THE INTERNATIONAL DESIGN STUDY FOR THE NEUTRINO FACTORY

IDS-NF: RF R&D ideas:

K. Long, 21 April, 2011

Imperial College London

IDS-NF: RF R&D ideas:

Neutrino Factory:

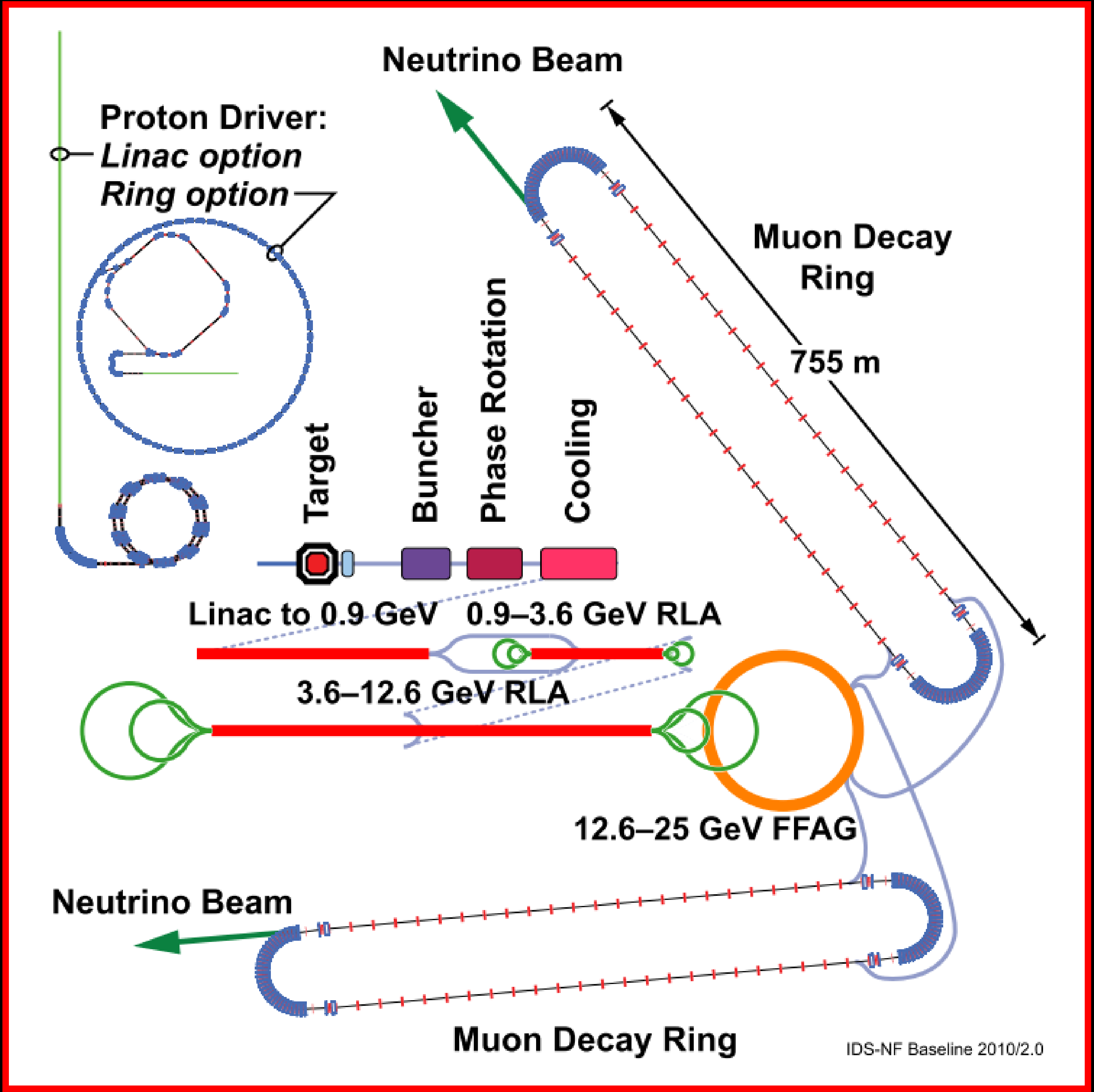
International Design Study for the Neutrino Factory

IDS-NF-020

Interim Design Report

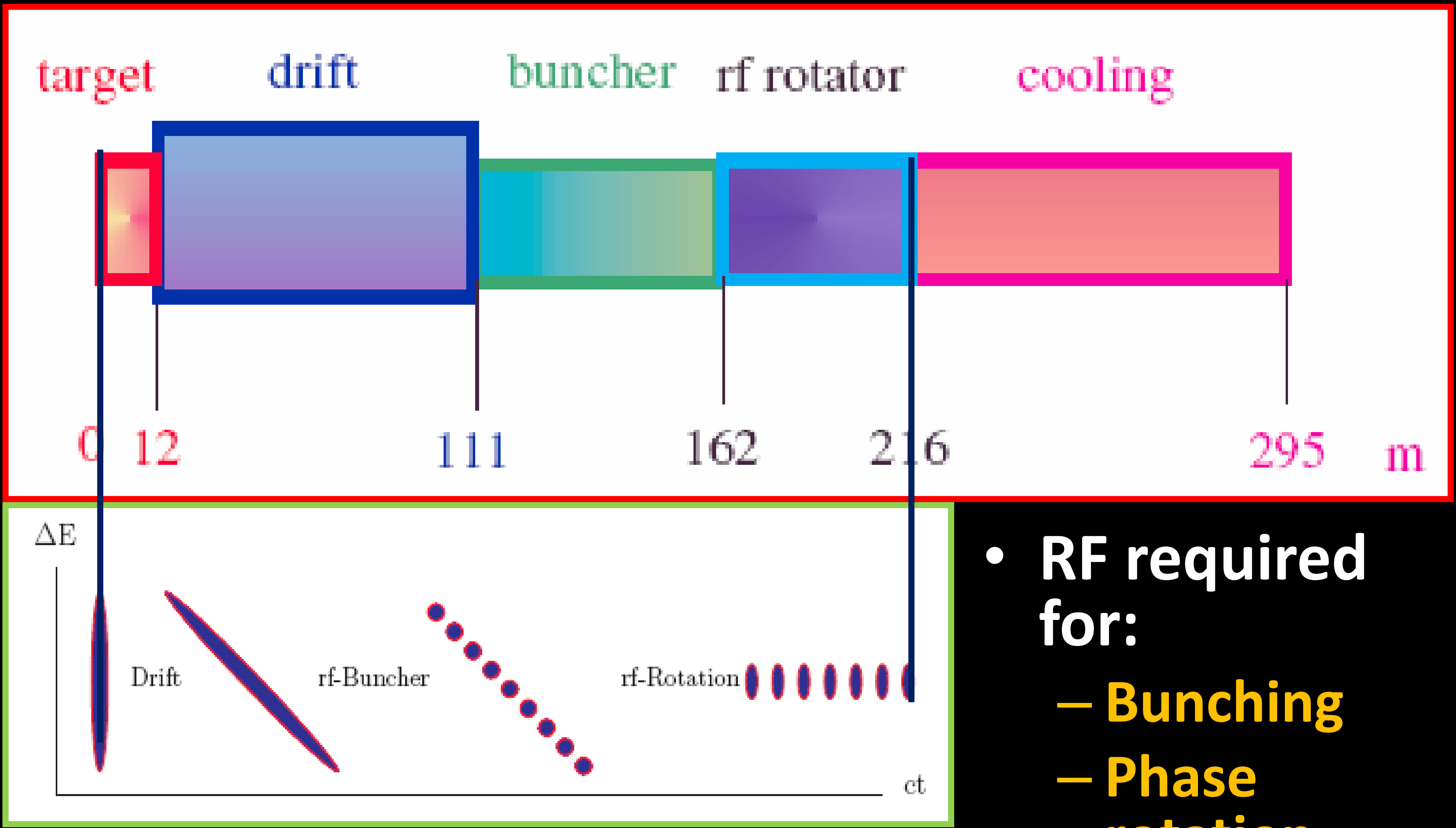
The IDS-NF collaboration

Available from IDS-NF site: https://www.ids-nf.org/



Neutrino Beam
Proton Driver:
Linac option
Ring option
Muon Decay
Ring
755 m
Target
Buncher
Phase Rotation
Cooling
Linac to 0.9 GeV
0.9–3.6 GeV RLA
3.6–12.6 GeV RLA
12.6–25 GeV FFAG
Neutrino Beam
Muon Decay Ring
IDS-NF Baseline 2010/2.0

Muon front-end:



- RF required for:
  - Bunching
  - Phase rotation
  - Cooling

Muon front-end: RF requirements:

	Length [m]	Number of cavities	Frequencies [MHz]	Number of frequencies	Peak gradient [MV/m]	Peak power requirements
Buncher	33	37	319.6 to 233.6	13	4 to 7.5	1–3.5 MW/freq.
Rotator	42	56	230.2 to 202.3	15	12	2.5 MW/cavity
Cooler	75	100	201.25	1	15	4 MW/cavity
Total	150	193	319.6 to 201.25	29		562 MW

- Large number of high-gradient, normally conducting cavities
  - Normal: operation in magnetic field

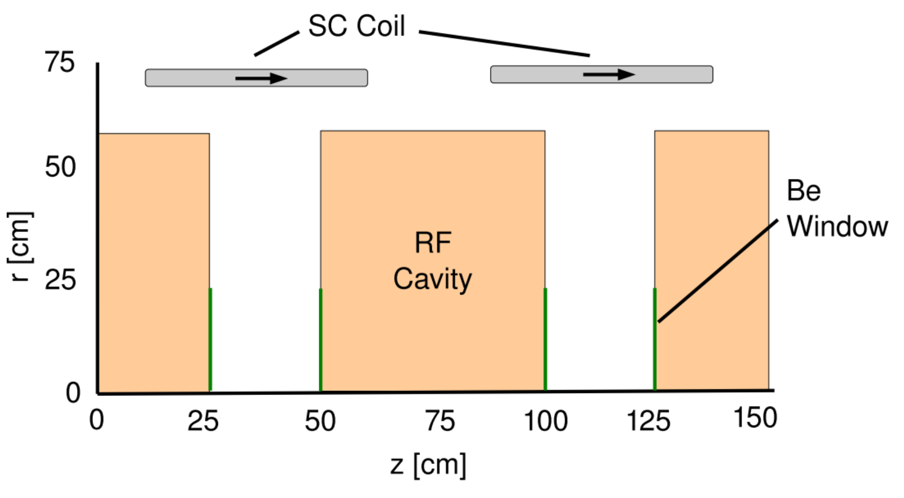


Figure 34. Schematic radial cross section of a rotator cell.

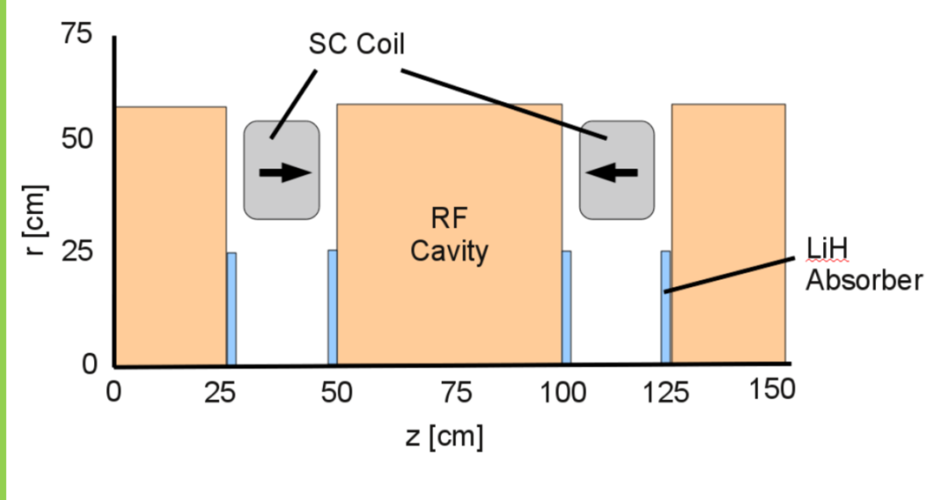


Figure 37. Schematic radial cross section of a cooling cell.

Muon front-end: summary:

Table XI. Front-end RF requirements for the rotator and cooler systems. f_{RF} is the RF frequency, V_{tot} is the total voltage required at that frequency, n_{cav} is the number of cavities at that frequency, E_{peak} is the peak gradient in each cavity, P_{avg} is the steady state RF power required per cavity, and P_{peak} is the peak RF power required per cavity.

f_{RF} [MHz]	V_{tot} [MV]	n_{cav}	E_{peak}	P_{peak} [MW]
Rotator				
230.19	18	3	12	2.3
226.13	18	3	12	2.3
222.59	18	3	12	2.3
219.48	18	3	12	2.4
216.76	18	3	12	2.4
214.37	18	3	12	2.4
212.48	18	3	12	2.4
210.46	18	3	12	2.5
208.64	24	4	12	2.5
206.9	24	4	12	2.5
205.49	24	4	12	2.5
204.25	30	5	12	2.6
203.26	30	5	12	2.6
202.63	30	5	12	2.6
202.33	30	5	12	2.6
Total	336	56		140
Cooler				
201.25	750	100	15	4

Table X. Front-end RF requirements for the buncher system.

Frequency [MHz]	Voltage (per frequency) [MV]	Number of cavities	Length [m]	Gradient [MV/m]	Peak RF Power (per frequency) [MW]
319.63	1.37	1	0.4 m	4	0.2
305.56	3.92	2	0.4	5	0.6
293.93	3.34	2	0.45	4	0.5
285.46	4.8	2	0.45	5.5	1
278.59	5.72	2	0.45	6.4	1.25
272.05	6.66	3	0.45	5	1.5
265.8	7.57	3	0.45	5.7	1.5
259.83	8.48	3	0.45	6.5	2
254.13	9.41	3	0.45	7	2.3
248.67	10.33	4	0.45	5.7	2.3
243.44	11.23	4	0.45	6.5	2.5
238.42	12.16	4	0.45	7	3
233.61	13.11	4	0.45	7.5	3.5
Total	98.1	37			22

Muon linac and RLAs:

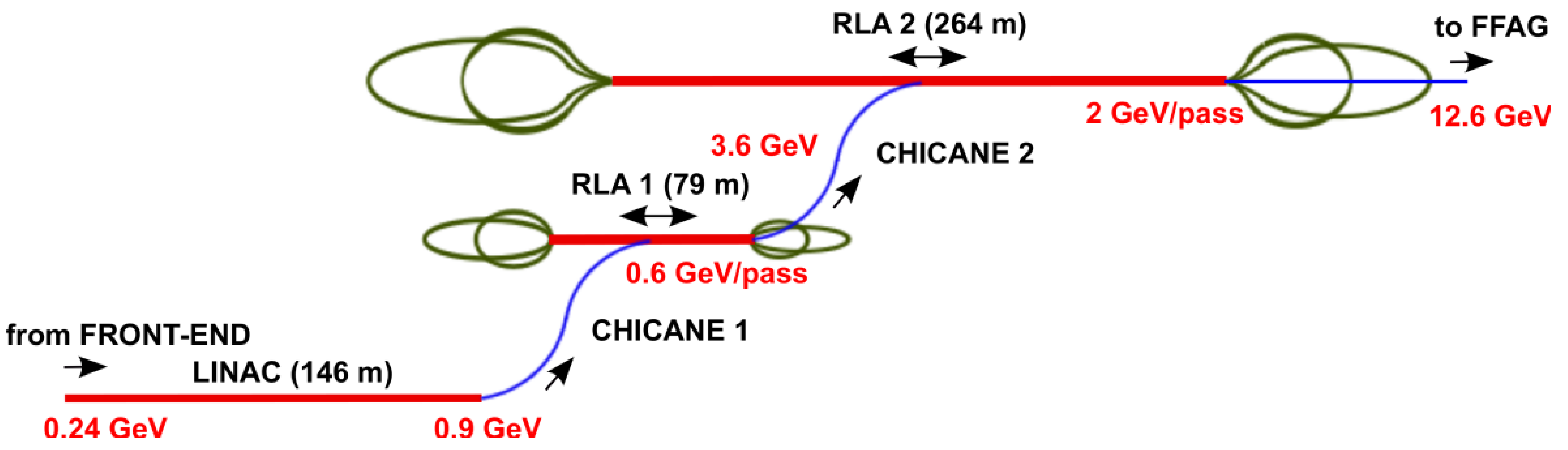
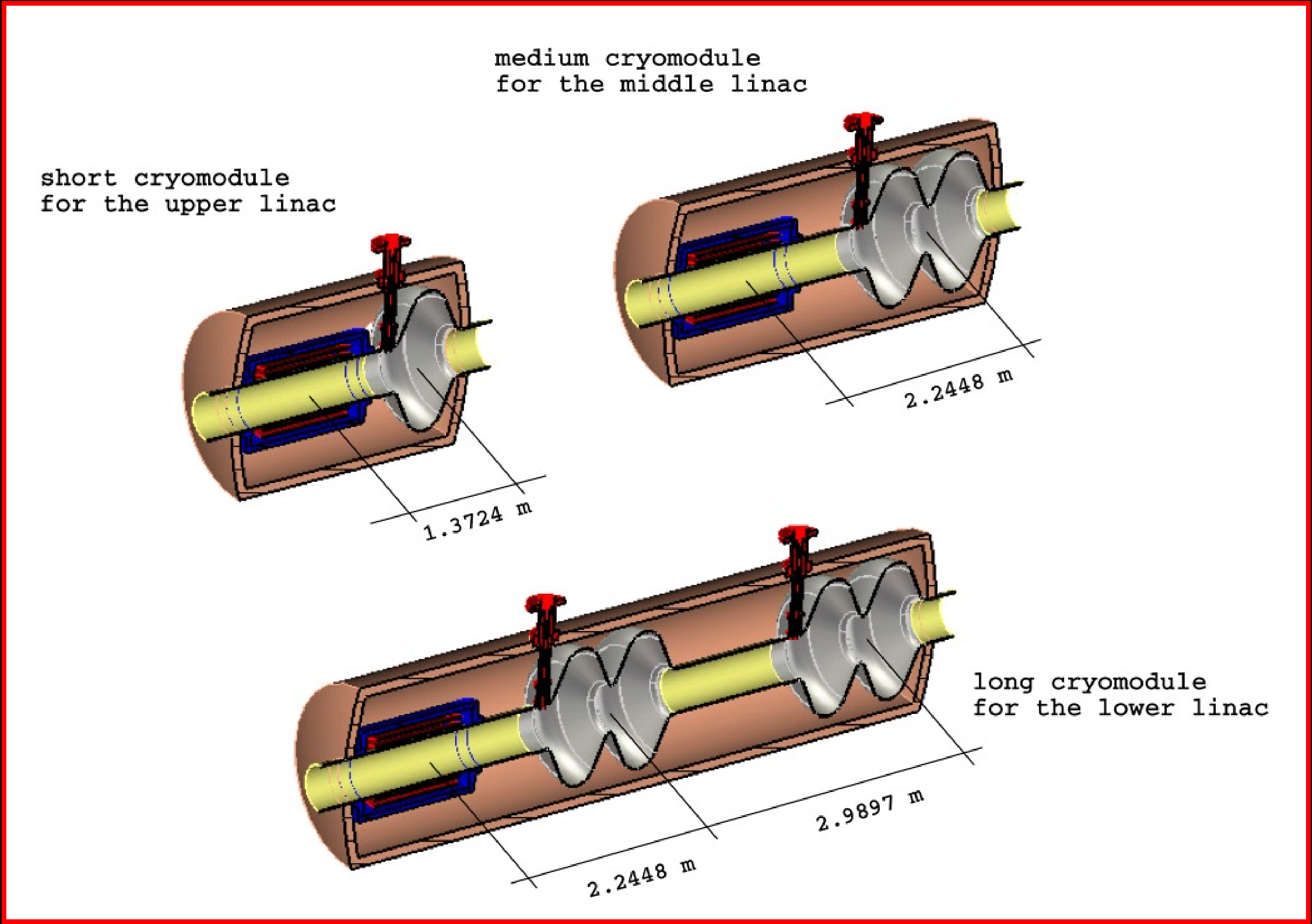


Figure 40. Layout of the linac and recirculating linacs connected by chicanes.

- Linac and RLAs:
  - Solenoid focusing
  - Superconducting (Nb on Cu) 201.25 MHz cavities

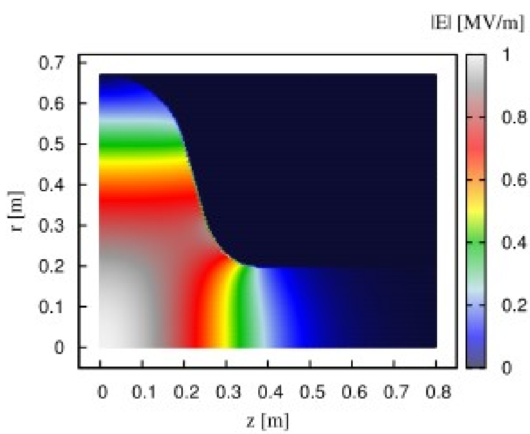
Muon linacs and RLAs:

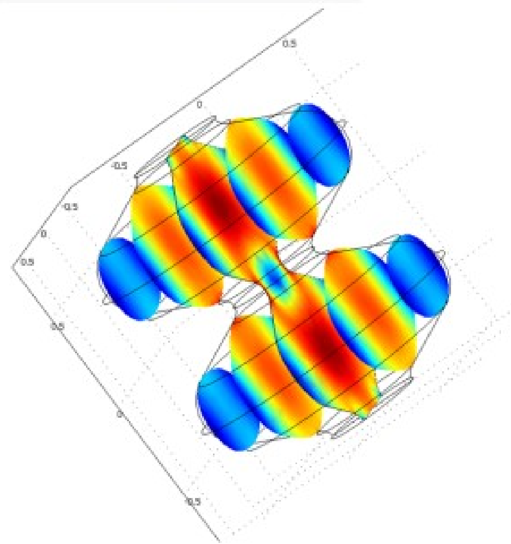


Muon linacs and RLAs:

RF frequency (MHz)	201.25	201.25
Cells per cavity	2	2
Aperture diameter (mm)	300	460
Energy gain/cavity (MeV)	25.5	22.5
Stored energy/cavity (J)	2008	1932
Input power/cavity (kW)	1016	980
RF on time (ms)	3	3
Loaded Q	10^6	10^6

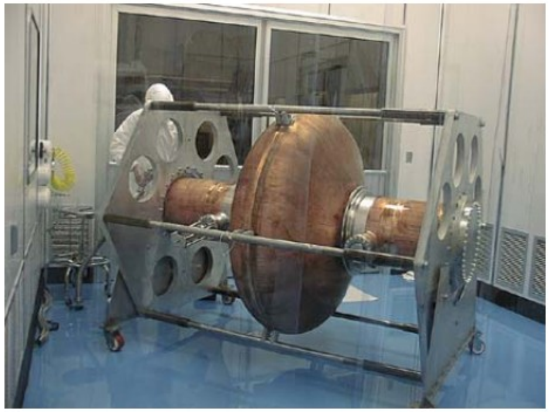
length = 0.7448 m
radius = 0.6854 m
resonance freq. = 201.247 MHz
quality fact. = 24.67×10^9
transit time factor = 0.650 - 0.690
peak $\hat{E}$ = 26.17 MV/m
$|E|^{max}_{surf}$ = 21.70 MV/m
$|H|^{max}_{surf}$ = 48.06 kA/m
stored energy = 712 J

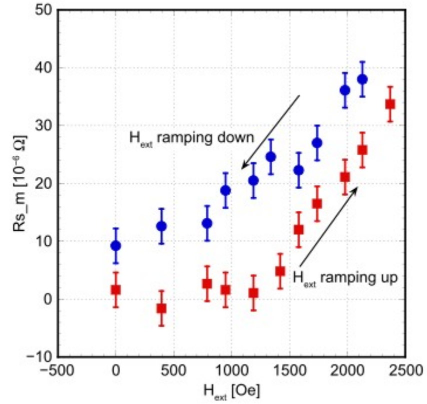


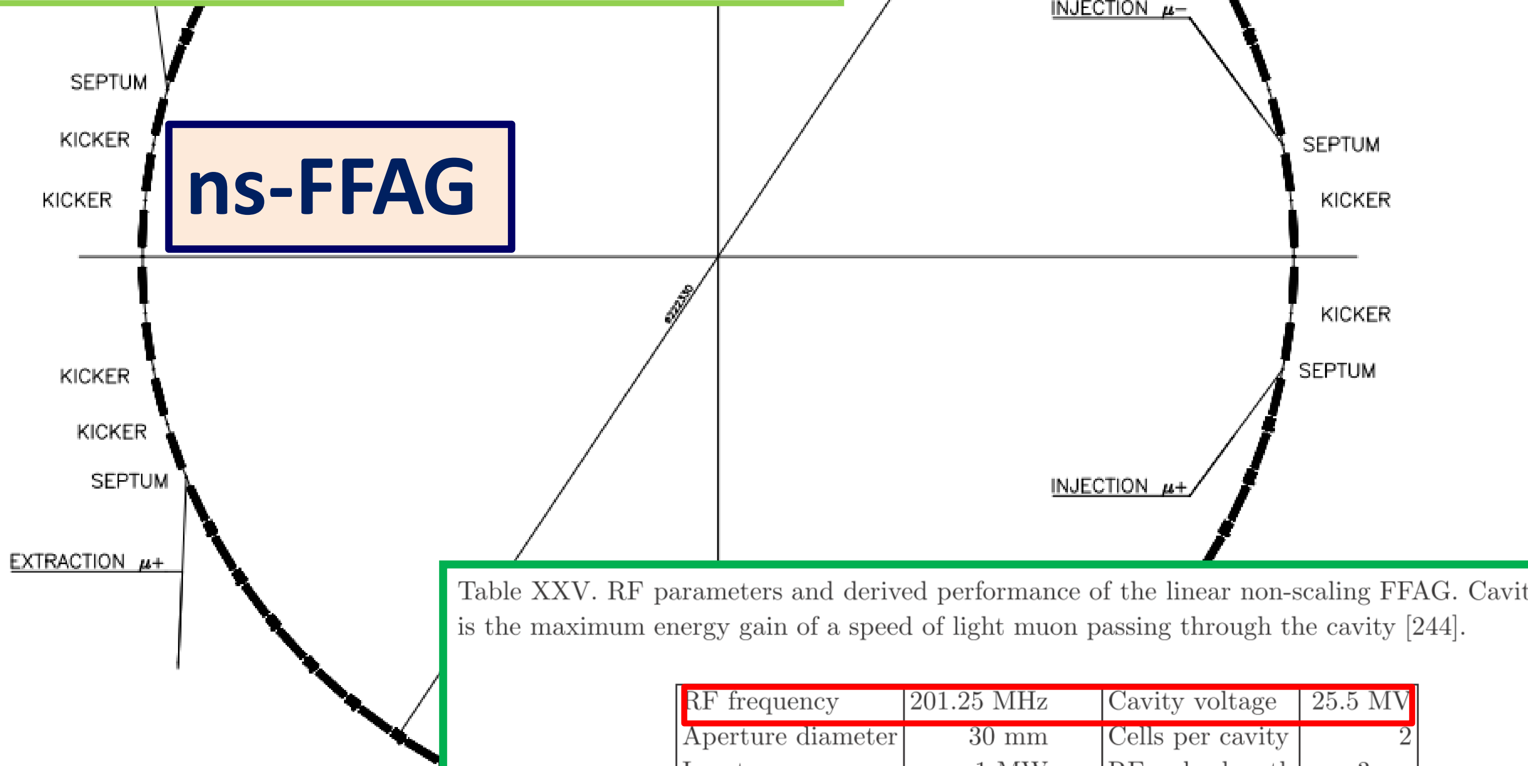


Muon FFAG:

- Up to 0.1 T at cavity surface







ns-FFAG

Table XXV. RF parameters and derived performance of the linear non-scaling FFAG. Cavity voltage is the maximum energy gain of a speed of light muon passing through the cavity [244].

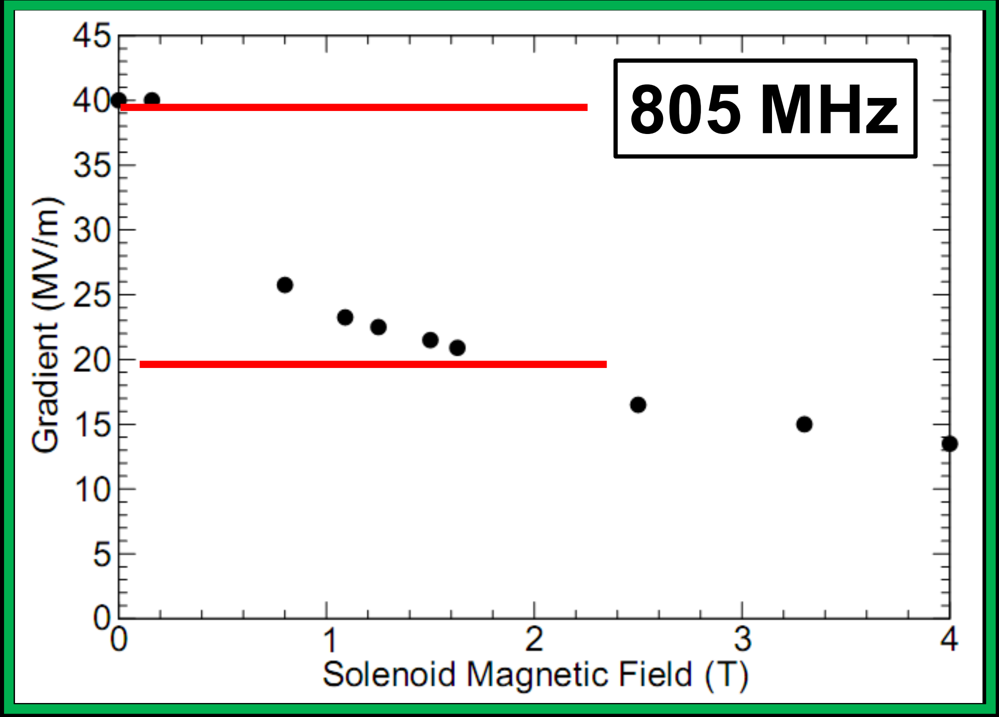
RF frequency	201.25 MHz	Cavity voltage	25.5 MV
Aperture diameter	30 mm	Cells per cavity	2
Input power	1 MW	RF pulse length	3 ms
Stored energy	2008 J		
Cavities	48	Total voltage	1214 MV
Turns	11.6	Decay loss	6.7%

IDS-NF: RF R&D ideas:

Issues:

MuCool: RF breakdown in magnetic field:

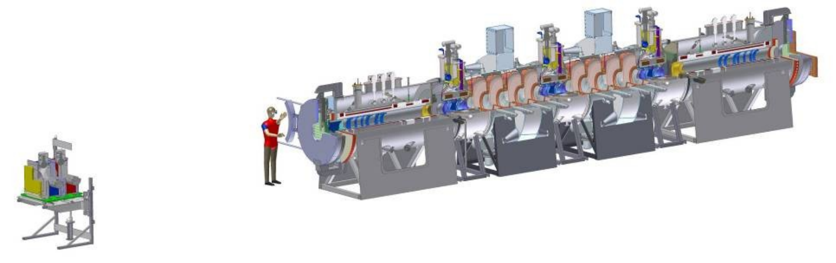
- Principal issue for cooling channel:
  - Gradient required in baseline cooling channel:
    - 15 MV/m from 201MHz cavities
- MuCool: study breakdown in presence of magnetic field
  - 805 MHz:
    - Reduction of factor of ~2 in max. gradient
  - 201 MHz:
    - In absence of *B* have achieved 20 MV/m
      - Test in magnetic field planned



Mitigation of RF gradient risk:

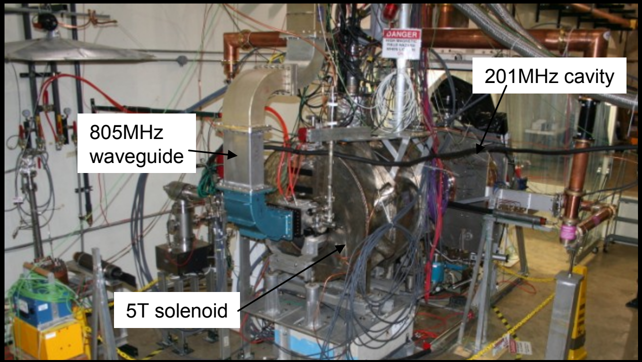
- Various options being considered:
  - Modified lattices, magnetic return, bucking coils, gas filled cavities…
  - Studies emphasise:
    - Priority: expedite MICE and MuCool programmes!

- Ionisation cooling

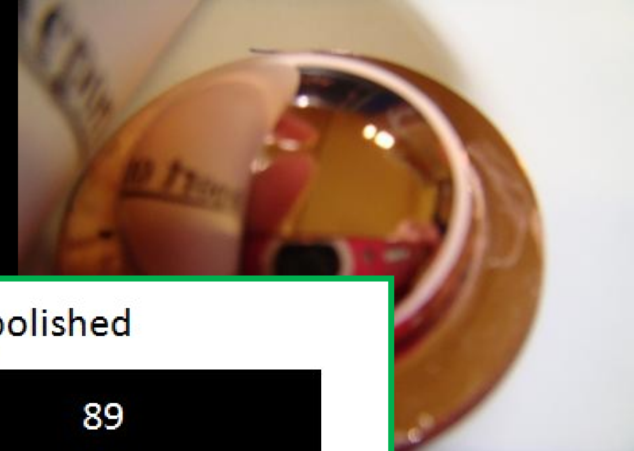


MICE
(under construction at RAL)

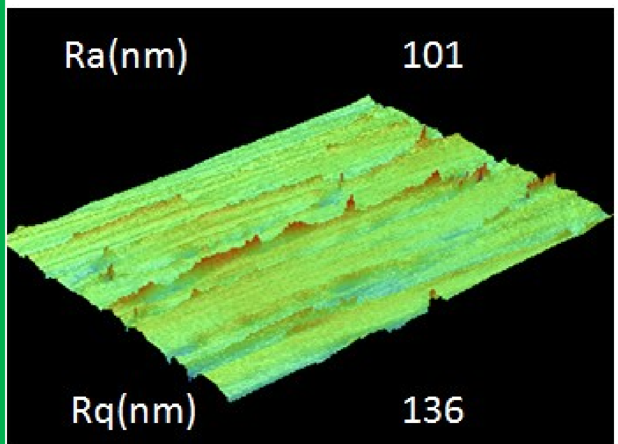
- RF cavity development

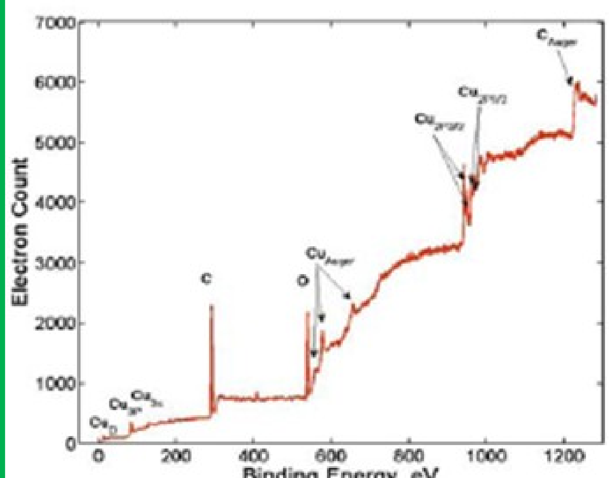


MuCool (part of US NFMCC)

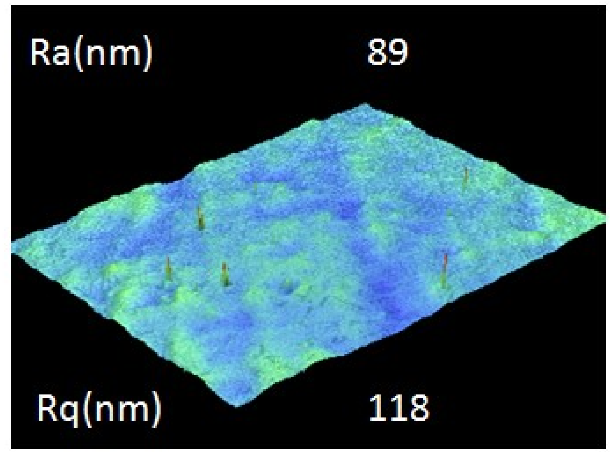


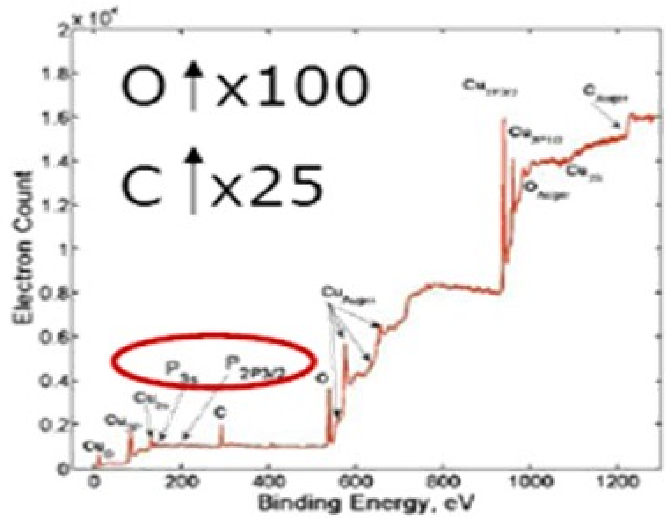
As received



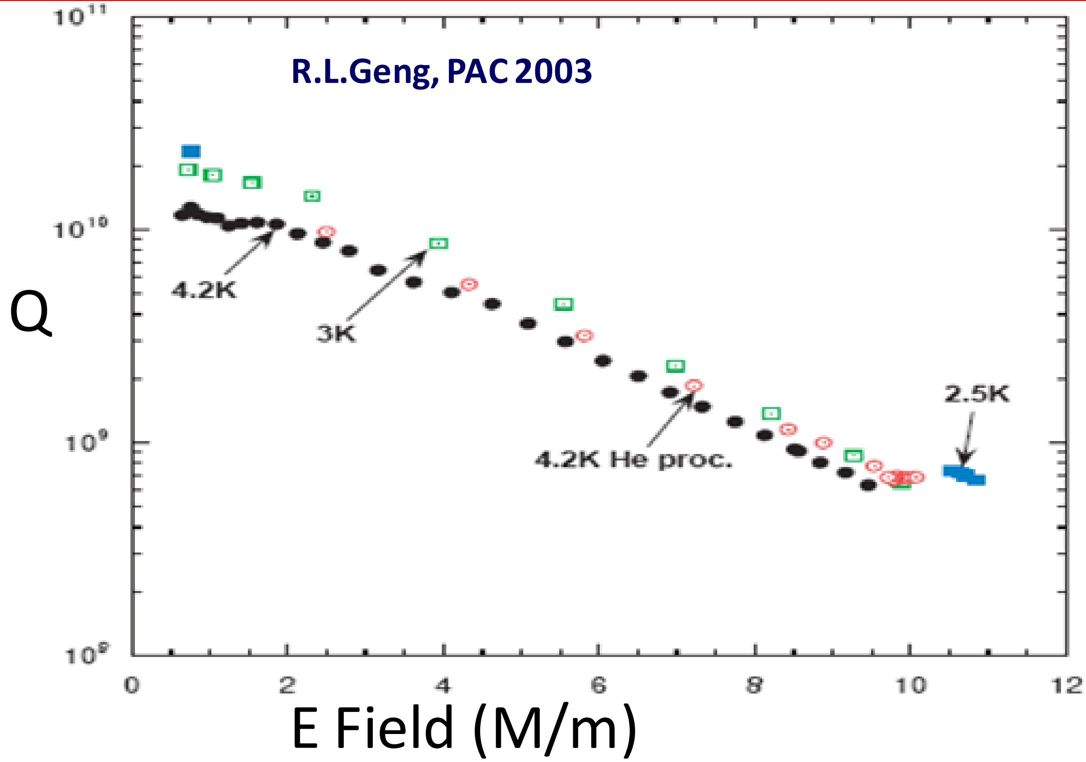


Electropolished



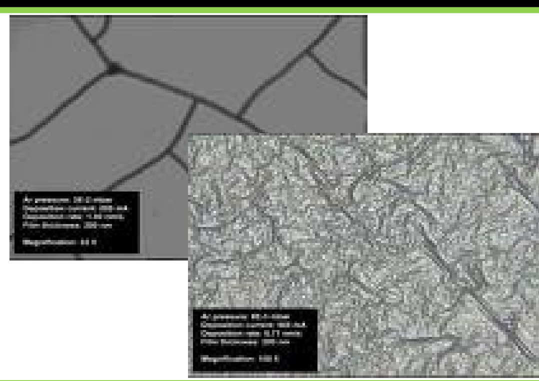


Superconducting: anomalous Q slope:

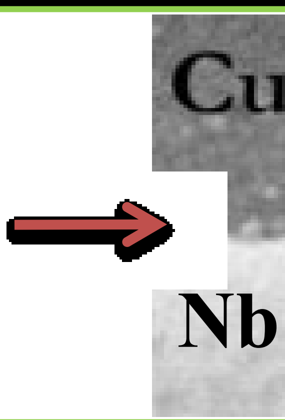


NF

Low Δ $\Rightarrow \dfrac{\ell_{mfp}}{\xi}$



High R_{inte}



Issues:

- Development of techniques for manufacture of high-gradient RF cavities at ~200 MHz:
  - Normal and superconducting ...
- What determines maximum gradient within and in the absence of magnetic field?
  - Surface texture
  - Surface quality (grain structure, impurities, etc.)
  - Processes in manufacture
- What are the manufacturing procedures required to deliver specified resonator with 90% confidence?

IDS-NF: RF R&D ideas:

Constituency:

IDS-NF and EUROnu:

Bulgaria	Sofia
France	IPHC Strasbourg
Germany	MPI Heidelberg, MPI Munich, Würzburg
India	HCRI Allahabad, SINP Kolkata, TIFR Mumbai
Italy	Milano Bicocca, Napoli, Padova, Roma III
Japan	Kyoto, Osaka, Tokyo Met.
Spain	Madrid, Valencia
Russia	INRR Moscow
Switzerland	CERN, Geneva
UK	Brunel, DL, Glasgow, Imperial, IPPP Durham, Oxford, RAL, Sheffield, Warwick
USA	BNL, FNAL, JLab, LBNL, Mississippi, MSU, Muons Inc., Northwestern, ORNL, Princeton, Riverside, Stony Brook, South Carolina, Virginia Tech., UCLA

Note also of benefit to systems that require large longitudinal acceptance.

THE MICE COLLABORATION -130 collaborators-

University of Sofia, Bulgaria

The Harbin Institute for Super Conducting Technologies PR China

INFN Milano, INFN Napoli, INFN Pavia, INFN Roma III, INFN Trieste, Italy

KEK, Kyoto University, Osaka University, Japan

NIKHEF, The Netherlands

CERN

Geneva University, Paul Scherrer Institut Switzerland

Brunel, Cockcroft/Lancaster, Glasgow, Liverpool, ICL London, Oxford, Darsbury, RAL, Sheffield, Warwick UK

Argonne National Laboratory, Brookhaven National Laboratory, University of Chicago Enrico Fermi Institute, Fermilab, Illinois Institute of Technology, Jefferson Lab, Lawrence Berkeley National Laboratory, UCLA, Northern Illinois University, University of Iowa, University of Mississippi, UC Riverside, Muons Inc. USA

Muon Accelerator Program

U.S. DEPARTMENT OF ENERGY

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- Animation

Neutrino Factory

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- Why a new neutrino source?
- How does it work?

Collaborating Institutions

The present list of institutions participating in MAP:

- Argonne National Laboratory (ANL)
- Brookhaven National Laboratory (BNL)
- Cornell University
- Fermi National Accelerator Laboratory (FNAL)
- Illinois Institute of Technology (IIT)
- Jefferson Laboratory (JLab)
- Lawrence Berkeley National Laboratory (LBNL)
- Muons Inc.
- Oak Ridge National Laboratory (ORNL)
- Princeton University
- SLAC National Accelerator Laboratory (SLAC)
- University of California – Berkeley (UCB)
- University of California – Los Angeles (UCLA)
- University of California – Riverside (UC Riverside)
- University of Chicago
- University of Mississippi (U-Miss)

Last modified: 03/03/2011

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- **Programme complementary to and in collaboration with MuCool.**
- **Leverage expertise, resources, parallel working.**

IDS-NF: RF R&D ideas:

Possible programme:

Outline programme:

- Basic physics/bench-top programme to:
  - Identify critical parameters that determine break down potential:
    - Normal and superconducting
    - In presence of magnetic field and in its absence
  - Understand how steps in manufacturing processes affect critical parameters:
    - Forming
    - Surface preparation
- Demonstration of techniques developed:
  - Linac (or FFAG) cryomodule
  - Cooling lattice cell or stand alone test rig
  - Longer timescale—proof of success:
    - Full demonstrator test rig:
      - Cavity or cavities from the procedures developed above; power sources (diacrode) developed from within TIARA
        - » Could be at the ICTF or at CERN; or warm cavity at ICTF and cryo-module at CERN