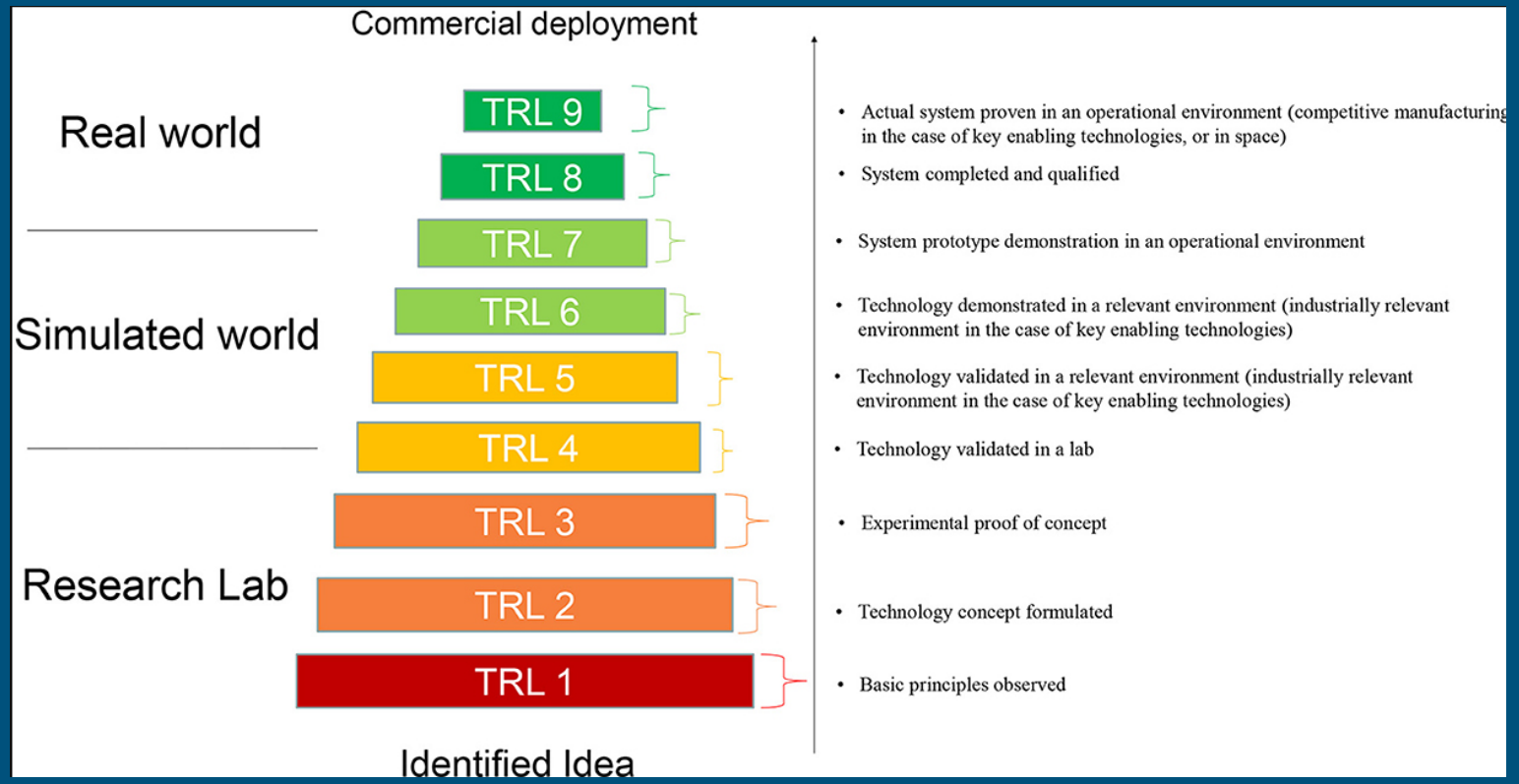
Risk Categories - I

Color	Meaning
	Technically feasible/ demonstrated, TRL7-9
	Concepts / solutions exist , TRL4-6
	Ideas exist / no solutions / path forward not clear, TRL1-3



Originally used by NASA to establish mission readiness for flight missions

Also from NASA, more explanations, and including SW

Technology Readiness Level Definitions

TRL	Definition	Hardware Description	Software Description	Exit Criteria
1	Basic principles observed and reported.	Scientific knowledge generated underpinning hardware technology concepts/applications.	Scientific knowledge generated underpinning basic properties of software architecture and mathematical formulation.	Peer reviewed publication of research underlying the proposed concept/application.
2	Technology concept and/or application formulated.	Invention begins, practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture.	Practical application is identified but is speculative, no experimental proof or detailed analysis is available to support the conjecture. Basic properties of algorithms, representations and concepts defined. Basic principles coded. Experiments performed with synthetic data.	Documented description of the application/concept that addresses feasibility and benefit.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Analytical studies place the technology in an appropriate context and laboratory demonstrations, modeling and simulation validate analytical prediction.	Development of limited functionality to validate critical properties and predictions using non-integrated software components.	Documented analytical/experi-mental results validating predictions of key parameters.
4	Component and/or breadboard validation in laboratory environment.	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments, and associated performance predictions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of relevant environment.
5	Component and/or breadboard validation in relevant environment.	A medium fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational environment performance predicted. Prototype implementations developed.	Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements.
6	System/sub-system model or prototype demonstration in an operational environment.	A high fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.
8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

Defining the key technical challenges per area – 2026-2036

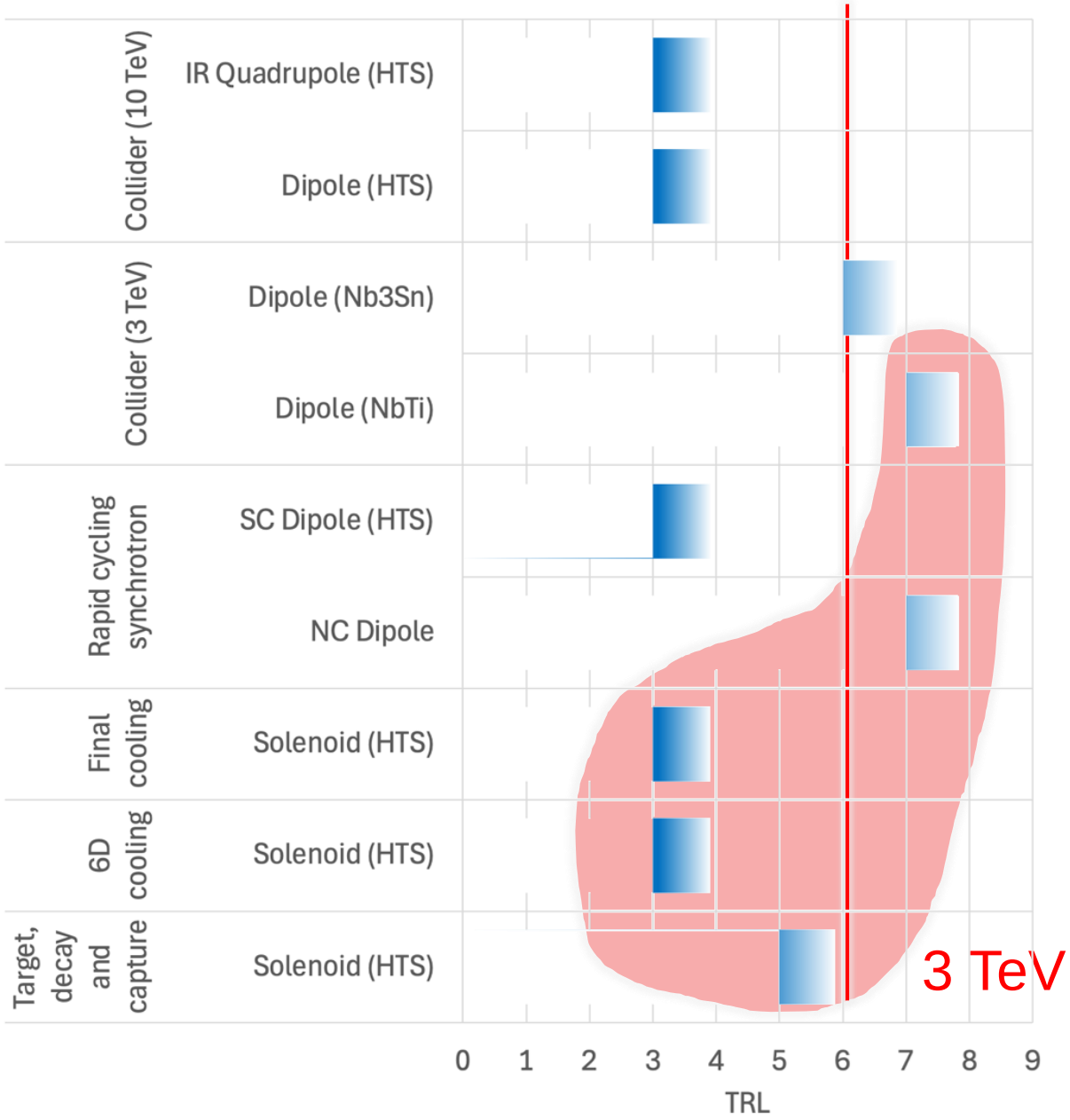
Accelerator area	Key challenges identified
Proton complex	-
Target	Solenoid Spent beam
Muon cooling	RF Magnets Absorbers
Initial linacs	-
RCS system	Pulsed magnets and power converters RF system
Collider ring	Collider ring magnets Neutrino flux/mover system
Accelerator Design	Luminosities and energy

Re-grouping challenges	TRL today	TRL goals 2036
Target solenoid (HTS)	5 (Luca)	6-7
Final cooling solenoid (HTS)	3 (Luca)	6-7
Cooling cell RF Cooling cell solenoid (HTS) Integrated in cell w/absorbers	5 3 or 4 (3 Luca) 4	6-7 for the three
Demonstrator	Relevant conditions for tests to reach TRL 7 for cooling HW, TDR by 2028-2030	
Pulsed magnets (NC) Integrated w/power converter SC magnets (HTS)*	7 (Luca)_ 4 3	7 6-7 6-7
Collider ring NbTi Collider ring Nb3Sn Collider ring (HTS)*	6-7 (Luca) 6 (Luca) 3 (Luca)	7 6-7 6-7
Acc. Design – S/E simulation, lattices** Acc. Design – Imperfections, Collective effects**	4 4	7-8 7

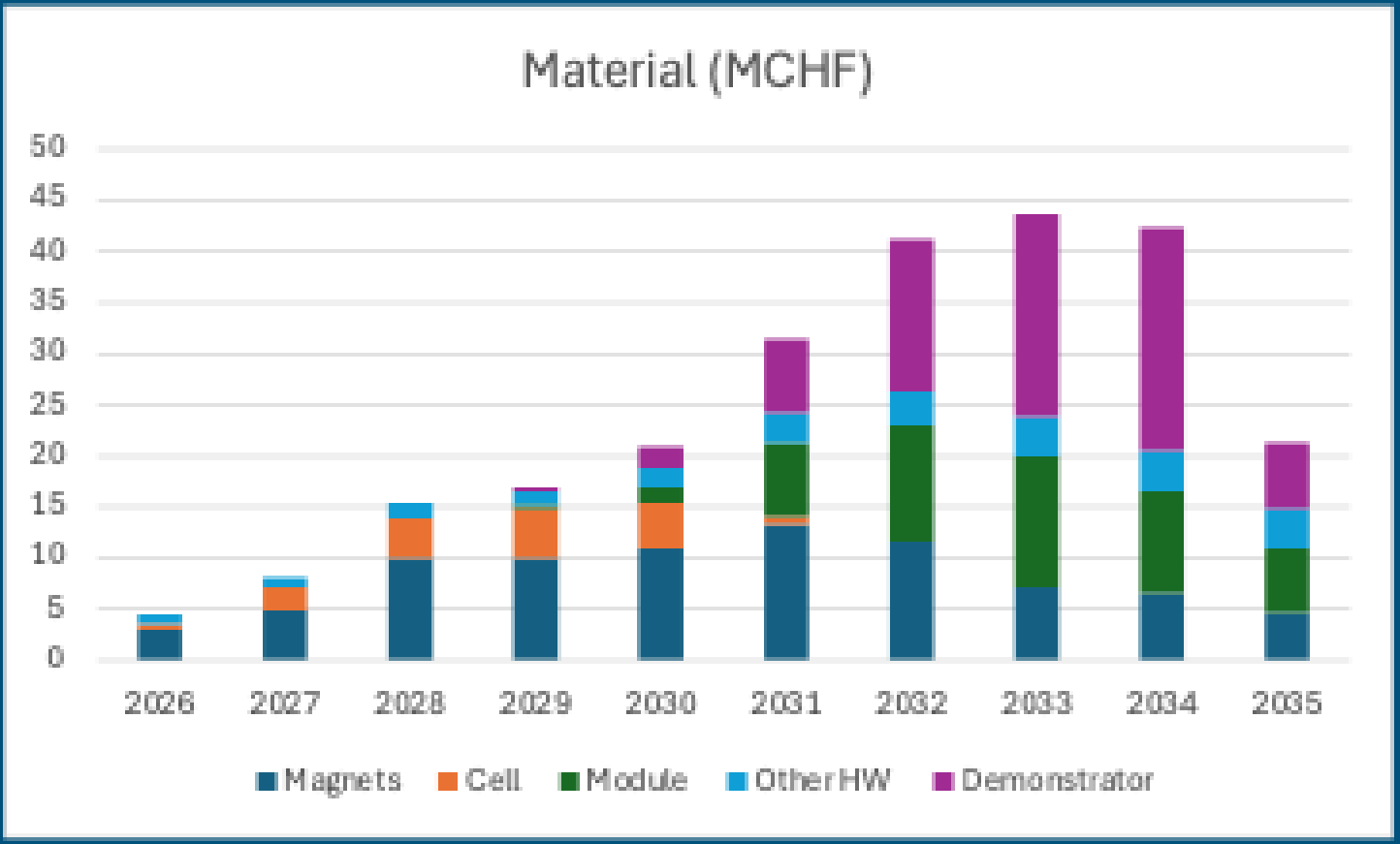
* Not needed for 3 TeV, ** To address performance (E/L), backgrounds, spent beam

TRL driven R&D

- The medium-term R&D proposal (10 years) aims at:
  - Increasing TRL of critical magnet systems to a level sufficient for a go/no-go decision (TRL 6)
  - Demonstrating engineering readiness of high-TRL magnets towards the first stage of the Muon Collider (3 TeV)



Resource summary - in works



- Material integrates to ~250 MCHF (see plot), main material items are the ones in the table of key technical challenges (Magnets, Cell+Module, Demonstrator)
- FTE integrated estimate at 1600-2000 FTEy (~250-300 MCHF)

Programme aims to:
- reach TRL 6 or more across the board by ~2036
- have complete design as needed for reliable cost, power, site layout, schedule, risk assessment, etc
- have implementation plan at specific site