MC RF WG WP structure proposal - NRF

Jean-Pierre Delahaye, Alexej Grudiev, Derun Li, Akira Yamamoto

Monday, July 12, 2021

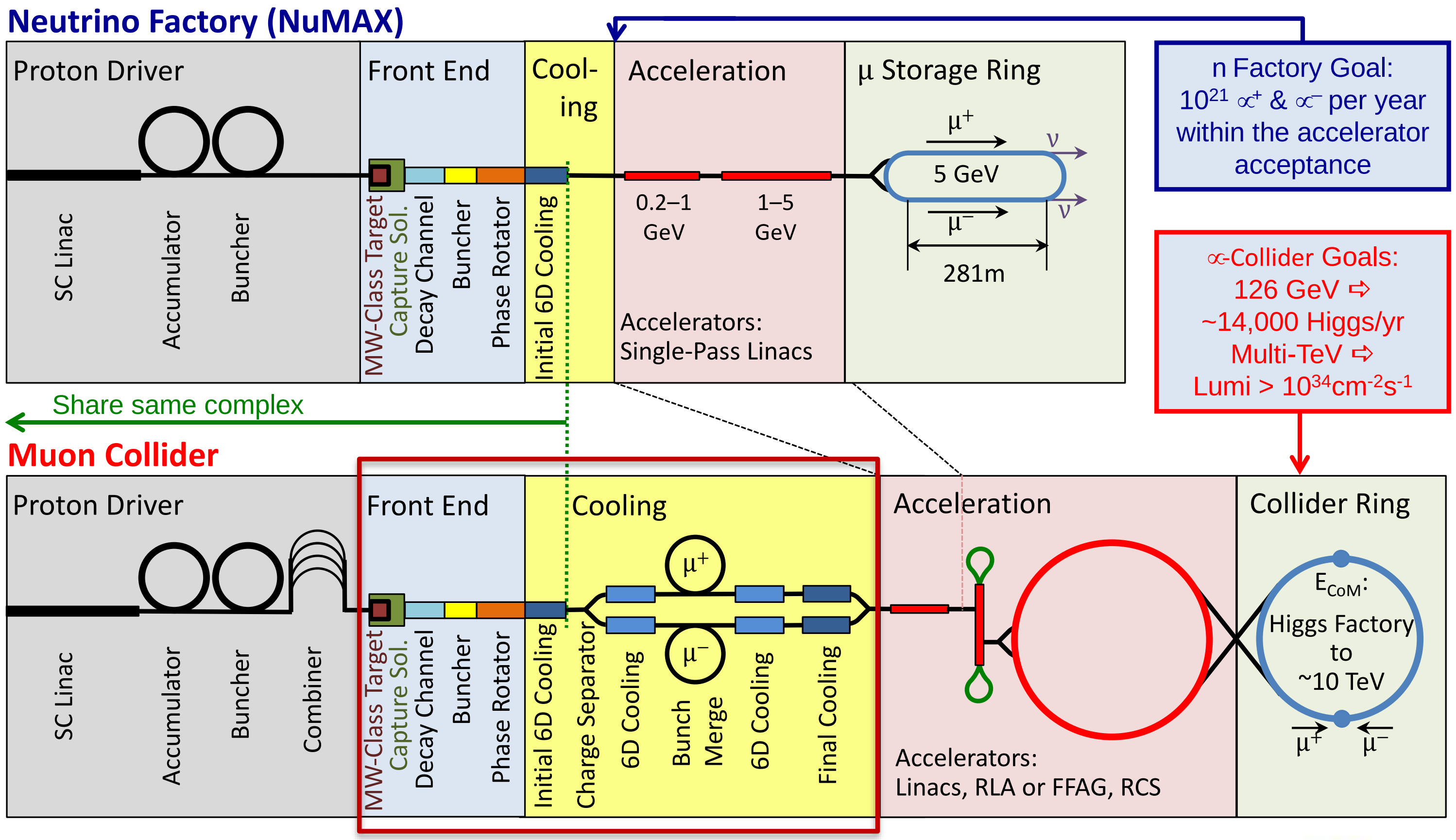
Charge for the 2nd community meeting

- During the 1st community meeting, we identified a set of challenges in the delivery of the muon collider.
- The **goal** now is to confirm those challenges and to develop them into a **prioritised and resource loaded R&D list**. In particular:
  - **Identify the R&D** that has to be carried out before the next ESSU-PP to scientifically justify the investment **into a full CDR** for the muon collider and the corresponding demonstration programme. (**next 5 years**)
  - **Identify** the main components of the **demonstration programme** together with the corresponding **preparatory work**.
  - Realistic but ambitious **targets** for the performance goals of the different collider systems.
- **This includes R&D** to develop a **baseline collider concept**, well-supported performance expectations and an assessment of the associated key risks, cost and power drivers.
- Also the working groups should **consider** what could be assumed for the **demonstration programme**, i.e. in one or more **test facilities starting in 2026**, as well what one can anticipate to be **available in 2035-2040 for a first collider stage** and in 2050 for an energy upgrade.
- **Collect e**xpression **of i**nterest **(EOI)** from potential **collaborators** interested to contribute to any specific work package (task)

Proposed Workpackage Description

Normal conducting RF (NRF) system for muon capture and cooling

- **Key Issues of NRF technology for muon capture and cooling**
  - High gradient at low frequencies
  - **In the presence of high magnetic field at multi-Tesla magnitude**
  - Large iris or Be windows;
  - High peak RF power, independently powered cavities;
  - RF sources and LLRF controls
  - Engineering challenges of system integration with RF, SC magnet, cryogenics, and etc.



Many NRF cavities

Proposed Workpackage Description

An example of MICE cooling channel:
Using normal conducting RF (NRF) system for muon cooling

nature

Explore our content ⌄ Journal information ⌄ Publish with us ⌄

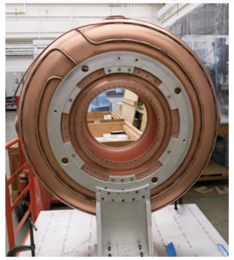
nature > articles > article

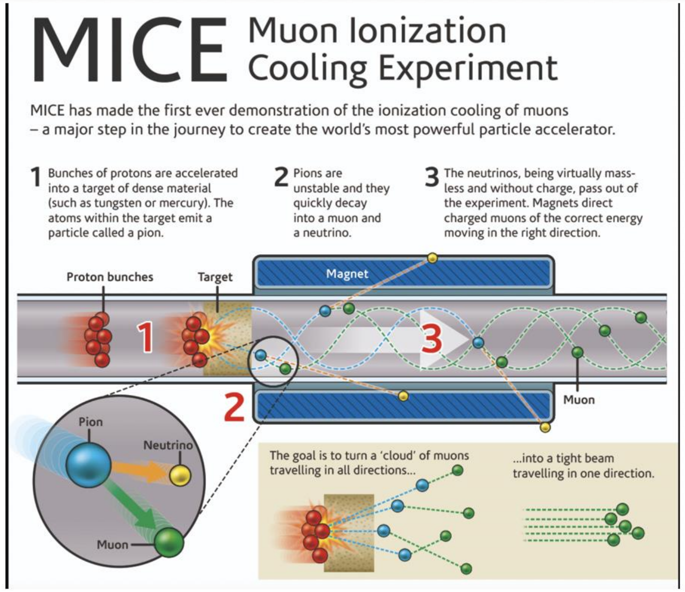
Article | Open Access | Published: 05 February 2020

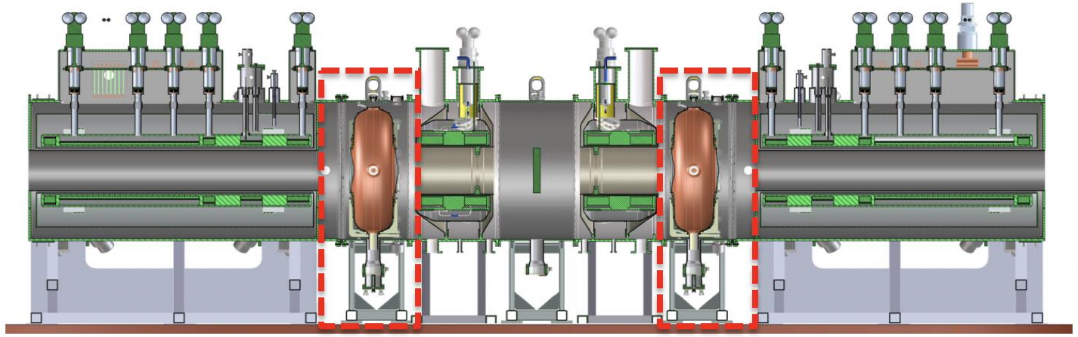
Demonstration of cooling by the Muon Ionization Cooling Experiment

The MICE collaboration

Department of Atomic Physics, St. Kliment Ohridski University of Sofia, Sofia, Bulgaria
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
Sichuan University, China
Sezione INFN Milano Bicocca, Dipartimento di Fisica G. Occhialini, Milano, Italy
Sezione INFN Napoli and Dipartimento di Fisica, Università Federico II, Complesso Universitario di Monte S. Angelo, Napoli, Italy
Sezione INFN Pavia and Dipartimento di Fisica, Pavia, Italy
Sezione INFN Roma Tre e Dipartimento di Fisica, Roma, Italy
UNIST, Ulsan, Korea
Nikhef, Amsterdam, The Netherlands
Institute of Physics, University of Belgrade, Serbia
University of Novi Sad, Dr Zorana Đinđića 1, 21000 Novi Sad, Serbia
CERN, Geneva, Switzerland
DPNC, Section de Physique, Université de Genève, Geneva, Switzerland
Brunel University, Uxbridge, UK
STFC Daresbury Laboratory, Daresbury, Cheshire, UK
School of Physics and Astronomy, Kelvin Building, The University of Glasgow, Glasgow, UK
Department of Physics, Blackett Laboratory, Imperial College London, London, UK
Department of Physics, University of Liverpool, Liverpool, UK
Department of Physics, University of Oxford, Denys Wilkinson Building, Oxford, UK
STFC Rutherford Appleton Laboratory, Harwell Oxford, Didcot, UK
Department of Physics and Astronomy, University of Sheffield, Sheffield, UK
Department of Physics, University of Strathclyde, Glasgow, UK
Department of Physics, University of Warwick, Coventry, UK
Brookhaven National Laboratory, NY, USA
Fermilab, Batavia, IL, USA
Illinois Institute of Technology, Chicago, IL, USA
Department of Physics and Astronomy, University of Iowa, Iowa City, IA, USA
Lawrence Berkeley National Laboratory, Berkeley, CA, USA
University of Mississippi, Oxford, MS, USA
University of California, Riverside, CA, USA







The RF module has never been used in MICE, unfortunately

Summary of IMC RF systems

https://www.dropbox.com/s/2e71dj9bzomglwm/MC_RF%20Summary%20Draft.xlsx?dl=0

System			Driver			Front-End	Cooling			Acceleration			Collider	TOTAL	CLIC
Sub-system			Driver Linac H- (SPL like)		Accum &Comp	Capture& Bunching	Initial	6D (2 lines)	Final (2 lines)	Injector Linac	RLAs (2stages)	RCS (3stages)	Ring	IMC	Acceleration
Reference expert			F.Gerigk		?	D.Neuffer	C.Rogers	D.Stratakis	C.Rogers	A.Bogacz		S.Berg	E.Gianfelice		
	Energy	GeV/c	0.16	5	5	0.255	0.255	0.255	0.255	1.25	62.5	1500	1500		1500
Beam (system exit)	# bunches (μ+ or μ-)	#	40 mA		1	12	12	1	1	1	1	1	1		312
	Charge/bunch	E12			500	3.57	2.56	7.21	4.39	3.73	3.17	2.22	2.20		3.72E-03
	Rep Freq	Hz	5	5	5	5	5	5	5	5	5	5	5		50
	Norm Transv Emitt	rad-m				1.5E-02	3.0E-03	8.3E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05	2.5E-05		660/20E-06
	Beam dimens. (H/V) in RF	mm	?	?	?	?	?	?	?	?	?	?	?		1?
	Norm Long Emitt	rad-m				4.5E-02	2.4E-02	1.8E-03	7.0E-03	7.0E-03	7.0E-03	7.0E-03	7.0E-03		
	Pulse/Bunch length	m	2.2 ms		0.6 (2ns)	1.1E+01	1.1E+01	9.2E-02	9.2E-02	4.6E-02	2.3E-02	2.3E-02	5.0E-03		4.4E-05
	Power (μ+ and μ-)	W	6.40E+04	2.2E+06	2.0E+06	1.8E+04	1.3E+04	3.0E+03	1.8E+03	7.6E+03	3.2E+05	5.4E+06	5.3E+06		2.8E+07
	Technology		NC Linac4	SC	SC	NC	NC	NC Vacuum	NC	SC	SC	SC	SC		NC High Grad
	Number of cavities	#	23	244	2	120	367	7182	32	52	360	2694	?	11076	149000
	RF length	m	46	237	1	30	105	1274	151	82	1364	2802	?	6092	30000
	Frf	MHz	352	704	44	326to493	325	325-650	20-325	325	650-1300	1300	800	4 to 1300	12000
RF cavities	Grf	MV/m	1-3.7	19 - 25	2	20	20 to 25	19-28.5	7.2-25.5	20	25 to 38	35	?	1 to 38	100
	Aperture	mm	28	80		?	?	?	?	300	150	75	120	28 to 300	2.75
	Magnetic Field	T	0	0		2	3T	1.7-9.6	1.5-4	0	0	0	0	0 to 9.6	0
	Installed RF field	MV	169	5700	4	434	2618	30447	1836	1640	50844	98062	250	1.92E+05	3.00E+06
	Beam Energy gain	MeV	160	4840	0	0	0	0	0	1250	62500	1437000	0	1.51E+06	1.50E+06
	Recirculations	#	1	1		1	1	1	1	1	4.5 to 5	13 to 23	1000	1 to 1000	1
	RF Power/pulse (η=0.6)	MW	25	220	3.E-01	99	429	1172	43	52	360	2024	1.98E-02	4425	1.2E+07
	Technology		klystron	klystron						Klytron-IOT					Two Beam
	Cavities/Power Source	#	23	244		4				1 to 2	1 to 2				2
RF power sources	RF Pulse (fill+beam) estim.	ms	2.20	2.20	3.20	0.10	0.10	0.10	0.10	0.03	0.06	0.73	14.80		0.142
	Prf/Power Source	MW	11.7	1.93						1	1				15
	Total Power Sources	#	17	244		30				52	341			?	1638
	Installed Peak RF Power	MW	34	275		164	515	1407	52	52	341	2429	2.38E-02	5269	2.46E+04
	Average RF power (η=0.6)	MW	0.27	2.13	0.01	0.05	0.21	0.59	0.02	0.01	0.11	14.88	0.00	18.28	143
	Wall plug power (η=0.6)	MW	0.45	3.55	0.01	0.08	0.36	0.98	0.04	0.01	0.18	24.81	0.00	30.46	289

NRF system parameters and challenges

International MUON Collider Collaboration

High gradient NRF cavities are required for muon cooling, and complex **normal conducting RF (NRF)** system, and many of the cavities need to be independently powered and controlled at many different frequencies in the ranges from 20 to 650 MHz. Majority of the cavities operate at two main frequencies: 325 and 650 MHz at high gradients in a strong magnetic field at multi-Tesla magnitude.

- **Low frequency (large cavity):** **325 - 650 MHz,**
- **High gradient:** **25 - 30 MV/m,**
- **Strong magnetic field:** **5 - 10 T**
- **High peak current before bunch merge:** 3.6E12 μ @325MHz => **187 A**
- **Large bunch charge after bunch merge:** 7.3E12 μ => **1168nC**
- **Large beam aperture/window:**
- **High level of beam losses and decay radiation**
- **Technology is far from being mature**. The closest example is a positron capture RF cavity: high frequency, high gradient, but not in so strong magnetic field.

Critical issues and R&D on NRF

- **Gap** between **performance** of the prototype and the test cavities achieved so far must be closed. Based on the nominal parameters from the Muon Cooling WG: frequency, gradient, B-field, aperture and on the existing (and future) test results, design, build and test prototype cavities for the muon cooling test facility.

- **Achievable high gradient** in a **strong magnetic field** requires continuous R&D on: alternative materials, gas versus vacuum, operation temperatures, pulse shapes and other new ideas. This requires a dedicated test stand on a time scale before the muon cooling test facility.

- **RF power source**: Existing commercial RF power sources are by design operate at lower peak power but higher average power than what is needed for muon collider. This is driven by current applications. A new design of the RF power source targeting muon collider parameters (higher peak power, lower duty factor) and high efficiency must be pursuit.

- **Engineering design and integration:** RF, SC magnet, cryogenics, etc.

- Safety, maintenance and etc. associated with using Beryllium materials on cavity walls and beam windows.

- **Collective effects**: beam loading, single and multi-bunch must be addressed.

NRF WP1: Baseline design of the RF system for Muon cooling complex. Design study for BDR

International MUON Collider Collaboration

	1	2	3	4	5	input	output
1. Collect consistent set of specification parameters for the design of **all** RF cavities for the muon cooling complex: frequency, gradient, length, B-field, aperture, …						MC	
2. Based on available knowledge, identify best concept for achievable accelerating gradient in magnetic field: material, pulse shape, temperature, gas, …							
3. Design few reference cavities which can be used to estimate parameters of all cavities specified in 1. Make a consistent set of parameters of **all** RF cavities and associated RF system							PPC
4. Integration RF cavities into cooling cell adapting design if necessary						MC,MG ,CR, …	MC
5. Calculation of cavity parameters for simulation and mitigation of collective effects including beam loading						MC, BD	MC, BD

NRF WP2: Conceptual design of the RF system for Muon Cooling Test Facility. Design study for MCRF CDR

	1	2	3	4	5	input	output
1. Collect consistent set of specifications for the design of RF cavity(es) for the MCTF: frequency, gradient, length, B-field, aperture, …						MC	
2. Design the cavities specified in 1 using the concept identified in WP1.2							TF
3. Design of the associated RF system for the MCTF							TF
4. Integration of the RF cavity into the MCTF cooling cell(s) including SC solenoid, cryogenics, diagnostics and etc.						MC,MG ,CR,…	TF
5. Engineering design of the cavity in its environment including cooling, thermal and mechanical stability, alignment, RF diagnostic and tuning, …							
6. Design of RF test stand for validating performance of RF cavities before installation in MCTF						MC,MG ,CR,TF…	TF

NRF WP3: R&D on high gradient in a strong magnetic field and potential test cavities

International MUON Collider Collaboration

	1	2	3	4	5	input	output
1. Identify infrastructure available for potential use as (or setting up) a test stand for testing RF cavities in strong magnetic field: RF power source, SC solenoid,…							
2. Design and build RF test stand based on available infrastructure, including diagnostics, vacuum and magnetic shielding and specified requirements							
3. Propose test program adapted to potential test setup, considering possible limitations in terms of available frequency, power, magnetic field strength and size of the cavity							
4. Design and build test cavities							
5. Test the test cavities							RF

NRF WP4: RF power sources for muon cooling RF system. Design study + synergy

International MUON Collider Collaboration

	1	2	3	4	5	input	output
1. Based on the parameters of RF cavities set target specifications for the RF power sources for Muon cooling complex						MC	
2. Address potential issues including: - Large number of different frequency, - Higher peak power requirements than currently available - High efficiency							
3. Baseline Design of RF power source(s) to provide information on the peak power capability, efficiency and cost							RF, PPC
4.							

NRF WP5: ?

International MUON Collider Collaboration

	1	2	3	4	5	input	output
1.							

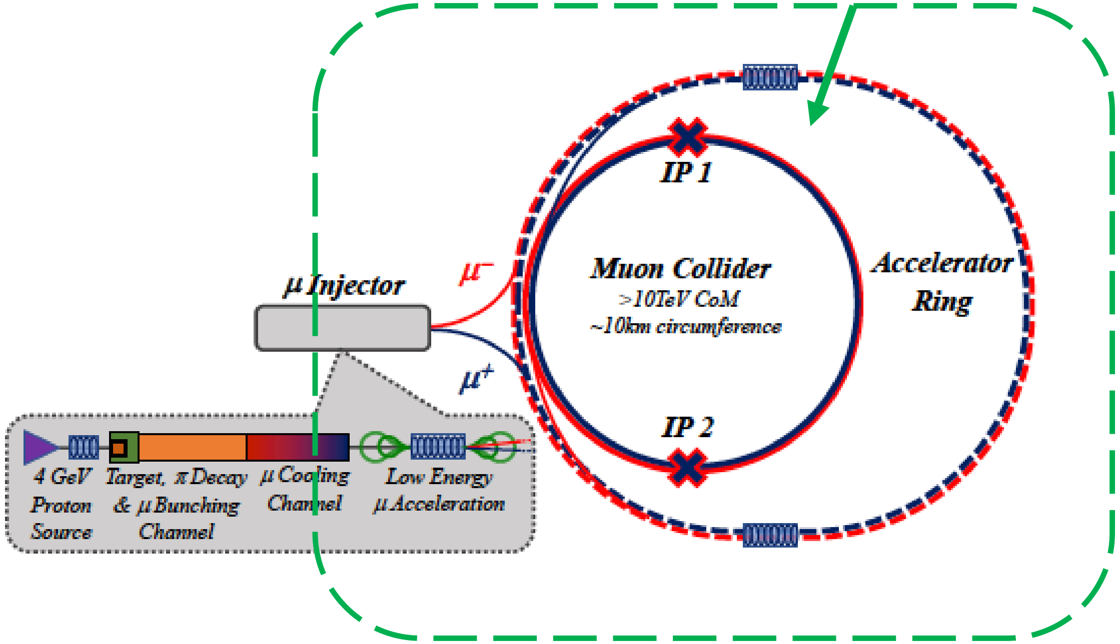
Appendix:

- General Guideline given by Daniel Shulte

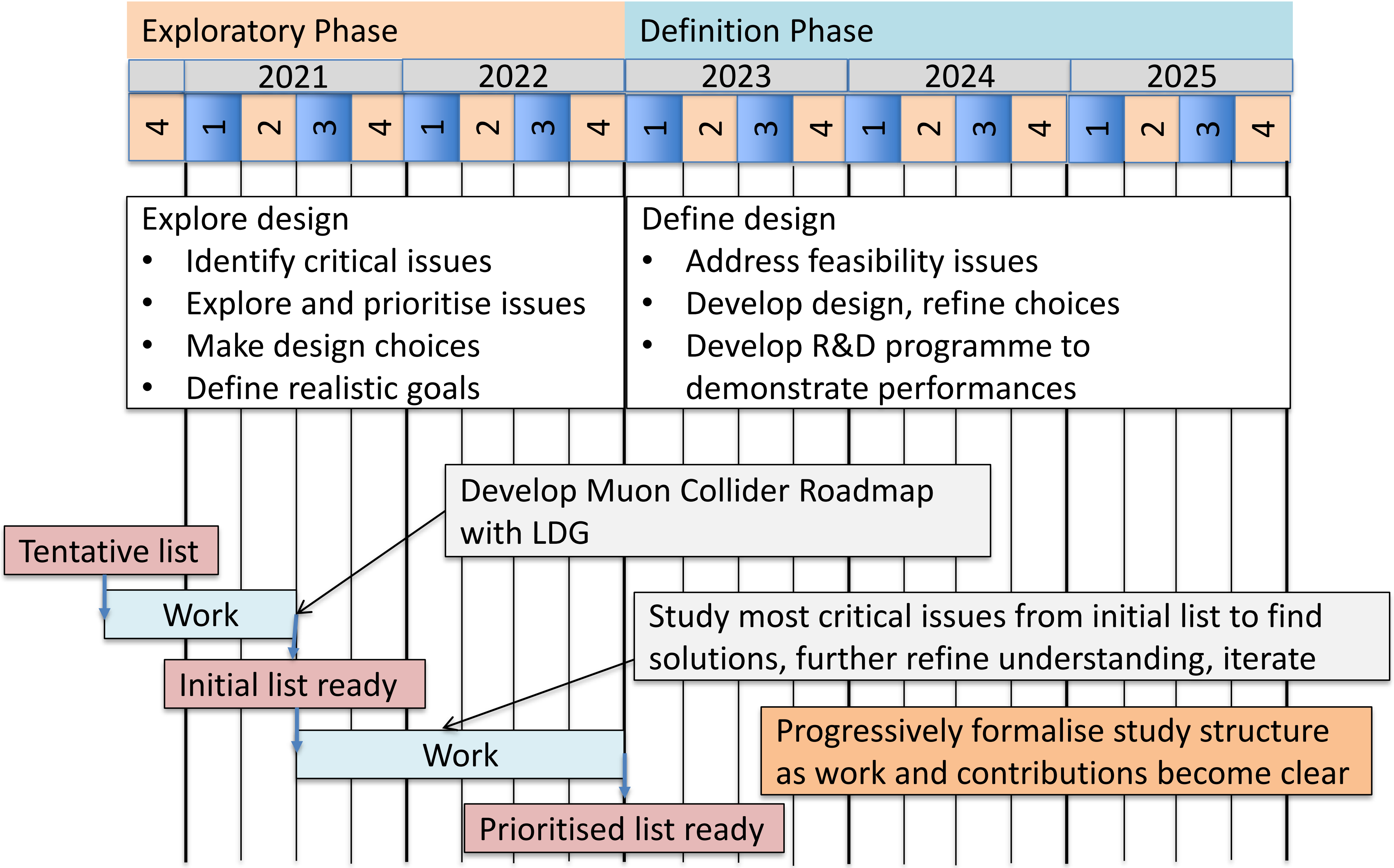
Proposed Workpackage Description

Super conducting RF (SRF) system for muon acceleration to high energy

- **SRF** system for **high efficiency** and **highest acceleration rate** to minimize the muon decay losses on **the way to** very high energies: **~10TeV**
- **Key Issues:**
  - High charge, short bunches,
  - **High efficiency** at **high gradient**
  - Manufacturing quality
  - Longitudinal and transverse stability



Timeline until next ESPPU



Proposed Workpackage Resources

A table of the initial estimated required resources in FTE years, specifying staff, post-doc and student. If possible, resources should be associated with the tasks.
This is only indicative to get over the shock of having to fill such tables.

Task	Staff [pm]	postdoc [pm]	student [pm]	Cash [kEUR]	Comment

Also a list of who is interested in participating to define the work and carry it out.
There is no commitment required.

Technically Limited Long-Term Timeline