Work Scenarios

D. Schulte for all of us

Overview

- Summary of the working group on parameters
  - muon collider motivation (cost, power and site)
  - timeline requirements
  - timeline limitations
  - roadmap scenarios

Conveners: J.P. Delahaye, Ph. Lebrun, M. Palmer, D. Schulte, M. Seidel, V. Shiltsev, J. Tang, A. Yamamoto

- Workplan consideration

- EU Design Study

The Muon Collider Benefits

- The muon collider can be cost effective
  - Vladimir Shiltsev's cost scaling model predicts it
  - Considerations on the facility scale indicate this
  - need to do a real study to confirm

- The muon collider can be power efficient
  - the luminosity per beam power increases with collider energy
  - need a more detailed study to confirm

- The muon collider can use a compact site
  - the 10 TeV collider would have a tunnel length between CLIC 3 TeV and FCC
  - could become even more compact with better ramping magnets

Cost Model (V. Shiltsev)

Future Colliders w.r.t. LHC

αβγ - Model

	Civil (km)	E_rf (TeV)	E_mag (TeV)	Site P (MW)	Cost* (LHCU)	Cost Reported
XFEL	3.3	0.017	0	15	0.25 ±0.1	1.7 BEUR
LHC* (green field)	27_{+28}	0	14.5	230	1.4 ±0.4	13-15 B?
LHC project	0_{+6}	0	14	120	**1.00**	8-10 B?
ILC-Higgs	21_{+3}	0.25	0	129	0.9 ±0.3	7 kOKU
CLIC - tt	11_{+6}	0.38	0	168	1.0 ±0.3	5.9 BCHF
CLIC-3	54_{+6}	3	0	580	2.9 ±0.9	18.9 BCHF
FCCee	100_{+20}	0.016	0.24	282	1.3 ±0.4	10.8 BCHF
FCChh*(no FCCee)	100_{+20}	0.01	100	580	3.4 ± 1.1	24 BCHF
FCChh after FCCee	0	0.01	100	580	2.8 ±0.9	17 BCHF
MC-HF	0.3_{+3}	0.02	0.13	200	0.6 ±0.2	?
MC-3	4.5_{+7}	0.06	3	230	1.2 ±0.3	?
MC-10 base	10_{+7}	0.07	10	310	1.5 ±0.5	?
MC-10 max M.P.	10_{+59}	0.13	10	310	1.8 ±0.5	?
MC-14* rcs-LHC tun	0	0.03	14	340	1.4 ±0.4	?

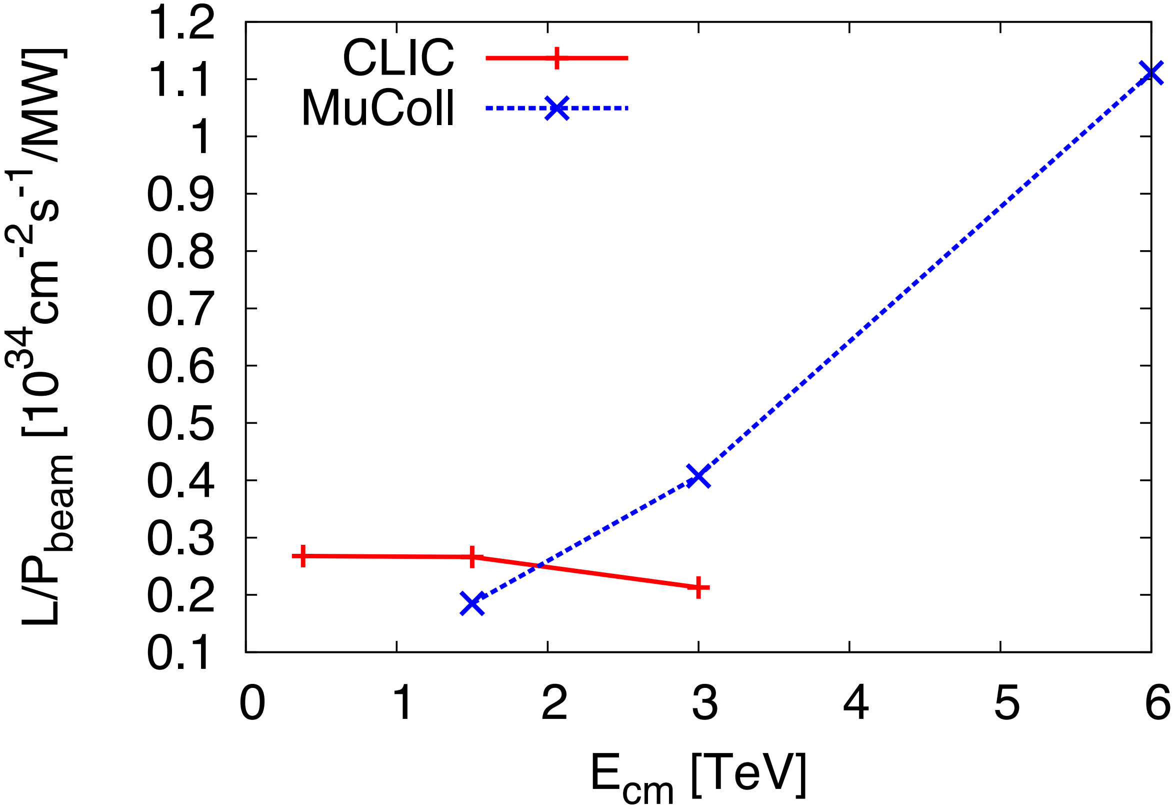
Comparing Luminosity in MAP vs. CLIC

In linear colliders luminosity per beam power is independent of collision energy for same technology

CLIC is at the limit of what one can do (decades of R&D)

No obvious way to improve

$$\mathcal{L} \propto \frac{N}{\sqrt{\beta_x \epsilon_x}} \frac{1}{\sqrt{\beta_y \epsilon_y}} P_{beam}$$



Luminosity per beam power increases with energy in muon collider

Muon colliders have the potential for high energies

$$\mathcal{L} \propto \gamma \langle B \rangle \sigma_\delta \frac{N_0}{\epsilon \epsilon_L} f_r N_0 \gamma$$

The Muon Collider Timeline

- Key input from CERN DG (based on EU strategy):

F. Gianotti at FCC week

International MUON Collider Collaboration

Remarks on a future collider at CERN

ESPP gives the preferred direction for future collider(s) at CERN: FCC

However, prudently:
- ❑ feasibility study first
- ❑ intensified accelerator R&D for FCC and to prepare alternative scenarios if FCC not pursued

No consensus in European community on which type of Higgs factory (linear or circular)

ILC:
- ❑ Strategy says it's compatible with ESPP if timely (otherwise conflict of resources with next collider at CERN)
- ❑ are ILC and FCC-ee complementary enough in terms of physics? No consensus.

Chinese colliders (CepC, SppC): "direct competition" with FCC

Desired timeline* for a future collider at CERN:
→ recommendation by next ESPP ~ 2026
→ approval by CERN's Council by end of the decade → construction's start early-2030's
→ operation's start mid 2040's.
Such a timeline is realistic for FCC-ee and CLIC, more difficult for FCC-hh (magnet technology, cost)

* A new facility running in the mid-2040's, i.e. within 10 years of end of HL-LHC, is crucial to retain (and expand) CERN's expertise and community → crucial for long-term survival of the field.

The Muon Collider Timeline

- Key input from CERN DG (based on EU strategy):
  - Prudently prepare alternative scenarios to FCC
  - No consensus that FCC-ee and ILC are complementary enough
- Can probably conclude: no consensus that CLIC 380 and CepC are complementary enough
- Three scenarios that require the muon collider to start operation in Europe before 2045
  - ILC is being constructed
  - CepC is being constructed
  - No higgs factory is being constructed before
- Need to have a muon collider option ready for operation before 2045

Staged Approach

- A 3 TeV collider has a physics potential comparable to CLIC at 3 TeV
- A 3 TeV muon collider option could be realised much faster than a 10 TeV option
  - It is cheaper
  - It is much more compact
  - It has a smaller power consumption
  - It can accept more compromises in technology performance
    - e.g. current 3 TeV collider ring magnets are comparable in performance to HL-LHC magnets
- A 10 TeV collider could then be realised using almost all infrastructure from 3 TeV
  - Except for the 4.5 km-long collider ring
- Need to support from physics that a staged approach is a good path

Resulting Work Load

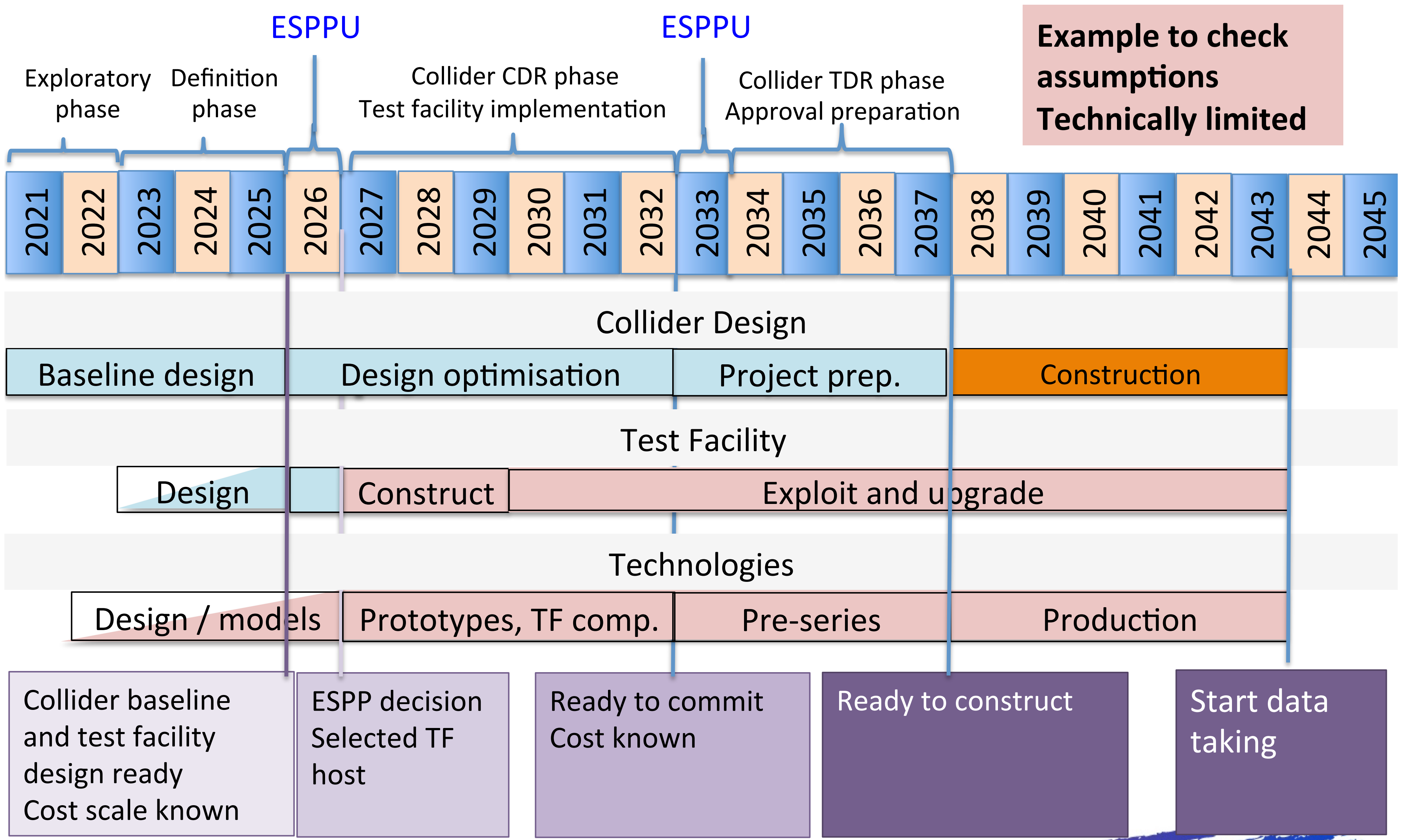
- The design of the 3 and 10 TeV collider options share all systems, except for the collider rings and the 1.5 to 5 TeV accelerator ring
  - Limited lattice design work
  - More work for MDI

- Some technology challenges are more important at 10 than at 3 TeV
  - higher dipoles fields in collider (O(15 T))
  - stronger final focus quadrupoles (O(18-20 T))
  - maybe more background in detector
  - shorter bunches in cavities of last accelerator ring
  - would like more performance accelerator ring systems to cut length and cost

- The total additional effort seems acceptable given the importance

Tentative Target for Long-Term Timeline

to asses when 3 TeV could be realised



What is on the Critical Path?

For the technologies we will adjust the performance of the collider to the availability of the technology

Charge from the first Community Meeting:

The working groups should propose realistic but ambitious targets for the performance goals of the different collider systems. In particular they 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.

Need this input still this year from the magnet and RF working groups

- It is obviously an educated guess
- But important to fix several of the tentative parameters
- We will not hold you responsible if the number changes as the work progresses
- A range from conservative to optimistic is also possible

Detailed Assessment based on MAP

Mark showed detailed analysis of maturity level for components and systems

Category	Sub-Category	Range Min	Range Max	Value	Description
Component Concept Maturity	**Component Feasibility**	1	5	1	Feasibility not yet demonstrated
				2	Feasibility assessment underway
				3	Indications of feasibility but further work required
				4	Detailed feasibility being evaluated through R&D and/or design studies
				5	Feasibility established
	Component R&D	1	5	1	Component R&D not started
				2	Component R&D underway OR similar components exist elsewhere
				3	Initial R&D complete but further R&D required OR similar components exist elsewhere
				4	Advanced component R&D underway if necessary
				5	Feasibility R&D complete or not needed (established concept)
	Component Conceptual Design	1	5	1	No Conceptual Design
				2	Preliminary conceptual design underway
				3	Preliminary conceptual design complete
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MAP focused heavily in this area with a mandate to verify component feasibility

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Example: Proton complex assessment

			Component Concept Maturity			Component Engineering Maturity			System Concept Maturity			System Engineering Maturity		
MC Complex	**System**	**Component**	*Component Feasibility*	*Component R&D*	*Component Conceptual Design*	*Component Engineering Concept*	*Component Prototyping*	*Component Engineering Design*	*System Design Concept*	*System R&D*	*Sub-System Engineering Concepts*	*System Interface Specification*	*Sub-System Prototyping*	*Full System Engineering Design*
Proton Complex	***H⁻ Source***								3	3	3	3	3	1
	LINAC								3	3	3	3	3	1
	Acuumulator								3	3	3	3	3	1
		H- Stripping	3	3	3	4	3	2						
	Buncher/Compressor								3	3	2	3	3	1
		RF System	4	3	3	4	3	3						
	Transport to Target								3	3	2	3	2	1
		Multi-Beam Trombone	4	3	3	4	3	3						
		Target Delivery Quadrupole	3	2	2	3	1	1						

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Example: Muon cooling complex assessment

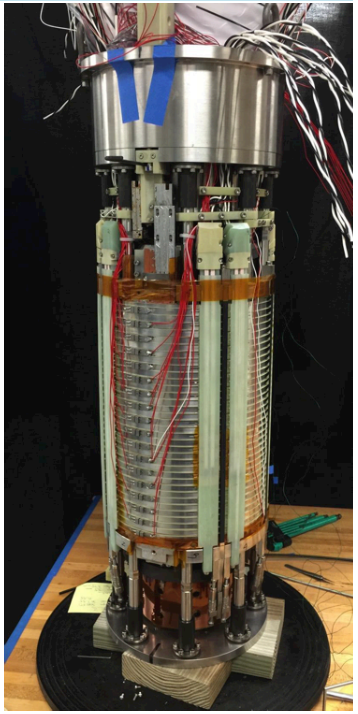
			Component Concept Maturity			Component Engineering Maturity			System Concept Maturity			System Engineering Maturity		
MC Complex	**System**	**Component**	*Component Feasibility*	*Component R&D*	*Component Conceptual Design*	*Component Engineering Concept*	*Component Prototyping*	*Component Engineering Design*	*System Design Concept*	*System R&D*	*Sub-System Engineering Concepts*	*System Interface Specification*	*Sub-System Prototyping*	*Full System Engineering Design*
Muon Cooling Complex	***Initial Cooling***								3	2	1	3	1	1
		RF in Magnetic Fields	4	3	2	2	1	1						
		Cooling Cell	3	3	2	2	1	1						
	Charge Separation								2	2	1	2	1	1
		RF in Magnetic Fields	4	3	2	2	1	1						
		Separator Magnets	3	2	2	2	1	1						
	6D Cooling - Stage 1								3	2	1	3	1	1
		RF in Magnetic Fields	4	3	2	2	1	1						
		Cooling Cell	3	2	2	2	1	1						
	Bunch Merge								3	2	1	3	1	1
	6D Cooling - Stage 2								3	2	1	3	1	1
		RF in Magnetic Fields	4	3	2	2	1	1						
		Cooling Cell	3	2	2	2	1	1						
	Final Coooling								3	2	1	3	1	1
		High Field Solenoids	4	3	2	2	1	1						
		Cooling Cell	3	2	2	2	1	1						
	Matching and Transfer								2	2	1	2	1	1

Technology Development

Some input from magnet group at this meeting

Magnets:

- Will profit from magnet Roadmap, in particular for HTS
- Fast-ramping magnets and powering is muon collider specific
  - should be possible on within 10-20 years
- For 3 TeV
  - Final cooling HTS solenoids are quite advanced
    - goal 45 T, 32 T demonstrated, 40 T planned
    - luminosity roughly proportional to field
  - Target solenoid is engineering challenge
    - can impact luminosity at some level, but mitigation options exist
  - Interaction region and collider arc magnets are quite mature
- At 10 TeV
  - Timescale depends on the HTS progress, will know more in 5 years
  - Have been warned to remain open for important progress



NHFML
32 T solenoid with HTS

Planned efforts to push even further

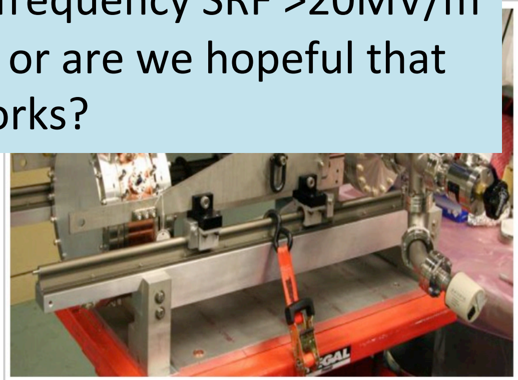
Tabea Arndt: In general, taking the fusion people as an example, I prefer to avoid a situation when the project plan is fixed and carved in stone (e.g. NbTi and Nb3Sn for the magnets and using old-fashioned and work-intense radial plate technology) while being passed by agile new private companies picking up new approaches (e.g. compact HTS magnets).

Technology Development

RF:

- Proof of principle of cooling RF in high magnetic exists for two options and reach more than the target gradient
  - Move from single demonstrations into practical cavities
- High energy superconducting RF needs to be developed based on existing technology

Do we need to demonstrate low frequency SRF >20MV/m now or are we hopeful that it works?



MuCool: >50 MV/m in 5 T

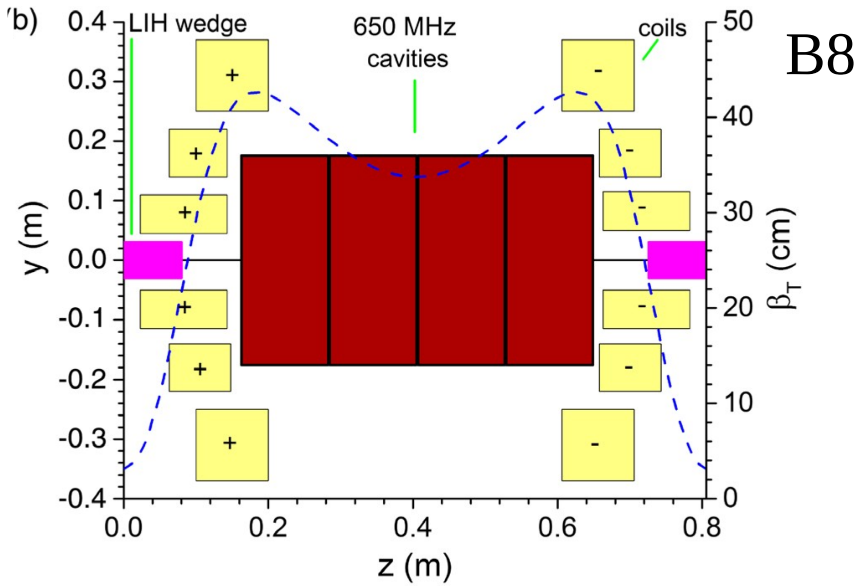
Target:
Studies of the shock by beam impact and of radiation
Some material test to improve shock resistance

Neutrino radiation mitigation:

- Need to design the system
  - Impact on magnet, cooling etc.
  - Impact on operation

Cooling cell design:

- Very involved engineering design required



All consistent with 10-20 years timescale

Roadmap Scenarios

- Prefer to provide scenario which fully achieves the timeline goal

- Can consider two reduced scenarios
  - One that leaves limited uncertainties in 2026 and limited delays of programme
  - One that leaves significant uncertainties in 2026 and substantial delays of the programme
- However, will not develop and volunteer this at this moment

- LDG will give some feedback

Workplan

What is Required in 5 Years?

- An end-to-end design
  - Covering all important systems
    - Defining the key performance specifications
- Evidence that the design can achieve luminosity goal
  - With tracking studies that show that this achieves the beam parameters
  - With studies of the key collective effects
  - With studies of the key tolerances
- Evidence that the design is realistic
  - Performance specifications supported by the technology teams
    - in particular RF and magnets
  - Studies supporting key hardware performance specifications
  - Studies of radiation protection as well as impact and mitigation of losses
  - Cost and power scale, site considerations
- A path forward
  - Test facility
  - Component development
  - Beam tests
  - System optimisation

Key Performance Drivers

Need to spell this out in items

High impact systems

- Neutrino flux mitigation system
- High-field magnets
- Fast ramping magnets and power systems
- Normal conducting cooling RF
- Superconducting RF
- RF power systems
- Target and dump
- Beam loss protection
- Vacuum, instrumentation, cryogenics and others also contribute

Drivers of functional specifications

- Radiation protection
- Machine detector interface
- Beam dynamics

Key Cost Drivers

Need to spell this out in items

High cost systems

- High-field magnets
- Fast ramping magnets and power systems
- Superconducting RF
- RF power systems
- Target and dump
- Civil engineering
- Others also contribute

Drivers of cost via specifications

- Beam dynamics
- Beam loss protection
- Radiation protection
- Normal conducting cooling RF

Key Power Drivers

Need to spell this out in items

Key power consumers

- High-field magnets
- Fast ramping magnets and power systems
- Superconducting RF
- Normal conducting RF
- RF power systems
- Others also contribute

Drivers of power via specifications

- Beam dynamics

Working Group Input

- Important progress since 1rst Community Meeting
- Excellent basis for the workplan
  - plenty of information from the working groups
- Will discuss this in more detail afterwards
- Need to make sure that other technologies are correctly considered
  - vacuum, instrumentation, cryogenics, …
  - for the collider and the test facility
  - current level at CERN is 0.1 FTE each
  - Philippe will have a look

Collider Design

Proton complex: potential partners are identified, need to make contact

International MUON Collider Collaboration

Very tentative and educated guess planning

- 2021-2022 :
  - Wrap-up of previous studies and performances of existing and future similar proton sources.
  - Define preferred rings schemes : w. or w/o acceleration in accumulator.
  - Identify studies with the BD work package to define possible energy intervals if any wrt to collective effects
  - Specify dedicated studies for FFA option wrt collective effects
  - Revise existing design of Linacs → needs to define final emittance (spot size on target)
- 2022 :
  - revision of state of the art of H^- sources and define best promising source technology
  - preliminary ring lattice design and target delivery system
  - conceptual design of recombination scheme —> revision of MAPS
  - FFA first lattice design
  - Improved studies of collective effects
- 2023:
  - Definition of the preferred energy range
  - Integration of linac and rings in real geometry
- 2024
  - conceptual design of proton complex

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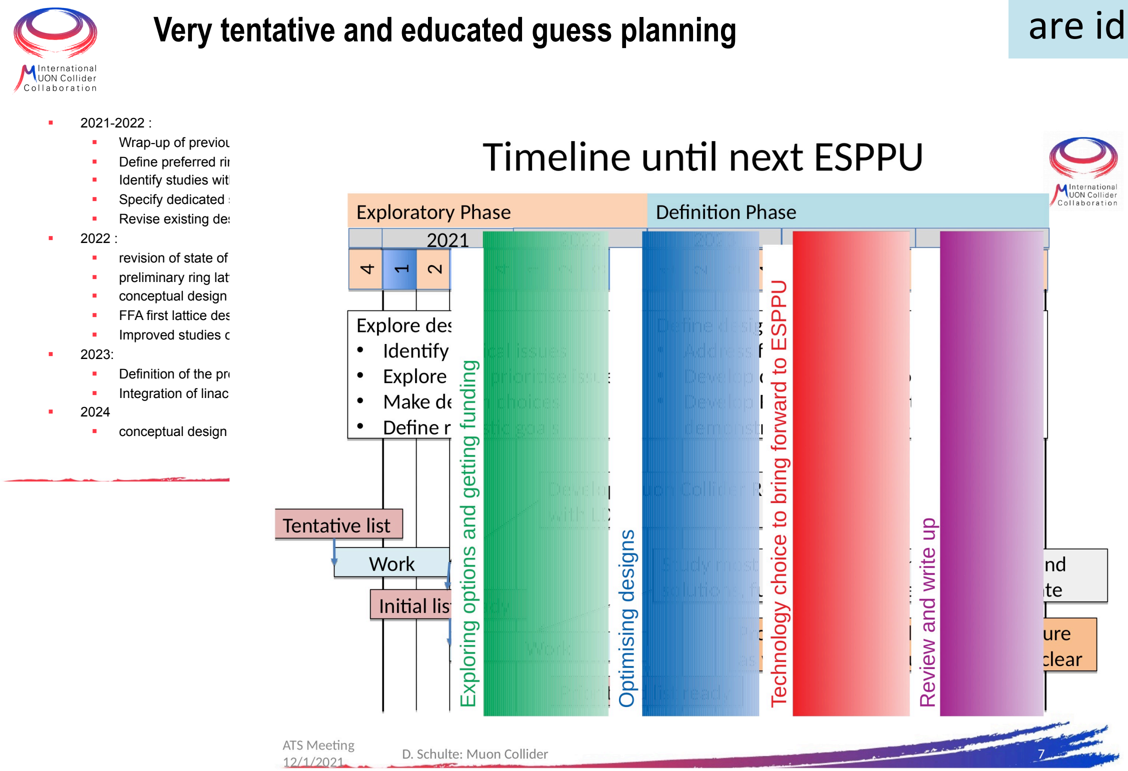
Collider Design

Proton complex: potential partners are identified, need to make contact

Muon Production and cooling: Needs are clear need to find partners (have some idea)



Collider Design

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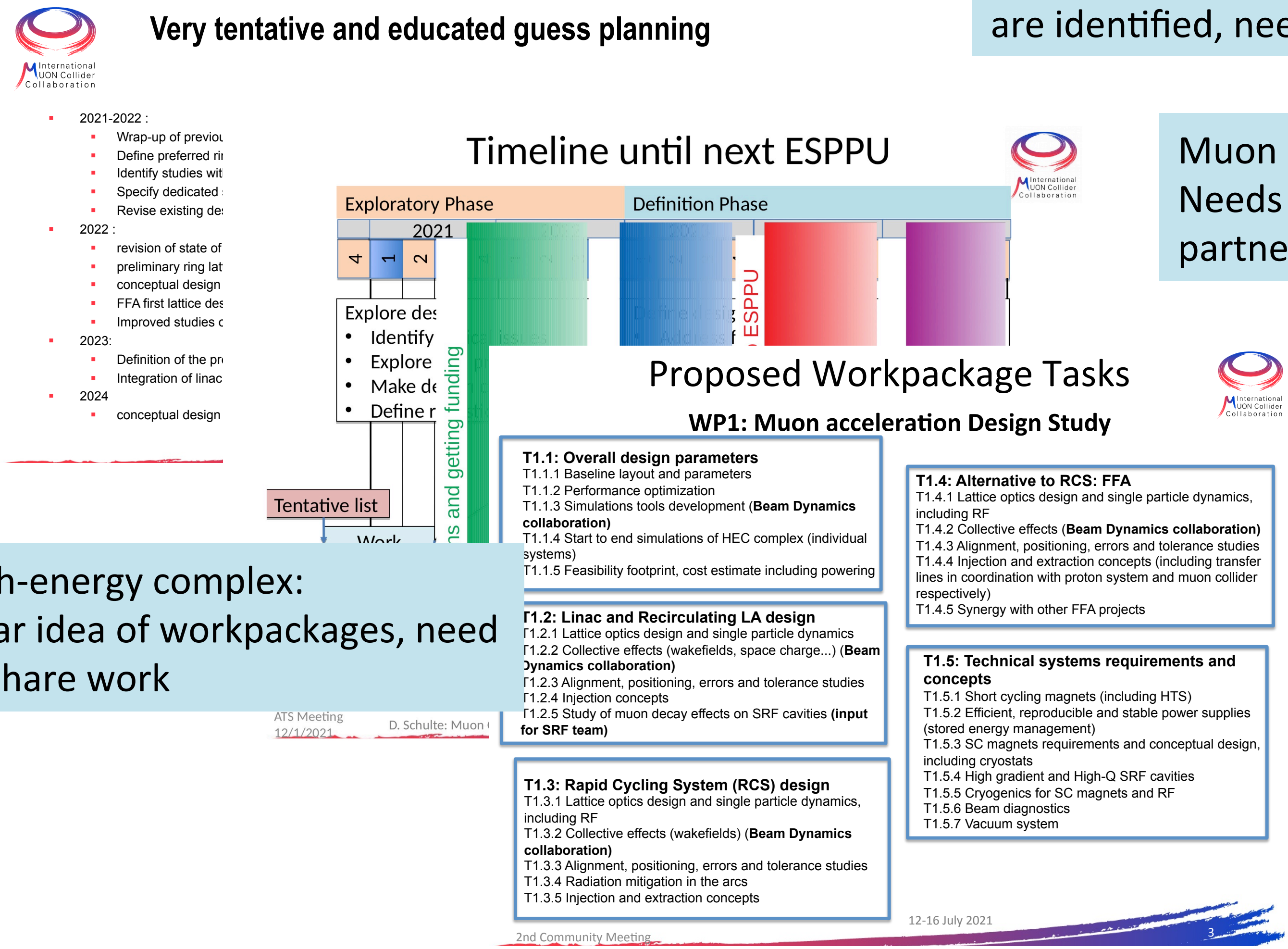
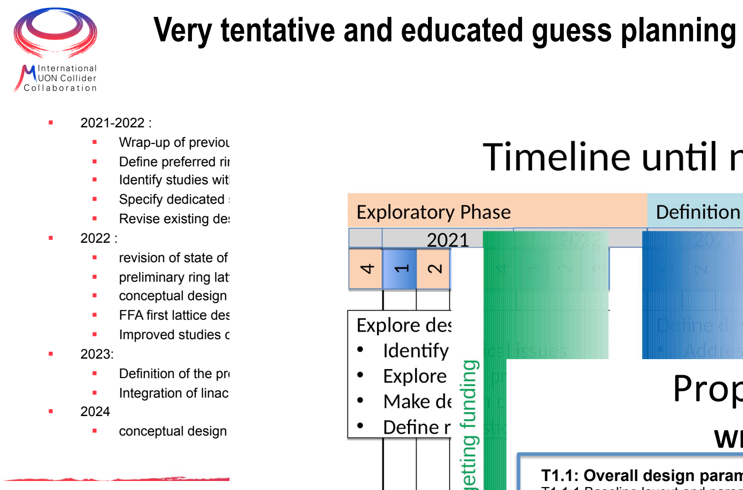
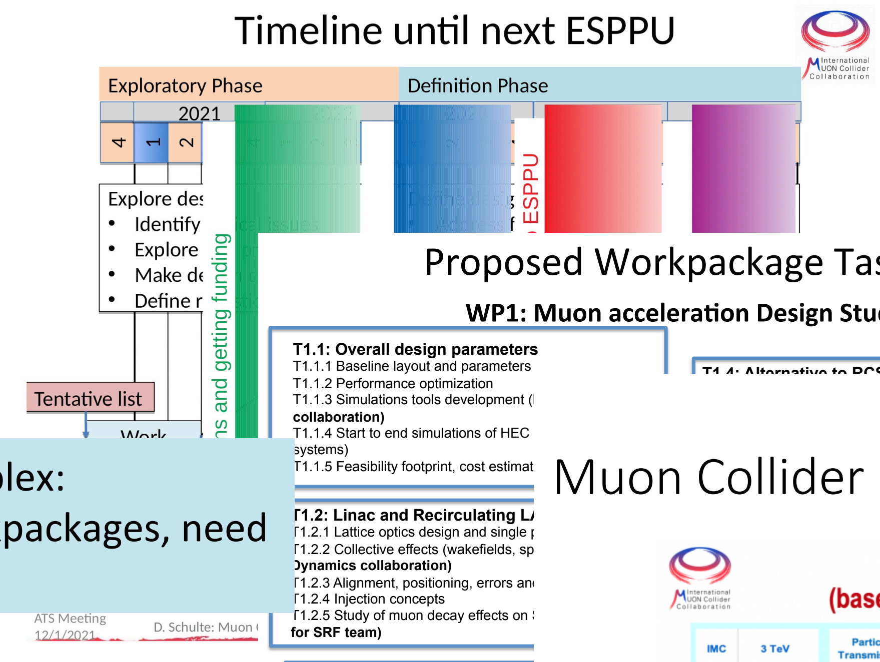


High-energy complex: Clear idea of workpackages, need to share work

Collider Design

Proton complex: potential partners are identified, need to make contact





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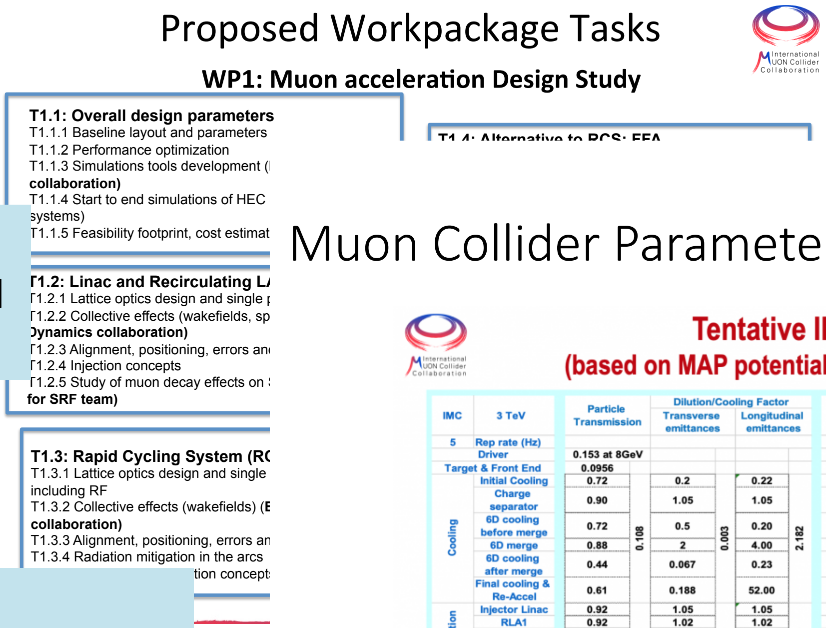

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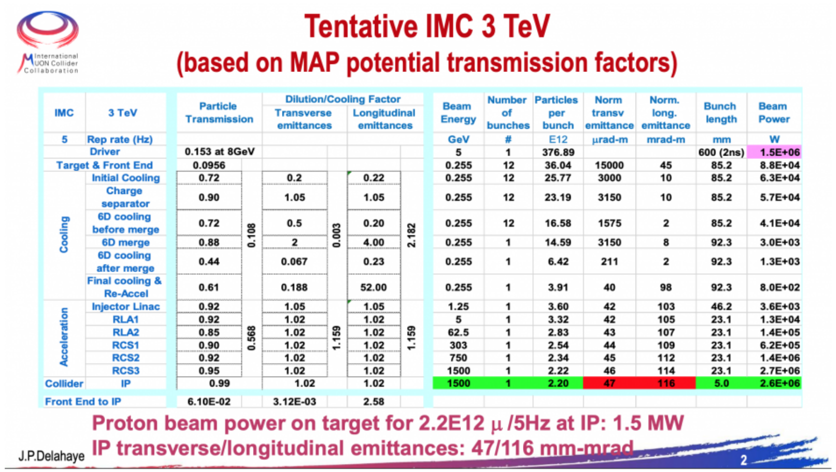
Muon Collider Parameters

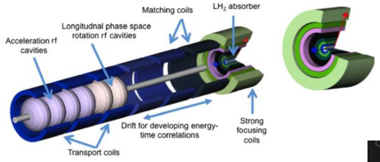


IMC	3 TeV	Particle Transmission		Dilution/Cooling Factor: Transverse emittances		Dilution/Cooling Factor: Longitudinal emittances		Beam Energy	Number of bunches	Particles per bunch	Norm transv emittance	Norm. long. emittance	Bunch length	Beam Power
								GeV	#	E12	µrad-m	mrad-m	mm	W
5	Rep rate (Hz)													
Driver		0.153 at 8GeV						5	1	376.89			600 (2ns)	1.5E+06
Target & Front End		0.0956						0.255	12	36.04	15000	45	85.2	8.8E+04
Cooling	Initial Cooling	0.72		0.2		0.22		0.255	12	25.77	3000	10	85.2	6.3E+04
Cooling	Charge separator	0.90		1.05		1.05		0.255	12	23.19	3150	10	85.2	5.7E+04
Cooling	6D cooling before merge	0.72		0.5		0.20		0.255	12	16.58	1575	2	85.2	4.1E+04
Cooling	6D merge	0.88	0.108	2	0.003	4.00	2.182	0.255	1	14.59	3150	8	92.3	3.0E+03
Cooling	6D cooling after merge	0.44		0.067		0.23		0.255	1	6.42	211	2	92.3	1.3E+03
Cooling	Final cooling & Re-Accel	0.61		0.188		52.00		0.255	1	3.91	40	98	92.3	8.0E+02
Acceleration	Injector Linac	0.92		1.05		1.05		1.25	1	3.60	42	103	46.2	3.6E+03
Acceleration	RLA1	0.92		1.02		1.02		5	1	3.32	42	105	23.1	1.3E+04
Acceleration	RLA2	0.85	0.568	1.02	1.159	1.02	1.159	62.5	1	2.83	43	107	23.1	1.4E+05
Acceleration	RCS1	0.90		1.02		1.02		303	1	2.54	44	109	23.1	6.2E+05
Acceleration	RCS2	0.92		1.02		1.02		750	1	2.34	45	112	23.1	1.4E+06
Acceleration	RCS3	0.95		1.02		1.02		1500	1	2.22	46	114	23.1	2.7E+06
Collider	IP	0.99		1.02		1.02		1500	1	2.20	47	116	5.0	2.6E+06
Front End to IP		6.10E-02		3.12E-03		2.58								

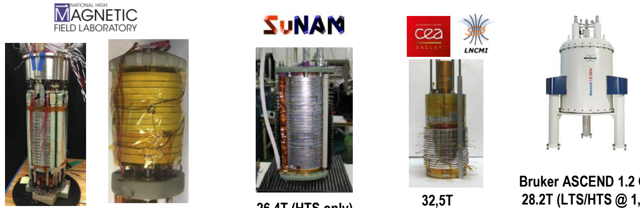
Beam dynamics: Clear idea of workpackages, need to find partners

Technologies

Cooling



- **Field target >30T, SC coil inner diameter of 50mm for the final cooling, as short as possible**
- **So far, achieved performances are still very far**



32T 17T HTS+ 15T LTS ID 40mm

45,5T 14,5T HTS+ 31T LTS ID 14mm

26,4T (HTS only) ID 35mm

32,5T 12,5T HTS+ 20T res. ID 50mm

Bruker ASCEND 1.2 GHz 28.2T (LTS/HTS @ 1,9K) 54 mm bore Strongest commercial NMR

- **For all projects, magnetic field is in the vertical direction, while we need horizontal magnets: mechanics is a big challenge**
- **Several demonstrators needed to address all the technical issues** (winding, joints, quench protection and detection of HTS magnets, radiation loads management, cooling management due to stagnant "Helium bubble")
- **Short term plan has to concentrate on realistic values (ID 50mm but only 15T to 20T or 30T but only ID 40mm to 45mm)**

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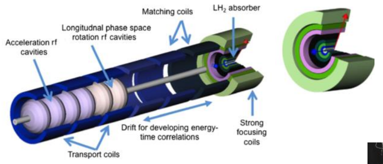
Magnets: First performance specifications but maybe based on conservative approach
Potential for collaboration will need to be explored

Technologies

Cooling



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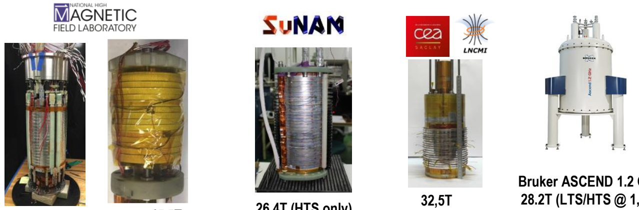

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RF: Detailed programme and partners are identified

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

	1	2	3	4	5	input	output
1. Collect specifications for the design of **all** RF cavities for the muon cooling complex: frequency, gradient, length, B-field, aperture (window size and thickness), …						MC	
2. Based on available knowledge both experimental and theoretical, identify best concept for achievable accelerating gradient in magnetic field: material, pulse shape, temperature, gas, …							
3. Calculate parameters of all cavities specified in 1. Provide a consistent set of parameters of **all** RF cavities and associated RF systems							PPC
4. Integration of RF cavities into cooling cell, adapting design if necessary						MC,MG ,CR, …	MC
5. Mitigation of collective effects including beam loading by design of RF cavities and RF systems						MC, BD	MC, BD

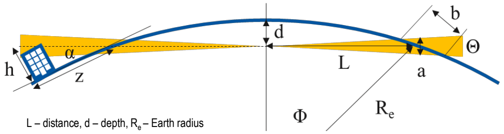
CEA, LBNL are interested

Radiation Protection and MDI

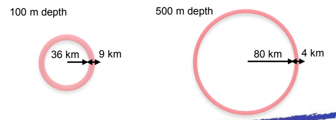
International MUON Collider Collaboration

Dose surface map

- Establish **surface map of dose**
- **Optimization** w.r.t. depth, orientation and inclination
- Investigation of different **site options**
- Evaluation of **uncertainties** of methodology (e.g. accuracy of terrain model) ➤ Sensitivity analysis
- Findings from simplified geometrical considerations (Earth as perfect sphere, no beam divergence, no collider inclination) for ν beam:
  - ν disk has a height (a) of ~1-2.5 m and traverses a region of width (b) of ~100-450 m
  - For dose additional spread of few m due to sec. particle shower
  - Exit angle of ν radiation is very small, wherefore **impacted area** can be of **several km** depending on height considered



E_{com} [TeV]	3	10	10	14	14
d (m)	100	200	300	400	500
L (km)	36	51	62	71	80
a (m)	2.5	1.1	1.3	1.1	1.2
b (m)	449	135	135	96	96



$L^2 = R_e^2 - (R_e - d)^2$
$\Theta \sim 1/\gamma$
$a \approx 2\Theta L$
$b \approx a/\Phi$, $\sin\Phi = L/R_e$

See also paper from Johnson, Rolandi and Silari, Radiological Hazard Due to Neutrinos from a Muon Collider, 1998

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Radiation protection:
Clear idea of RP work, need to consolidate other contributions (but in principle mostly clear)

Radiation Protection and MDI

International MUON Collider Collaboration

Dose surface map

International MUON Collider Collaboration

CERN

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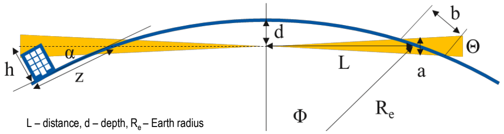

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a (m)					
b (m)					

100 m depth

See also paper from Johnson, Rolandi and Silari, Radiological Hazard Due to Neutrinos from a Muon Collider, 1998

Radiation protection:
Clear idea of RP work, need to consolidate other contributions (but in principle mostly clear)

MDI:
Clear idea of work and potential contributors

Requested Workpackage Resources

International MUON Collider Collaboration

A table of the initial estimated required resources in FTE years, specifying staff, post-doc and student.

Task	Staff [pm]	postdoc [pm]	student [pm]	Cash [kEUR]	Comment
MDI 3 TeV	0.5 FTE	1 FTE			- INFN 0.3 FTE Staff + 0.5 FTE postdoc (1Y) - CERN - LBL* - Fermilab*
MDI 10+ TeV	0.5 FTE	1 FTE			- CERN 0.2 FTE Staff + 0.5 FTE postdoc - INFN - LBL* - Fermilab*

* assuming support by Snowmass/P5
FTE are requested for 5 years.

Synergy and Test Facility

Next steps

- Clear synergies in high-power proton and muon development programmes in Asia
  - Conclusion as for the N/A and European contributions from last time
- Need further discussion to understand programmes by which to enhance scientific o/p with R&D work done in support of muon collider development
- nuSTORM-4-MUC test facility:
  - nuSTORM synergies as part of MUC test facility discussed last time
  - Pion yield in phase space of interest sufficient
    - Will now include in nuSTORM discussions

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Synergy: Need to see how to be use synergies for mutual benefit

Synergy and Test Facility

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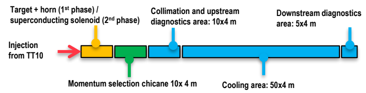
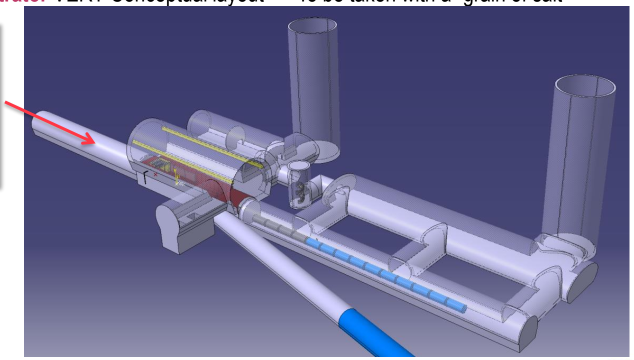
Synergy: Need to see how to be use synergies for mutual benefit

Conceptual layout



MUC Demonstrator VERY Conceptual layout → To be taken with a “grain of salt”

CERN TT10 branch



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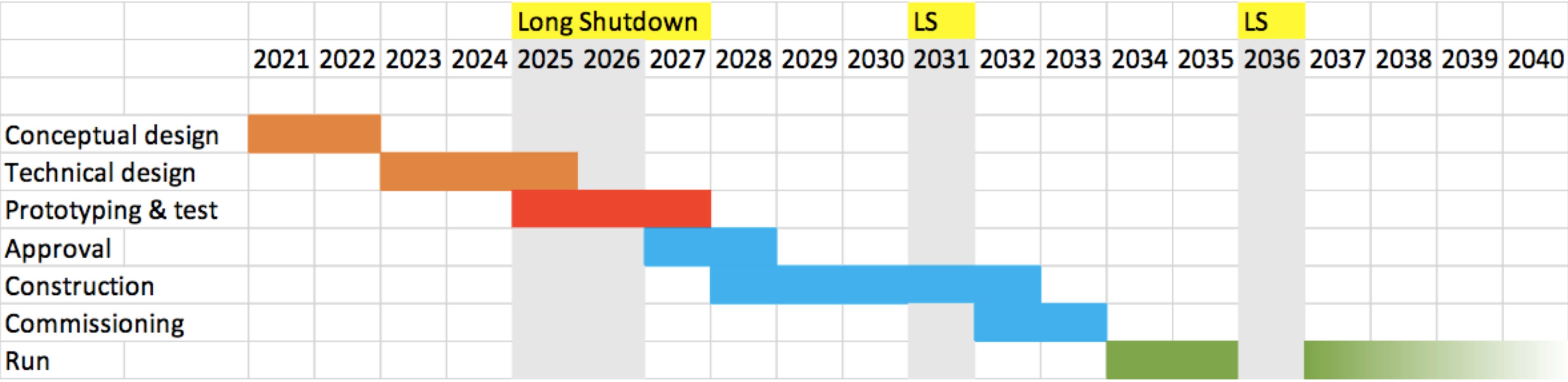
Test facility: Test at ESS and CERN discussed. Rapid progress on facility design.

Test Facility Timeline

In timeline have start of test facility operation in 2030

- Need civil engineering (cavern to connect test facility) in 2025, approval in 2023
- Or have break in injector operation in 2026 or 2027

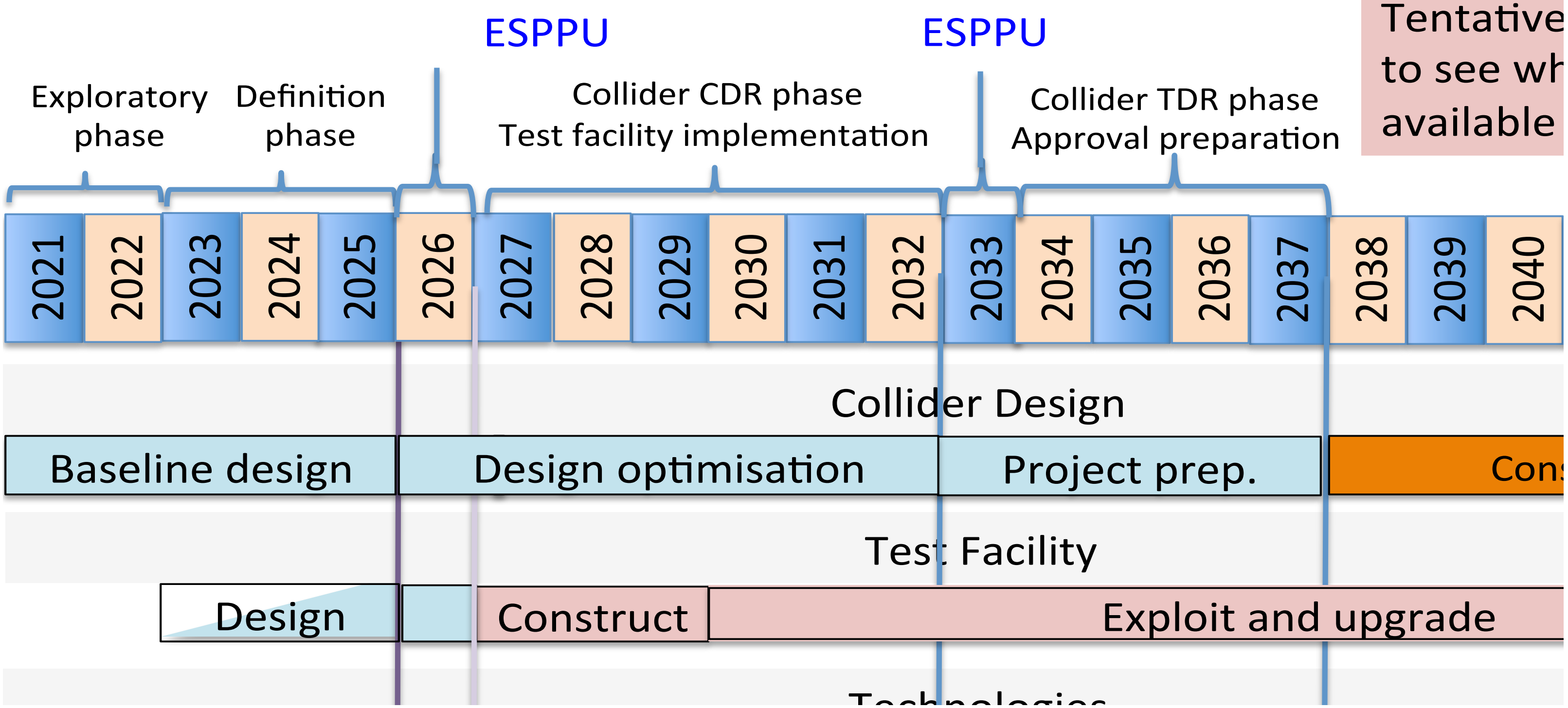
If we wait with civil engineering until after ESPPU, the test facility would be delayed by 3-4 years
In this case should delay test facility work to some degree

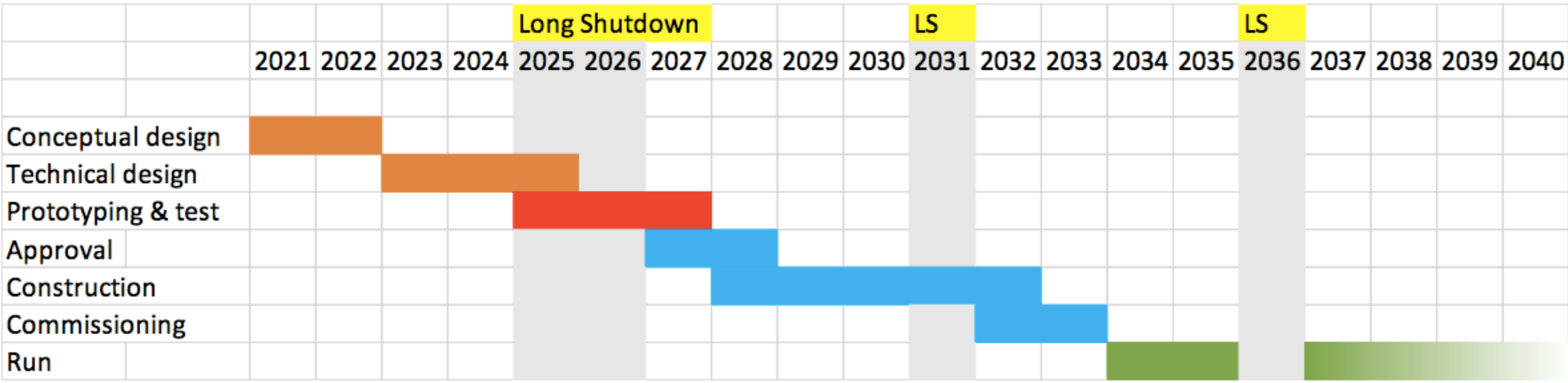


Need to understand which prototyping is required
Need to understand construction schedule (3 years in
Need to secure resources now

Need to highlight the potential delay to Roadmap

Test Facility Timeline





Baseline Development

Still need to define parameters for several interfaces

- e.g. between cooling and acceleration complex
- Will start from MAP parameters with some adjustments
  - some uncertainties, e.g. on final cooling emittance
- Will need input to the parameters:
  - Question: What is the budget for emittance dilution in the linacs?
  - Answer: What do your initial studies of emittance dilution indicate is a reasonable budget?

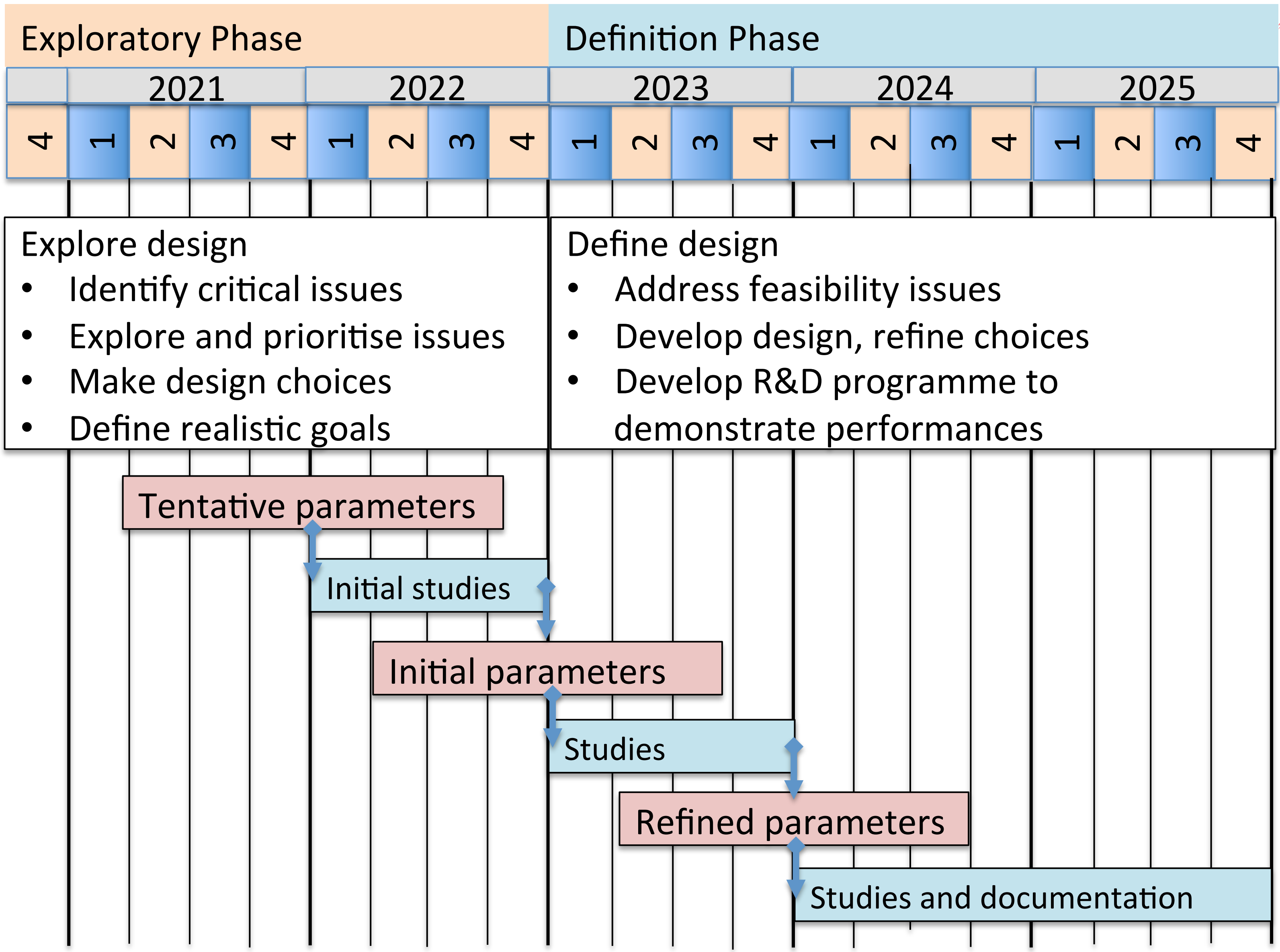
Need to fix some general performance specification parameters

- e.g. which gradient can be used in the superconducting cavities of the accelerator complex
- Need input from the magnet and RF working groups

Need to make a number of choices

- e.g. RCS or FFA or a mixture?
- Need some studies on both options before we can converge

Timeline until next ESPPU



Baseline Development

In 2021 define tentative parameters based on MAP and Roadmap

- Use these tentative parameters to start working
- Derive first feedback

Toward end of 2022

- Based on feedback propose initial baseline parameters
- Make choices where possible
  - but maintain useful alternatives

Toward end of 2023

- Adjust parameters to final baseline parameters
- Make final choices for baseline
- Maintain useful alternatives

Will need to be practical in making decisions

Need to have good, not fully optimised design

Decisions to be taken in form of some review

Tentative Project Breakdown Structure

Proton complex

- H- source
- Linac
- Accumulator
- Buncher
- Combiner

Muon generation complex

- Target system
- Decay channel
- Chicane, capture and buncher
- Dump

Muon cooling complex

- Initial cooling
- 1rst 6D cooling
- Merger system
- 2nd 6D cooling
- Final cooling
- Matching and transfer

High-energy acceleration

- Linac
- 1rst recirculating linac
- 2nd recirculating linac
- RCS 1 / FFA 1
- RCS 2/ FFA 2
- RCS 3 / FFA 3 ?
- RCS HE / FFA HE

Collider Ring

- Collider ring 3 TeV
- Collider ring 10 TeV

Note:
Transfer between systems should typically belong to the first system

- seems to make interface simpler

Tentative Work Breakdown Structure

Accelerator Design
- Proton complex
- Muon production
- Muon cooling
- High-energy acceleration complex
- Collider ring
- Machine detector interface

Implementation Studies
- Parameters and layout
- Integrated beam studies
- Radiation protection
- Civil engineering siting studies
- Cost scale determination
- Power consumption scale determination

Test Programme Development
- Integrated cooling cell design
- Neutrino radiation mitigation system
- Test facility using other workpackages
- Specific studies for test facility implementation: civil engineering, proton complex, …

Technology Design Studies
- Cooling RF design
- Superconducting RF
- Efficient RF power systems
- Fast ramping magnets and powering
- High-field solenoids
- High-field dipoles / combined function magnets
- Target system
- Beam-matter interaction
- Other technologies

Experimental Programme
- Fast-ramping magnet component tests
- Cooling RF tests
- Low-frequency superconducting cavity tests
- Target material tests
- Neutrino mitigation system tests

Ongoing Resource Estimate

WG	Staff [FTE]	postdoc [FTE 3 y.]	student [FTE 3 y.]	Cash [kEUR]	Comment
proton	3.7	5	7		
muon production		5			
muon cooling		6			
High-energy		5 ?			
MDI	1	2			
Beam dynamics		7			
RF					
Magnets					
Radiation protection	0.6	2			
Test facility					
CE		1			
Sum	5.3	32 +	7		
Estimated sum	?	O(50 +)	?		
CERN budget	3.5-5	10	5		

Improving the Resource Estimate

WG	Proton complex	Generation complex	Cooling complex	Accel. complex	Collider ring	Test facility	NC test stand etc
Integration							
Lattice design							
Tracking studies							
Collective effects							
SC solenoids							
SC magnets							
Fast-ramping magnets							
NC RF							
SC RF							
Beam-matter interaction							
Other technologies							
Radiation protection							
Civil engineering							

Matrix management approach to avoid double counting

Tasks for partners will be made in a practical way combining parts of the matrix
⇒ voice your wishes

EU Design Study

HORIZON-INFRA-2022-DEV-01-01: Research infrastructure concept development

Expected EU contribution: 1-3 MEUR
Total budget 21.8 MEUR
Type of Action: Research and Innovation Actions

<u>Expected Outcome:</u>
Projects are expected to contribute to all the following expected outcomes:

- sound science cases for new research infrastructures, including expected scientific breakthrough, gap analysis and feasibility/design studies to support planning and decision making at the national level (e.g. funding bodies, governments) and at European level (e.g. ESFRI);
- a better alignment of the development of the research infrastructure landscape with the advancement of excellent science and frontier research;
- new services and access opportunities available to the research community, allowing to better tackle scientific and societal challenges.

EU Design Study

Scope:

This topic aims at supporting the development of new concepts for the next generation of research infrastructures of European interest (A research infrastructure is of European interest when is able to attract users from EU or associated countries other than the country where the infrastructure is located.), single/multi sited, distributed or virtual, that none or few countries might individually be able to afford. All fields of research can be considered.

Major upgrades of existing infrastructures may also be considered if the end result is significantly transformative and equivalent to a new infrastructure concept.

Proposals for RI concept development will tackle all key questions concerning the technical and conceptual feasibility of new or upgraded fully fledged user facilities.

In this respect, proposals should address all following aspects:

- demonstrate relevance in relation to ERA, including to the existing landscape, and the advancement with respect to the state-of-art of the new infrastructure;
- highlight the research challenges the new research infrastructures will make possible to address, including at global level;
- indicate the gaps in the research infrastructure landscape the new infrastructure will cover and the synergies with existing infrastructures at European and global level, including those co-financed from other EU instruments (e.g.: Cohesion policy);
- indicate, when relevant, the potential impact of the new research infrastructure at regional level.

EU Design Study

Proposals should also provide evidence that the project will effectively:

- identify technologies and develop research infrastructure architecture (e.g. single site or distributed, ...);
- identify scientific user communities (and their related needs) that will benefit from access to RI services, including scientific data and instrumentation, and develop the planning of research services to users;
- identify governance options and strategic approaches for institutional/stakeholders' commitment and engagement;
- develop initial financial plans for the RI construction (or major upgrades) and operation as well as preliminary ideas for long-term sustainability, including synergies with other funds and programmes (e.g.: ERDF);
- develop plans for an efficient data curation and preservation and for the provision of access to data collected or produced by the future infrastructure, in line with the FAIR principles.

Proposals considering just a new component of a research infrastructure are not in scope of this topic.

When relevant, environmental (including climate-related) impacts as well as the optimisation of resource and energy use should be integrated in the concept development of new research infrastructures. In this topic the integration of the gender dimension (sex and gender analysis) in research and innovation content is not a mandatory requirement.

EU Design Study

In short:

Could hope to add up to 10 post docs to already existing resources

Submission in March 2022

Need to secure resources from interested partners

Non-EU partners can participate but not receive funding ("associated partner")

Potential Workpackage Structure

Proton complex

Muon production and cooling
- Muon production
- Muon cooling
- Accelerator radiation (target)
- Target system

High-energy complex
- Linacs
- RCS
- FFA
- Collider ring
- Accelerator radiation (collider ring)

Physics application and outreach
- Muon collider
- Synergies
- outreach (industry, education)

Magnets
- Fast-ramping magnet and powering system design
- High-field solenoids
- High-field dipoles / combined function magnets

RF
- Cooling RF design
- Superconducting RF
- Efficient RF power systems

Test programme development
- Integrated cooling cell design
- Test facility design
- Neutrino radiation mitigation system
- Application of other workpackages to test facility (should be the same people)
- Studies for test facility implementation: civil engineering, proton complex
- Other technologies

Management and project integration
- Radiation protection
- Beam dynamics
- Civil engineering

Conclusion

- Important progress in workplan
- Need to continue
- Prepare scenario for Roadmap and bid for EU
- Need to continue identifying the potential contributions
- The MoC is ready for signature
- Thanks to Chris and Elias, the Muon Beam Panel, the conveners and all of you