Table 1. **Next Generation Requirements for the Frontier Capabilities**

	Secondary / tertiary beam requirements					Proton Beam Requirements *			
Particle beam	**Integrat-ed Flux**	**Purity**	**Energy**	**Spatial characteristics**	**Timing characteristics**	**Energy**	**Power**	**Timing Charact eristics**	**Comments**
Photons									
Convention-al Super beams:									
Muon neutrinos Kate		< 1% electron neutrinos	0.5-5.0 GeV	Pulsed-horn forward narrow beams	Duty factor < 10^{-3}	>~ 9 GeV?	>1MW	Duty factor < 10^{-3}	Classical super-beam technique for both short and long baselines.
Anti-Muon neutrinos Kate		< 5% electron neutrinos	0.5-5.0 GeV	Pulsed-horn forward narrow beams	Duty factor < 10^{-3}		>1MW	Duty factor < 10^{-3}	Classical super-beam technique for both short and long baselines.
Muon Storage Ring beams:		<1% Pions, protons, electrons	3 GeV	<~40 pi mm-mrad		>~9 GeV	0.3MW		Use Q method for pileup systematics, assumes lattice qcd will improve the theory calculation.
Muon neutrinos		< 1% electron neutrinos	1.0-5.0 GeV	Forward narrow beams (skew optics)		>3-5 GeV, < 15 GeV	>1MW	Duty factor < 10^{-3}	Neutrino factory beams for both short and long baselines.
Electron neutrinos		< 5% electron neutrinos	1.0-5.0 GeV	Forward narrow beams			>1MW	Duty factor < 10^{-3}	Neutrino factory beams for both short and long baselines.
Pion DAR neutrinos:									
Muon neutrinos			0-53 MeV, 30 MeV (anti)	Isotropic, point-source (10 m –~ 10 km)	Duty factor < 10^{-3}	< 3 GeV	>1MW	Duty factor < 10^{-3}	Proton duty factor applicable for near surface detectors, not needed for deep detector

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	Secondary / tertiary beam requirements					Proton Beam Requirements *			
Electron neutrinos			0-53 MeV	Isotropic, Point-source	Duty factor < 10^{-3}	< 3 GeV	>1MW	Duty factor < 10^{-3}	
Kaon DAR neutrinos:									
Muon neutrinos		< 1% electron neutrinos	235 MeV	Isotropic , point source	Duty factor < 10^{-3}	> 3 GeV	>1MW	Duty factor < 10^{-3}	
Positive Muons for CLFV (B. Bernstein)	10^{18}-10^{19}	>95%	29.8 MeV surface beam, could go lower	Polyethylene or similar stopping target	CW, microstructure > 500 MHz.	~1 GeV	1MW	As CW as possible	Scaling to x10 statistics over MEG at 1 GeV and 3e7 second live. Two experiments, so this much for each
Positive muons for EDMs (Yannis S.)	$5x10^{16}$		500 MeV		300 ns			High rep rate as possible, up to 50 kHz	
Positive muons for muonium osc. (B. Bernstein)	$1x10^{15}$		29.8 MeV surface beam, could go lower	Polyethylene or similar stopping target		1 GeV	1 kW	100 kHz	Scaling existing experiment for x100 in statistics and 5 muon lifetimes = 14,841; # of protons in old expt based on hep-ex 9807011 and private data from MEG, large uncertainty
Negative muons for CLFV (B. Bernstein)	10^{22}-10^{23}	>95%	As low as possible - 5-70 MeV/c	1-10cm transverse stopping on thin foils.	0.5-10 MHz of <10-100 nsec pulses.	1 GeV	1 MW		6 yr run based on Mu2e method; FFAG-based calculation immature

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Positive Kaons S. Kettel	10^{16}	>70% at stopping target	400-600 MeV/c	1-10cm transverse incident on stopping target.	CW, microstructure > 50 MHz.	3 GeV	100kW -1 MW		
Low energy Neutral Kaons **L. Littenberg**	10^{16}	$<10^{-4}$ neutrons per beam kaon outside of beam solid angle	300-1000 MeV/c	20-100 μSR neutral beam	20-50 MHz of <50 psec pulses	> 3 GeV			1.e-7 hadron halo requirement
High energy neutral Kaons	10^{16}	<10-4 neutrons per beam kaon outside of beam solid angle	1.5-15 GeV	5 μSR neutral beam	CW				
Cold Neutrons (Y. Kamyshkov)	$2.47\mathbf{x}10^{23}$ neutrons to the exp. Acceptance (2-3 year operation)	Minimal content of gammas, fast neutrons > 1 MeV, and charge particles in the beam	< 1 eV from initial moderator < 100 neV for UCN	Horizontal beam perpendicular to the proton beam; luminous source area dia 30 cm or area 710 cm^2; Focusing equipment access to the cold source starts from the	cold neutron flux: typical ~ 8.75 x 10^{12} $n/cm^2/s/sterad/MW$ CW cold beam, with usage duty factor 80-90% due to proton-beam-pulse-time suppression;	0.8-2.5 GeV kinetic (1.3 GeV is optimum)	> 0.8 MW	pulsed beam with duty factor 10-20%, e. g. for pulse width 1 ms with repetition 100-	CW operation possible, but less preferred

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				distance 1 m from the luminous source surface and has opening area 1 x 1 m^2 (~ 0.66 sterad)	measurement time $2x10^7$ s/yr for 3 yrs.			200 Hz	
Neutrons EDM (A. Young)	$(1\text{-}5)x10^{20}$ $n/cm^2/SR$	γ, fast neutron, and charged particles < signal neutron	< 25 meV	Source < 30 cm $(2–10)x10^{12}$ $n/cm^2/s/SR$ over large solid angle.	Pulsed preferred, CW possible. $(2–10)x10^{12}$ $n/cm^2/s/SR$	0.8 – 2.5 GeV	200-500 kW	Quasi CW	Cryogenics will be critical
Inclusive charm									
Inclusive Bottom									
Isotopes									
Polarized Protons (Y. Semertzidis)	10^{15} integrated	> 99% > 80% polarization	$4x10^{10}$ p/20 minutes		2 Pulses /20 minutes	233 MeV, 0.7 GeV/c	1 mW	< 250 ns base length	$(dp/p)_{rms}$=2.e-4, $\varepsilon_{norm\text{-}95\%}$: hor=2 mm mrad vert= 6 mm mrad
High Energy polarized protons (A. Krisch)					1 pulse /1 min. pulse length 5 sec with 10e13 protons	60-120GeV		5 sec per minute	Polarization > 60%

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Table 2. Proton accelerator capabilities: existing, planned upgrades and new facilities.

	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
Present Capabilities						
LANSCE area A	800 MeV	80-120kW	120 Hz	linac		
LANSCE isotope production line	100 MeV	250 kW	40 Hz	linac	Isotope production	
ISIS Present	800 MeV	200 kW	0.5 μs x 40 Hz to TS-1, 0.5 μs x 10 Hz to TS-2	70 MeV H^- linac + RCS	160 kW to TS-1, 40 kW to TS-2, 30 MeV/c muons from 1-cm-thick graphite target in proton beam line to TS-1	≤240 MeV/c muons from pion decay in flight for MICE from Ti target in synchrotron. Cavern within 10 m of TS-1 target — neutrinos?
SNS Existing	935 MeV	1 MW	60 Hz x 700 ns	1 GeV linac + accumulator Ring	parasitic use only - beam on neutron target	Muon and electron DAR neutrinos
SNS Existing	935 MeV	50-100 kW	60 Hz x 1 ms		waste beam from Ring Injection	
FNAL Linac present	400 MeV	≤12 kW	15 Hz x 50 μs	H-, NC linac		Injection into Booster and beam to MTA
FNAL Booster present	8 GeV	40 kW	7 Hz x 1.6 us	RCS		used for all Intensity frontier at experiments at Fermilab

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
FNAL MI present	120 GeV	400 kW	9.4 us every 2.2 s	RCS	used for neutrino applications	Long baseline muon neutrinos and anti-neutrinos
BNL -BLIP - present	200 MeV	25-30 kW	6.67 Hz x 440 us (5 ns u spacing)	linac	Isotope production + Rad damage	
BNL Booster	2 GeV	30 kW	6.67 Hz	RCS		
BNL AGS	28 GeV	100 kW	0.333 Hz	RCS	slow extraction - seconds, fast extraction < 1 us	
PSI	590 MeV	1.3 MW	CW, 50MHz	2 stage cyclotron	400 kw to muon target + 900 kW to SINQ neutron scattering facility	
J-PARC linac	181 MeV	20 kW	25 Hz x 0.5 ms			
J-PARC RCS	3 GeV	300 kW	25 Hz x 1 us (2 bunches)	181 MeV linac + RCS	For MLF (Muon facility + neutron scattering)	
J-PARC MR (FX)	30 GeV	240 kW	0.4 Hz x 5 us (8 bunches)	3 GeV into RCS	For T2K experiment	
J-PARC MR (SX)	30 GeV	15 kW	0.17 Hz x 2 s (debunched)	3 GeV into RCS	For Hadron Experimental Facility	
TRIUMF	60-520 MeV	100 kW	CW, 23 MHz	cyclotron	4 simultaneous extraction lines	
CERN PS	14 GeV/c	45 kW	1.2 s cycle length, 2.3×10^{13} ppp			

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
CERN SPS operation	400	470 kW	4.4 s cycle length,4200 bunches, 1.05×10^{10}p/bunch, 5 ns spacing	linac + 2 stage RCS	CERN Neutrinos to Grand Sasso operation	
CERN SPS	400	565 kW	4.4 s cycle length,4200 bunches, 1.3×10^{10}p/bunch, 5 ns spacing	linac + 2 stage RCS	CERN Neutrinos to Grand Sasso operation - record	
Planned Upgrades						
FNAL Boost + PIP (3 years)	8 GeV	90 kW	15 Hz		used for neutrino applications + muon physics	Muon neutrinos and antineutrinos; negative muons for CLFV and g-2
FNAL MI + ANU < 1 year	120 GeV	700 kW	9.4 us every 1.33 s		used for NOVA + SX at a few kW	Muon neutrinos and antineutrinos
FNAL MI + ANU < 1 year	80-120 GeV	700 kW	9.4 us every 0.8 - 1.33s		by 2020	Muon neutrinos and antineutrinos
BNL BLIP + upgrade (< 5 yrs)	200 MeV	50-60 kW	6.67 Hz x 880 us (5 ns u spacing)	linac	Doubling of pulse length	
BNL BLIP post upgrade - BLAIRR (5-10 years)	> 1 GeV	250-300 kW	6.67 Hz x 880 us (5 ns u spacing)	linac	existing linac + FFAG, some beam is needed for isotopes, target R&D, ..	
BNL AGS Upgrade (> 5-10 yrs)	28 GeV	1 MW	2.5 Hz	RCS	Requires SCL linac injection at 1.2 GeV	

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
SNS in 4 years	1 GeV	1.4 MW	60 Hz x 700 ns	linac + accumulator	Planned power increase, no major upgrades	Muon and electron DAR neutrinos
SNS + 2nd target [Ref. 9] (10 years)	1.3 GeV	2.5-3 MW	60 Hz x 700 ns	linac + accumulator	Energy increased 30%, current increased 50%	Muon and electron DAR neutrinos
LANSCE + Refurbishment (2017)	800 MeV	800 kW	120 Hz x 625 us	linac	100 Hz is available for other applications	
ISIS Upgrade , 10–20 years	800 MeV	400 kW	0.5 μs x 45 Hz to TS-1, 0.5 μs x 5 Hz to TS-2	180 MeV H^- linac + RCS	360 kW to TS-1, 40 kW to TS-2, 30 MeV/c muons from graphite target in proton beam line to TS-1	
J-PARC linac	400 MeV	130 kW	25 Hz x 0.5 ms			
J-PARC RCS	3 GeV	1 MW	25 Hz x 1 us (2 bunches)	400 MeV linac + RCS	For MLF (Muon facility + neutron scattering)	
J-PARC MR (FX)	30 GeV	750 kW	0.75 Hz x 5 us (8 bunches)	3 GeV into RCS	For T2K experiment	
J-PARC MR (SX)	30 GeV	100 kW	0.17 Hz x 2 s (debunched)	3 GeV into RCS	For Hadron Experimental Facility	

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Deleted: ISIS Upgrade , 20 years + ... [1]

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
CERN SPS after LHC injector upgrade (2020)	400 GeV	747 kW	4.4 s cycle length,4200 bunches, 1.7×10^{10}p/bunch, 5 ns spacing	linac + 2 stage RCS	CERN neutrino to Grand Sasso operation	
Long Term Upgrade Concepts						
BNL AGS Upgrade (> 5-10 yrs)	28 GeV	1 MW	2.5 Hz	RCS	Requires SCL linac injection at 1.2 GeV	
SNS 3rd target (>10 years)	1.3 GeV	0.5-1 MW	10-20 Hz x 1 ms	linac	~ 0.5-1 MW may be available to an alternate station in a long-pulse mode (60 Hz x 1 ms), dependent on 2nd target station requirements	Cold neutrons, neutron EDM for possible 3rd target station
ISIS Upgrade , 20 years +	3 GeV	1 – 5 MW	~2 μs pulse x 50 Hz, each pulse consisting of 5-10 pulses ~0.3 μs apart	~800 MeV H^- linac + ~3 GeV RCS	Split between target stations undecided	Conceivably combined with proton driver for neutrino factory?
New Machines						
CERN with low power SPL + high power PS	75 GeV	2 MW	1 Hz x 148 bunches, 1.1×10^{12}p/bunch, 25 ns spacing	linac + accumulator	5 GeV input Energy tp PS, CERN Neutrions to Pyhasaimi program	

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
CERN with high power SPL + accumulator ring	5 GeV	4 MW	50 Hz x 6 bunches, 1.7×10^{13} p/bunch, 160 ns spacing	linac + RCS	Superbeam user	
CSNS- Phase I, 2020	1.6 GeV	100 kW	400 ns x 25 Hz	80 MeV linac + RCS	4 kW proton beam for mupn production (neutriono R&D, uSR)	
CSNS- Phase 2, 2024	1.6 GeV	500 kW	400 ns x 25 Hz	230 MeV linac + RCS	4 kW proton beam for mupn production (neutriono R&D, uSR)	
China long term	1.5 GeV	15 MW	CW, 15 mA		Medium baseline superbeam,	
China loner term	128 GeV	4 MW	31 uA, $1.ex10^{-6}$ duty factor, 1.25 Hz	2 stage RCS + accumulator ring	Long baseline superbeam	
ESS	2.5 GeV	5 MW	14 Hz x 2.9 ms	pulsed SCL	Potential compressor ring upgrade, for spallation, could also source a neutrino beam (Uppsala proposal).	
Deaδalus	800 MeV/amu	3 stations (1 + 2 + 5) MW	1 ms x 200 Hz (relatively arbitrary, 20% DF, on time >= 1 ms)	Beam: H2+ Injector: 60 MeV/amu compact cyclotron (IsoDAR) Main cyclotron:	5 emA peak current (10 mA peak protons on target). 3 accelerator stations at 1.5(1MW), 8(2MW) and 20(5MW) km from detector, operating in sequence at	Neutrinos from Decay-at-Rest (DAR) of p+

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
				separated-sector superconducting (6T) ring, stripping foil extracted	about 20%	
IsoDAR	60 MeV/amu	600 kW	CW	Compact cyclotron, (DAEdALUS injector) septum extracted	Prototype Injector cyclotron for DAEdALUS, mounted underground close to ~1 kton detector	Electron antineutrinos from DAR of 8Li
Project-X						
						Conventional Superbeams
	60-120 GeV	2.3 MW	Duty Factor 1E-5	Synchrotron	Stage-3	Muon Neutrinos
	60-120 GeV	2.3 MW	Duty Factor 1E-5	Synchrotron	Stage 3, same as above, reduce horn polarity	Anti-Muon Neutrinos
						Muon Storage Ring Beams
	3 GeV	1-3 MW	Duty Factor 1E-4	SC CW Linac + Accumulator Ring	Stage 2, duty factor requires ancillary accumulator/compressor rings	Muon Neutrinos

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
	3 GeV	1-3 MW	Duty Factor 1E-4	SC CW Linac + Accumulator Ring	Stage 2, duty factor requires ancillary accumulator/compressor rings	Electron Neutrinos
						Pion DAR Neutrinos
	1 GeV	<1 MW	Duty Factor 1E-4	SC CW Linac + Accumulator Ring	Stage 1, duty factor requires ancillary accumulator/compressor rings	Muon Neutrinos
						Kaon DAR Neutrinos
	1 GeV	<1 MW	Duty Factor 1E-4	SC CW Linac + Accumulator Ring	Stage 1, duty factor requires ancillary accumulator/compressor rings	Muon Neutrinos
	1 GeV	<1 MW	CW	SC CW Linac	Stage 1	Positive Muons for CLFV
	1-3 GeV	<1 MW	1 MHz of 50 nsec pulses		Stage 1,2	Negative Muons for CLFV
	3 GeV	Up to 750 kW	CW, 20 MHz		Stage 2	Positive Kaons
	3 GeV	Up to 750 kW	CW, 20 MHz, <50 psec bunch length		Stage 2	Low Energy Neutral Kaons

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	Energy	Power	Timing Characteristics	Accelerator Type	Comments	Intensity Frontier Application
	1 GeV	0.2 MW	pulsed beam, 20% DF		Stage 1, for timescales>1 usec, power = 1 MW x DF	Cold Neutrons
	1 GeV	0.9 MW	CW, 40 MHz microstructure		Stage 1	Cold Neutrons
	1 GeV	0.2-0.5 MW	pulsed beam, 20% DF - CW		Stage 1	Neutron EDM
	0.233 GeV	1 mW	$(dp/p)_{rms}$=2.e-4, enorm-95%: hor=1.2 mm mrad, vert= 1.2 mm mrad		Stage 1, momentum spread to be confirmed	Polarized proton EDM

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