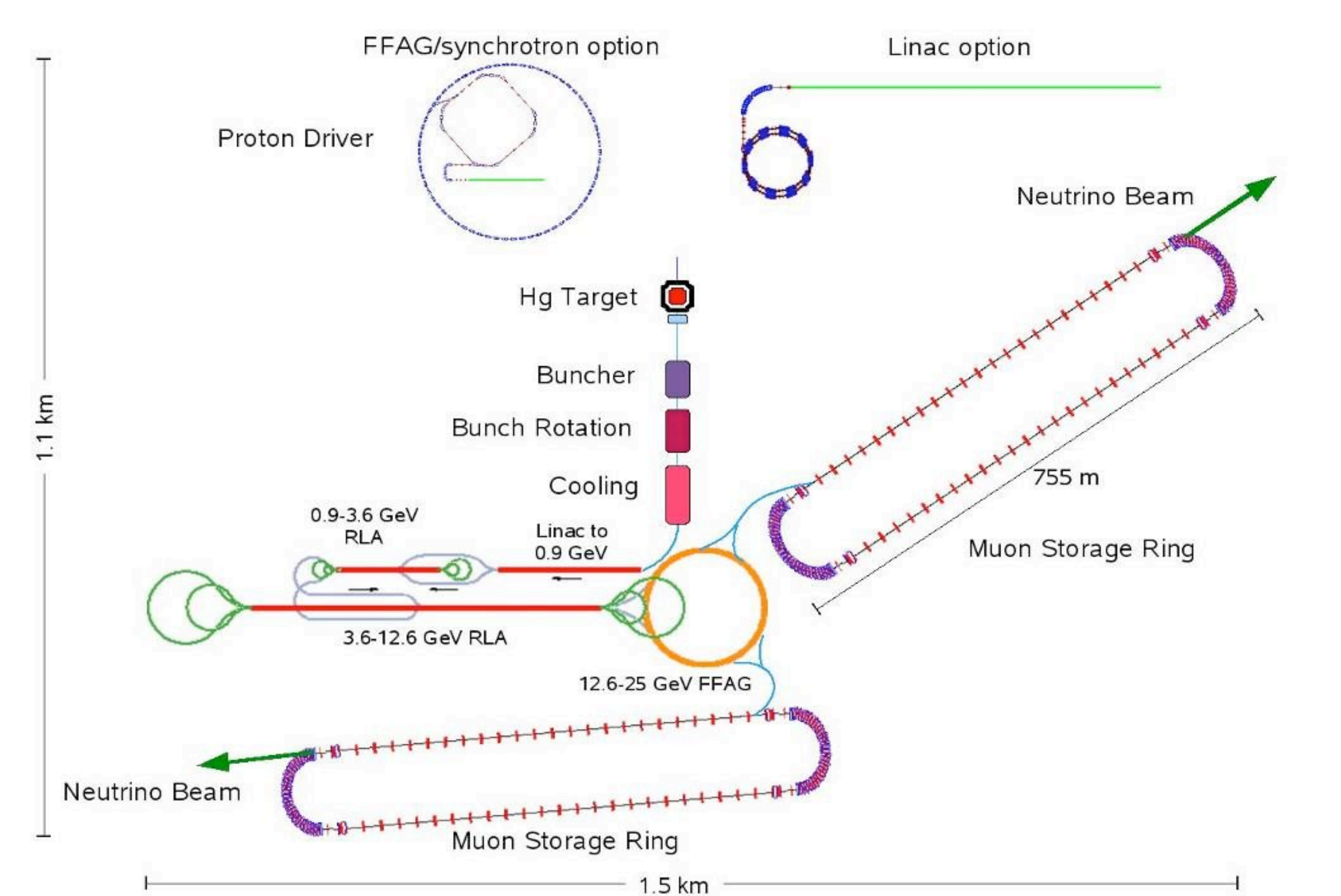
IDS/Euroν - aims

- To deliver an interims design report until end of 2010
  with a first costing to be 50-70% accurate
  ⇒Costing exercise for RDR costing

- To deliver an reference design report until end of 2012
  End to end simulations and performance evaluation of facility
  costing to be 30-50% accurate

=> but a significant amount of costs will be site specific
(proton driver, decay rings, safety, etc.)

The NF baseline-overview



Proton driver

R&D for the proton driver is decoupled from IDS as a hosting lab specific solution is assumed,………but required beam parameters on target have been defined. Within Euroν the proton driver is part of the super beam work package. As the proton driver costing is strongly related to the hosting lab the following conveners have agreed to contribute:

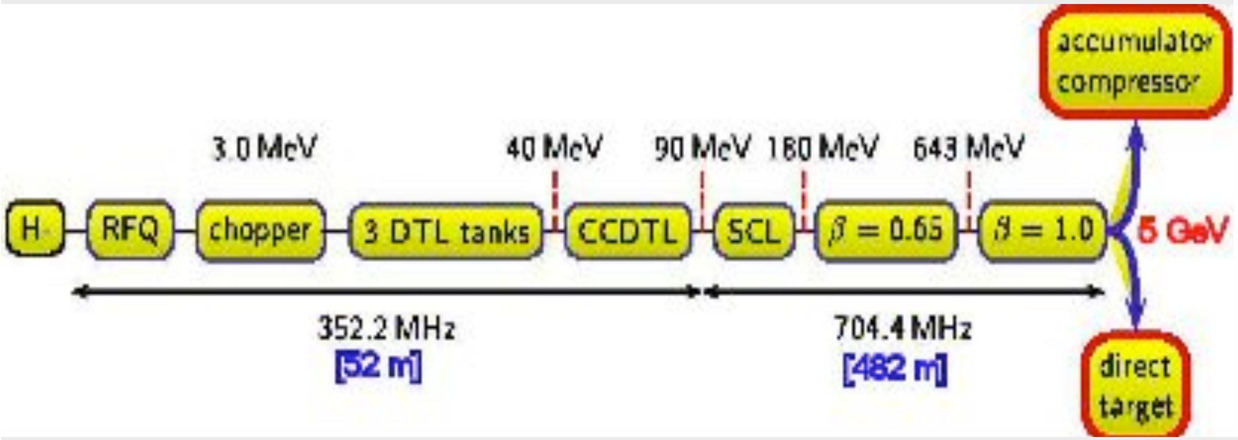
CERN LINAC 4 / SPL : Roland Garoby

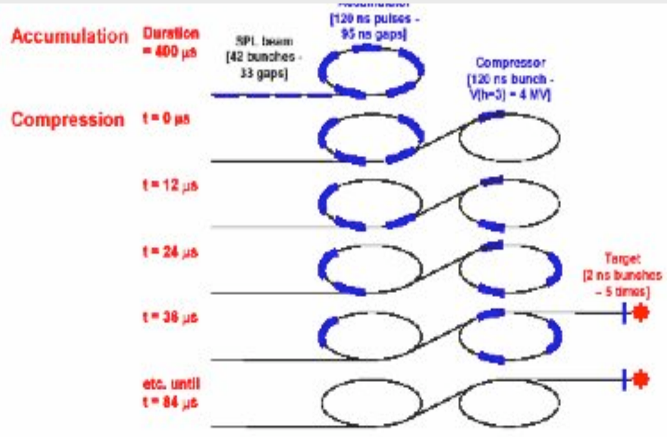
Fermilab Project X : Keith Gollwitzer

RAL - ISIS upgrade : John Thomason

Linac / compressor ring option at CERN & Fermi lab

Beam power (MW) 4	Beam power (MW) 200 kW/2.3 MW
Beam energy (GeV) 5	Beam energy (GeV) 8 / 120
Repetition rate (Hz) 50	Repetition rate (Hz) <1
Average current (mA) 40	Average current (mA) 30





Costs of proton driver are strongly dependent on site specific boundary conditions like use of accelerator design and technology, available hardware and infrastructure and synergies with other site specific projects utilizing intensive proton beams. Risks are comparably low compared with other subsections and are connected with bunch compression => mainly a cost optimizing exercise. Main cost drivers : RF, civil engineering, cryo….. 500 M€ + rings

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Summarised cost estimate

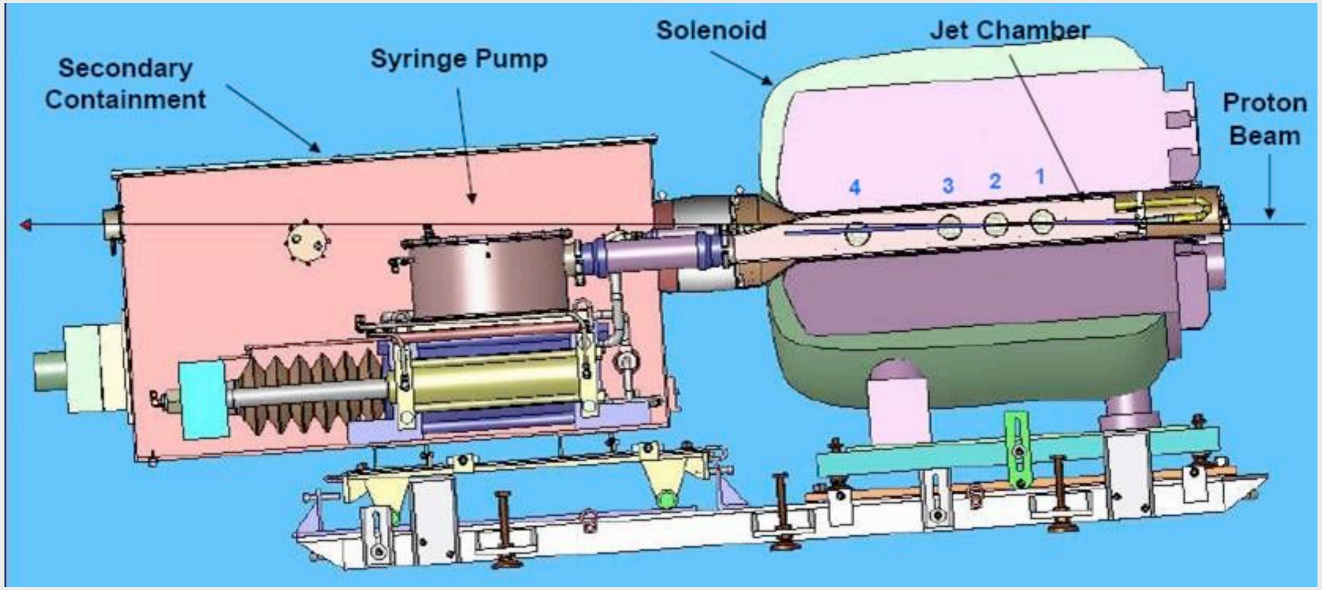
R. Garoby EURONu costing workshop – 15/03/2010

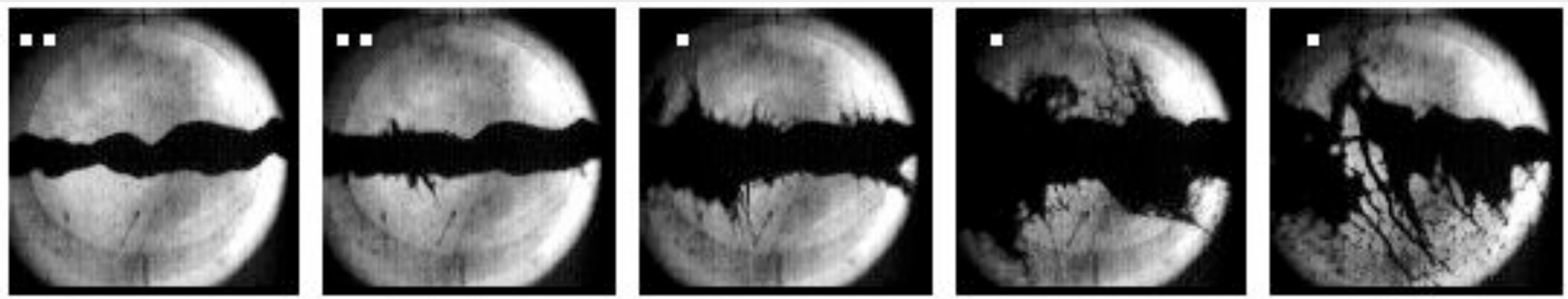
4. Result

Item	Cost (MCHF)	
RF equipment (80 klystrons for 160 b=1 cavities + 66 IOTs for 66 b=0.65 cavities + power supplies, waveguides, LLRF, inte rlocks & controls, etc.) and 2 test places for cryomodules.	219	45.6 %
Civil Engineering (underground & surface buildings) + cooling/ventilation & electrical infrastructure	113	23.5 %
Cryomodules (20 cryomodules with 8 b=1 cavities + 1 1 cryomodules with 6 b=0.65 cavities + 226 tuners & couplers + 80 quadrupoles + 30 BPMs)	79	16.4 %
Cryogenics (6.4 kW at 4.5 K + distribution)	17	3.5 %
Dumps (~1.4 and 4 GeV) and ejection system to ISOLDE (20 ms rise/fall time deflection system + stripping foil and H0 dump)	15	3.1 %
Beam instrumentation (transformers, beam loss monitors, laser wire profile monitors, screens…)	15	3.1 %
Controls (including machine interlocks)	10	2.1 %
Accelerator v acuum (including isolation vacuum in cryomodules)	8.5	1.8 %
Safety & access (monitors, alarms, access doors with control system)	3	0.6 %
Magnets (normal conducting in the transfer line + power supplies)	1.3	0.3 %
TOTAL	**480.8**	**100 %**

IDS-NF baseline mercury target

The Merit experiment : Feasibility of target, but no long term experience.





Costing for NF Target

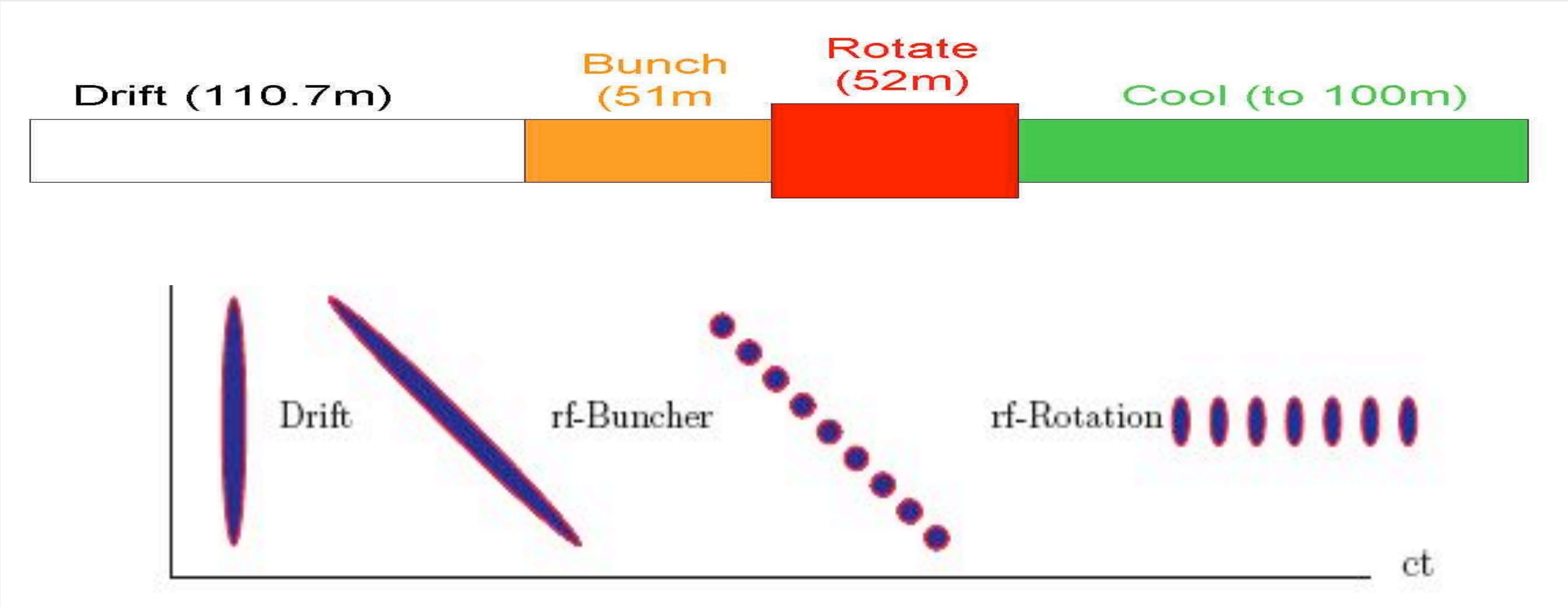
Within Euroν the super beam work package will be responsible for the costing of the solid target proposed.

Costing of baseline mercury target must be performed in close collaboration with SNS Oakridge.

Magnets, radiation shielding and health and safety will be the main cost driving factors. Those are very similar for the different target options.

The muon front end layout

- **Goal is capture and cool as many μ's as possible**
- **High Frequency buncher/rotation**
- **Common for ν-Factor and μ⁺-μ Collider**
- **Major risk : High RF gradient requested in baseline might not be achievable -> risk mitigation**



RF cavities in magnetic fields

Problem :

To contain the beam within the acceptance of the cooling channel transversal focussing (solenoids 5T) is required together with an field gradient in the cavities of ~ 15 MV/m

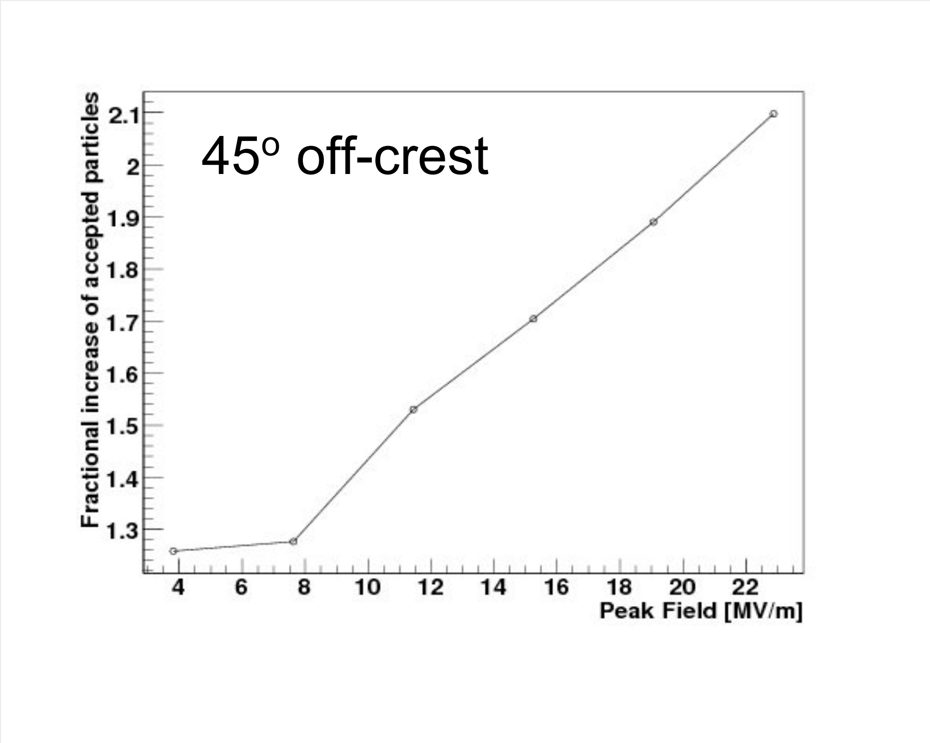
High magnetic fields degrades the available accelerating voltage (dark currents, RF breakdown) to below 10 MV/m and causes damage of RF cavities

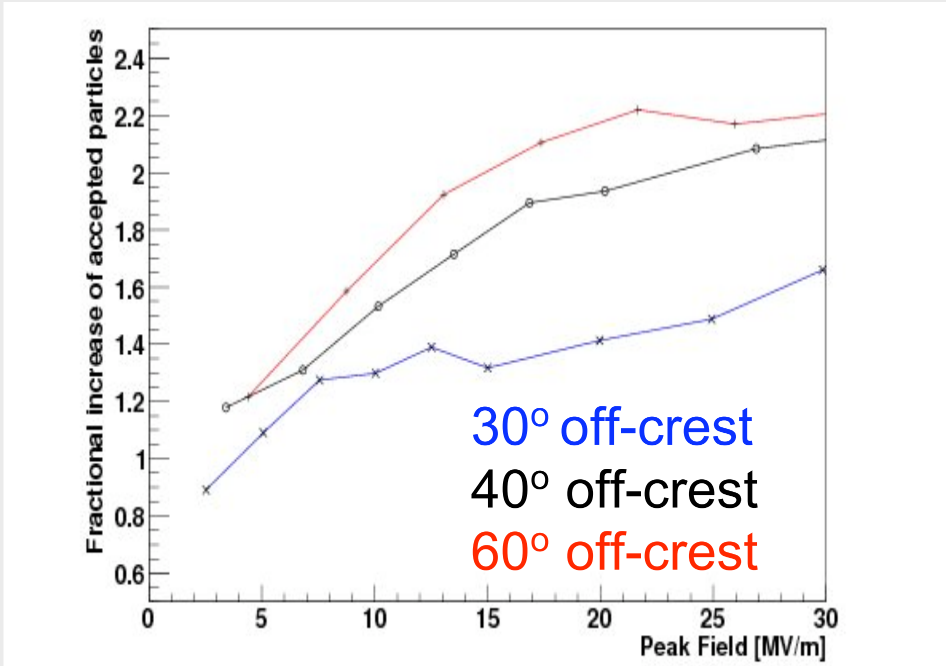
Extensive experimental program underway to investigate this problem (surface roughness, coating, magnetic isolation, high pressure gas filled cavities)

=> Achievable gradient will strongly influence the design, performance and costs of muon front end together with magnets and civil engineering.

Cooling performance with reduced gradients

ICOOL code (left) and G4MICE code (right):

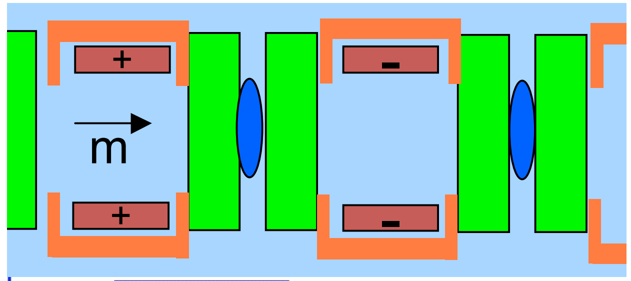


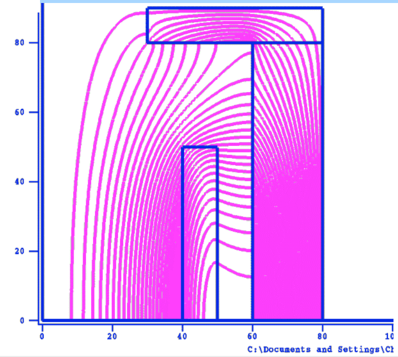


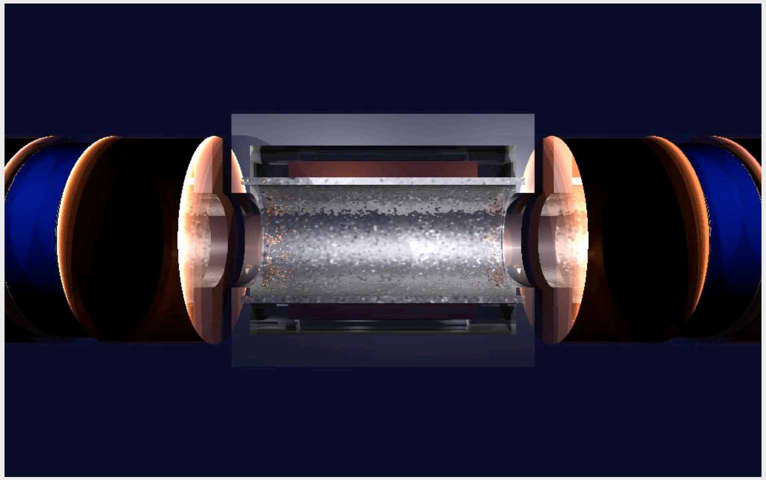
Difference in performance likely due to differences in LiH modelling.

Shielded RF Lattice

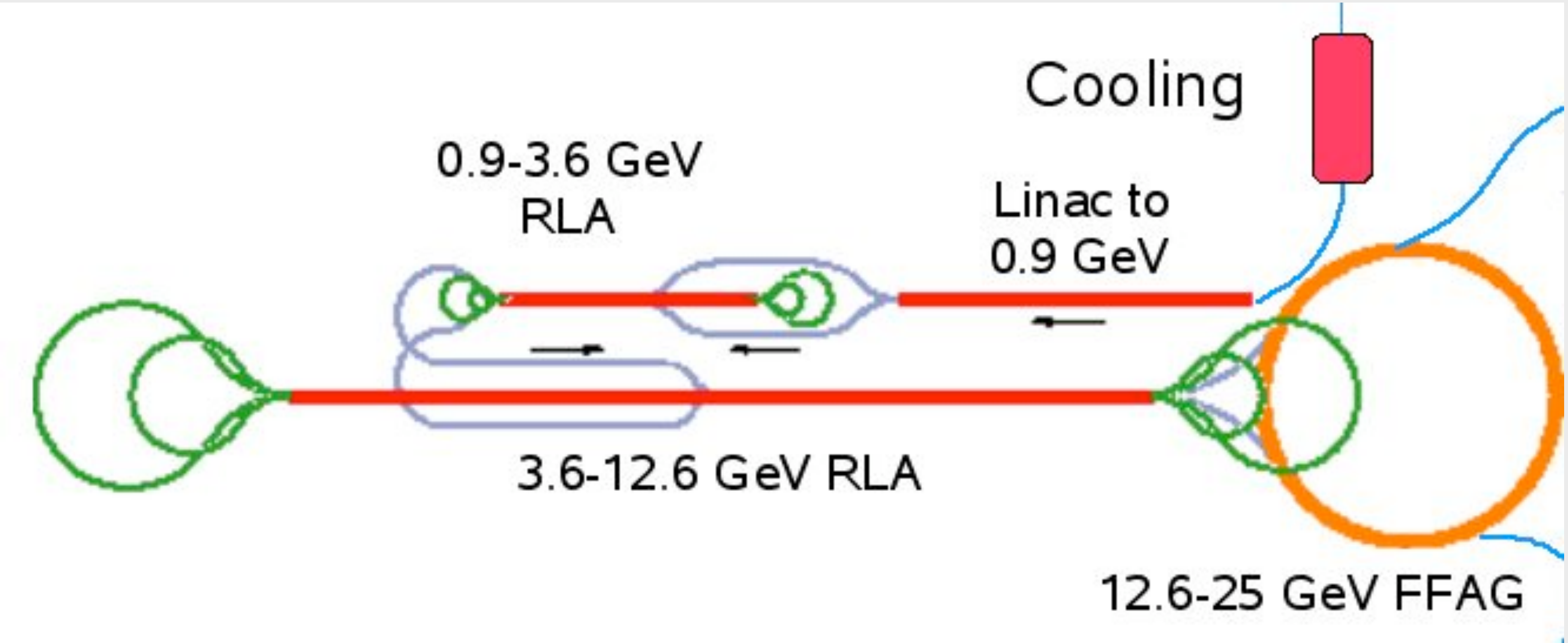
- Aim is to shield RF cavities from solenoid fringe field
- Shorter solenoids have big spherical aberrations
- Requirements for big acceptance and tight focussing difficult to achieve
- Race between RF packing and optics performance
- Simulations show that a reduced RF gradient will consequently reduce particle yield and increase costs.



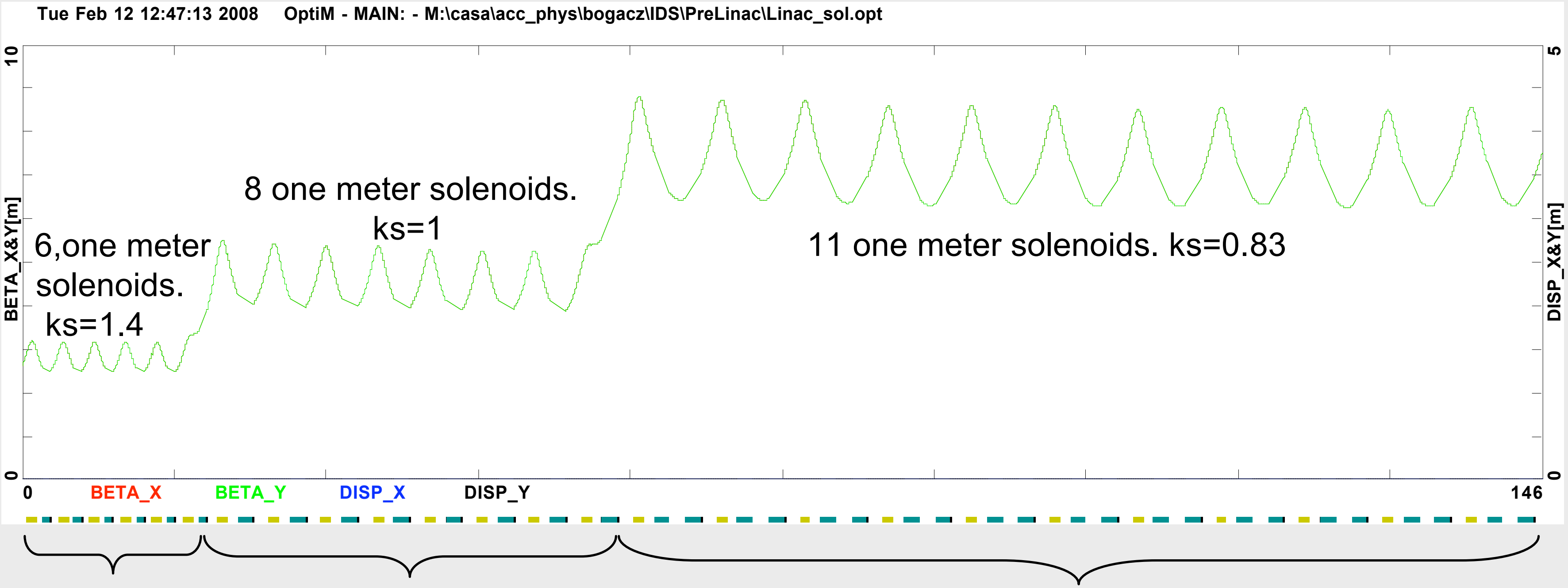




Fast acceleration: Linac, RLA & FFAG



Linac layout



6 short cryos

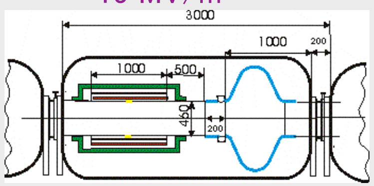
15 MV/m

8 medium cryos

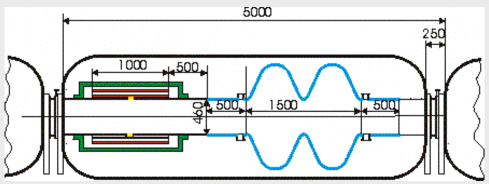
17 MV/m

11 long cryos

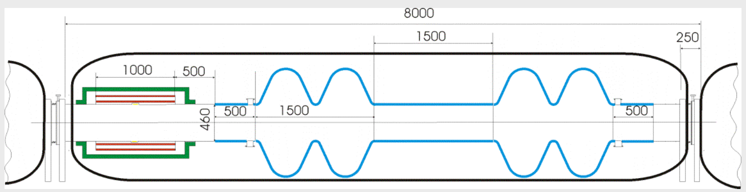
17 MV/m



1.1 Tesla solenoid



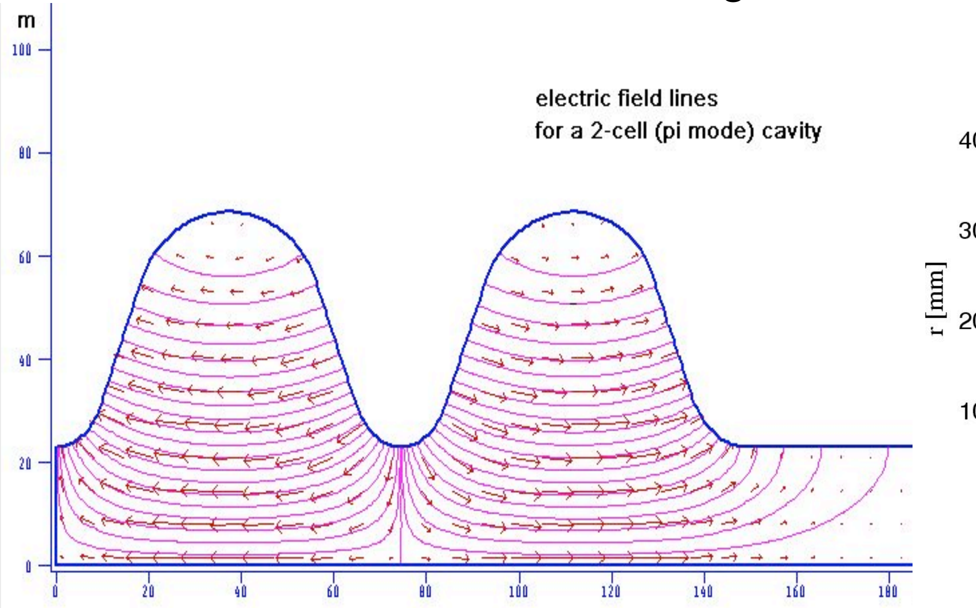
1.4 Tesla solenoid

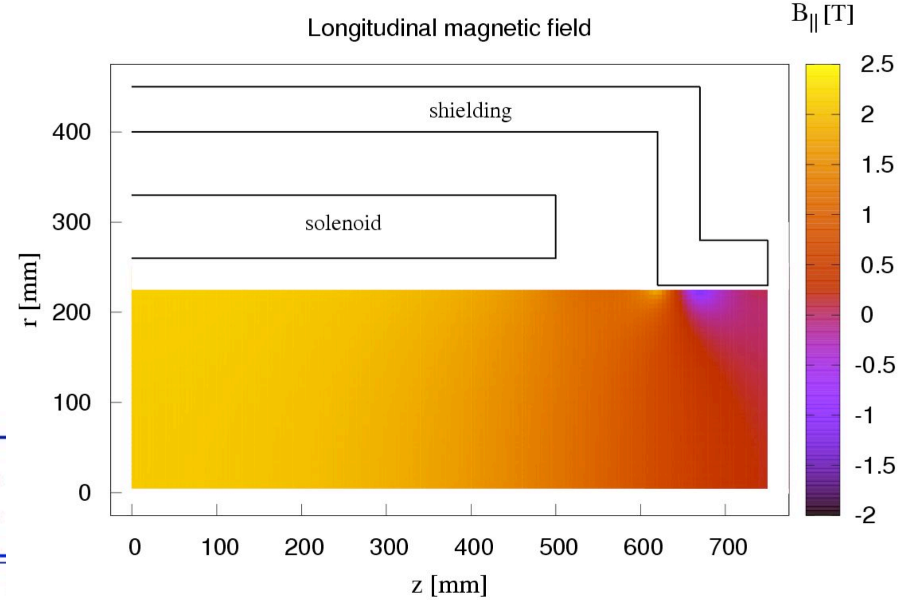


2.4 Tesla solenoid

Linac components

Modelling of solenoids and cavities





The solenoid design is quite advanced and no significant technical risk is expected, quench protection might be cost sensitive. The dimensions and performance may change slightly but with minor effect on costs.

Costing of the solenoids for the IDR can be based on scaling from similar devices based on meters of cables and kg of iron.

While the cavity design it is well defined they contain a serioous technical risk as performance have not been shown. A costing based on the amount of material required and its manufacture by rescaling from other projects may not deliver the required accuracy.

Linac & RLA risks

Technical risks are relatively moderate and only moderately cost driving.

Still optimisation of accelerator layout to reduce total costs underway (FFAG like arcs for RLA's).

Main cost driving factors are RF, civil engineering and cryogenics.

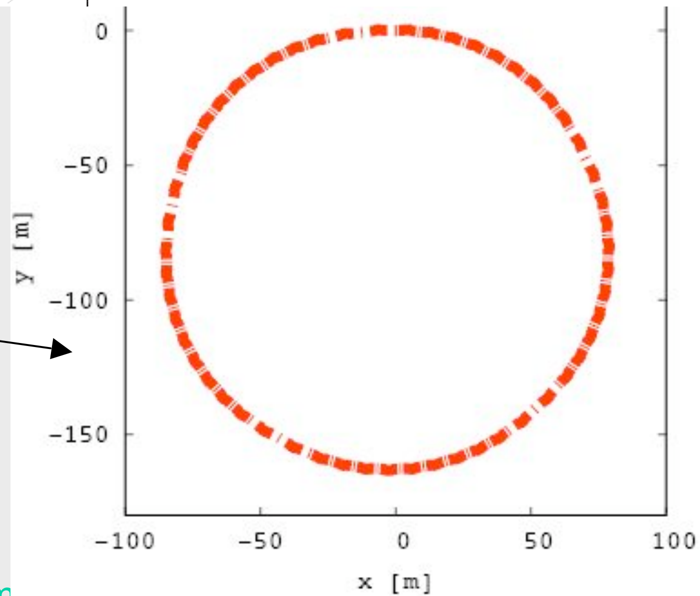
- Cryomodule costs also depend on the thermal insulation solution and helium flow scheme but this can be learnt from CERN;
- Solenoids are all of the same type as well and it's probably easier to do cost rescaling in connection with the cooling channel if the current (physics and engineering) design proves to be reliable;
- costing accuracy will be correlated with the number of details taken into account but for the time of the IDR the main cost drivers (tunnel and cryomodules) can be evaluated.

Fast acceleration - FFAG

- Quasi-Isochronus linear Non-Scaling FFAG was proposed for muon acceleration in the Neutrino Factory (12.6 – 25 GeV).
- It allows to use 200 MHz RF system and has a very large transverse acceptance.
- Beam dynamics in NS-FFAGs was studied using independent codes with a very good agreement.
- Lattice update was performed (Scott Berg).
- Alternative lattice with chromaticity correction and insertions was proposed (S. Machida).
- Schemes based on scaling FFAG are under study in Japan (Y. Mori *et al.).*

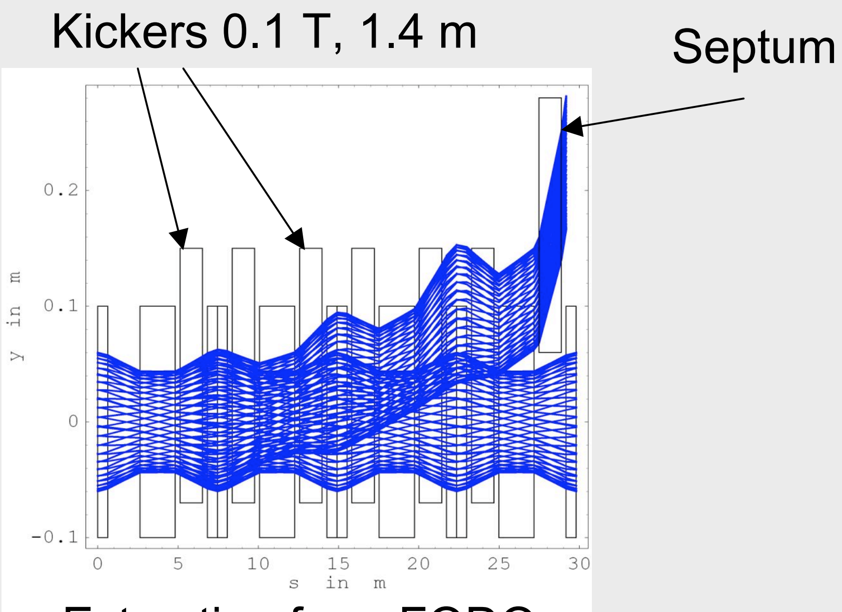
IDS-NF FFAG Parameters

	FCDC	FDFCC	FDFC
Cells	68	60	80
D radius (mm)	94	102	87
D field (T)	6.4	7.9	7.0
F radius (mm)	200	144	115
F field (T)	3.1	4.0	4.0
Average Gradient (MV/m)	2.8	2.6	1.6
turns	9.0	13.0	17.3
Length (m)	521	393	479
Cost (A.U.)	170	155	142

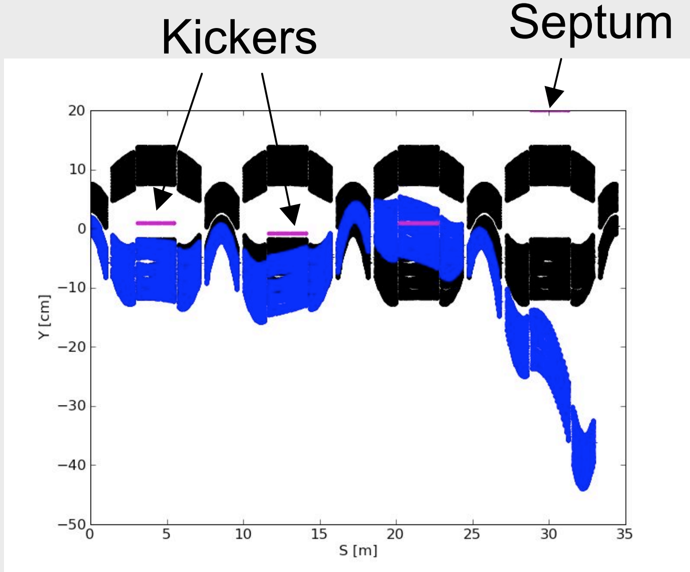


Fast acceleration - FFAG

- Injection and extraction schemes in the baseline triplet and FODO lattices have been evalueted (D. Kelliher, J. Pasternak)
- Triplet lattice seems to be easier due to the longer available drift length.
- All schemes require many kickers and large aperture magnets.
- Symmetry breaking effect due to those additional large aperture magnets is manageable.
- Parameters of the kicker magnets were estimated and are within the reach of the present technology



Extraction from FODO



Injection into triplet lattice (⇦ beam direction)

FFAG risks

FFAG is still in the lattice design phase and has to be frozen as soon as possible.

The ns-FFAG PoP experiment EMMA will be commissioned this summer. => PAMELA costing will give an indication of component costs (SC magnets).

Main cost driving factors will be RF, civil engineering, and magnets (including beam injection and extraction).

Decay rings - risks

Except for the risk involved with tunneling (slope, water table) no major risks are expected. Main cost drivers are :

Civil engineering (tunnel slope)

Magnets

Starting point for costing

Preliminary cost breakdown structure consists of 6 (7) levels:

- Level 0 : Total costs for a NF (for Euroν this is level 1)
- Level 1: Costs for NF sections (Accelerators, Detector, Infrastructure, etc)
- Level 2: Cost for NF sub-sections (Proton driver, Target, FFAG, etc.)
- Level 3: Costs for main structures (Proton front end, linac, rings)
- Level 4: Cost for main components (magnets, cavities, vacuum)
- Level 5: Subdivision of components costs (sc coils, shielding, power supply…)
- Level 6: Costs for materials, manufacture etc.

NF cost breakdown level 0,1 & 2

Neutrino factory

LEVEL 1	LEVEL 2
accelerator	proton driver
	pion production
	proton beam dump
	decay region
	phase rotation region
	bunching region
	cooling channel
	cooling→linac transfer line
	muon linac
	linac→RLA 1 transfer line
	(double chicane 1)
	muon RLA 1
	linac→RLA 2 transfer line
	(double chicane 2)
	muon RLA 2
	RLA 2 → FFAG transfer line
	muon FFAG
	FFAG → ring transfer line
	muon decay ring
detector	
auxiliary infrastructure	civil engineering
	safety
	control systems
	environment
operation	power consumption
	maintenance
	manpower
dismantling	hardwear
	constructions
	decontamination
site specific costs	site 1
	site 2

Construction, assembly

Linac - Level 3 to 6

beam optics (lattice)	solenoids	superconducting coils	… km of strands/solenoid
		iron shield	… kg of iron alloy/solenoid
		power connectors	…
		manufacture	
RF technology	cavities	material	… kg of NiTi/cavity
		surface processing	
	tubes		
	wavegiudes		
	couplers		
	tuners		
	SLED type cavities?		
vacuum	vaccum pumps		
	main vaccum chamber	material	
		surface processing	
	pipes		
cryogenics	thermal shield		
diagnostics			
correction			

RLA – level 3 to 6

beam optics (lattice)	dipoles	warm coils	… m of copper/dipole
		iron shield/yoke	… kg of iron alloy/dipole
		power connectors	… m of cable/dipole
		manufacture	
	quadrupoles	warm coils	
		iron shield/yoke	
		power connectors	
		manufacture	
	sextupoles	warm coils	
		iron shield/yoke	
		power connectors	
		manufacture	
RF technology	cavities	material	… kg of NiTi/cavity
		surface processing	…
	tubes		
	wavegiudes		
	SLED type cavities?		
vacuum	vaccum pumps		
	main vaccum chamber		
	pipes		
cryogenics	thermal shield		
	cooling agent storage		
	cooling agent distribution		
	refrigerators		
diagnostics			
correction			

Summary

Costing just started

Very complex tasks due to various options partly site specific

Work (& cost) breakdown structure in preparation

IDR costing will only be the beginning and in a large fraction be based on scaling => exercise for the RDR which must be more detailed to achieve required accuracy.