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AF2: Accelerators for Neutrinos

Snowmass 2021 Community Summer Study

July 20, 2022

Status of AF2 Accelerators for Neutrinos

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Taking as input the anticipated needs of particle physics and the requirements for neutrino beams in terms of energy, flux, temporal and spatial characteristics, this group will discuss:

- The proton (or other) beam requirements to meet the neutrino physics community needs
- The capability of existing or planned accelerator facilities to satisfy the above requirements, and If not: the necessary upgrades or new facilities.
- Enabling R&D, technologies, and test facilities necessary to develop upgrades and new facilities

For Today

- Present draft tables of worldwide needs and capabilities of Accelerators for Neutrinos
- Brief comments here, or offline. Interested in facilities, and key requirements (columns)
- Final draft tables available after CSS for further comment (will update with more current numbers, especially for PIP-II successors in subsequent presentations.

For Friday:

- Extended session 8am-9:40am to present and discuss draft TG report in Kane 130
- Final draft report with tables available after CSS for further comment

Existing and Near Future Neutrino Beams

		Secondary beam					Primary beam				
Project	Primary Physics Goal	Particle	Purity	Energy [GeV]	Spatial characteristics	Timing	Particle	Energy [GeV]	Power [MW]	Timing	Ref.
NuMI/NovA Upgrade	ν_μ LBLO	$\nu_\mu, \overline{\nu_\mu}$		2	Pulsed-horn forward beam	?	p	120	>0.9	?	NF145
T2K Upgrade	ν_μ LBLO	$\nu_\mu, \overline{\nu_\mu}$		2	Pulsed-horn forward beam	?	p	30	1.3	?	NF187
LBNF/DUNE	ν_μ LBLO	$\nu_\mu, \overline{\nu_\mu}$		0.5–4	Pulsed-horn forward beam	Low Duty Factor	p	30–120	1.2	Low Duty Factor	DUNE TDR
LBNF/DUNE Upgrade	CP viol.	$\nu_\mu, \overline{\nu_\mu}$		0.5–4	Pulsed-horn forward beam	Low Duty Factor	p	30–120	>2.4	Low Duty Factor	AF092, DUNE TDR
LBNF/DUNE Timing Upgrade	CP viol.	$\nu_\mu, \overline{\nu_\mu}$		0.5–4	Pulsed-horn forward beam	Low Duty Factor	p	120	1.2	<200 ps bunches	NF116
LBNF/DUNE Low Energy Upgrade	CP viol., solar oscillation parameters	$\nu_\mu, \overline{\nu_\mu}$		0–4	Pulsed-horn forward beam	Dual BNB/MI timing	p	30/120	?	Dual BNB/MI timing	AF092, DUNE TDR
LBNF/DUNE High Energy Upgrade	ν_τ appearance: unitarity, NSI	ν_μ		0.5–10	Pulsed-horn forward beam	Low Duty Factor	p	120	>1.2	Low Duty Factor	AF092, DUNE TDR
FASER2/ FASERν2	ν interaction, Dark matter	ν_e, $\overline{\nu_e}$, ν_μ, $\overline{\nu_\mu}$, ν_τ, $\overline{\nu_\tau}$			Secondary beams emerging from collider IP	25 ns structure	p	7000		25 ns structure	EF038
ORNL SNS	BSM, interactions, sterile ν, Dark Matter	ν_e, ν_μ, $\overline{\nu_\mu}$	99% [1]	0–0.052	High-purity π decay at rest	≈400 ns width for prompt π decay, 2.2 μs for μ decay @ 60 Hz	p	1–1.3	1.4–2.0 (FTS), eventually 1.8 FTS+0.6 STS	400 ns @ 60 Hz	NF108, NF095, NF111, NF067, NF161
LANL SNS	?	?	?	?	?	?	?	?	?	?	
JPARC SNS	Sterile ν, BSM, interaction	ν_e, ν_μ, $\overline{\nu_\mu}$		0–0.053–0.236	Beam dump	2 × 100 ns pulses @ 25 Hz	p	3	0.75–1	2 × 100 ns pulses separated by 500 ns @ 25 Hz	NF128

Table 1: Existing neutrino beams or under construction/upgrade. For the latter requirements are presented. BNB=(FNAL) Booster Neutrino Beam, BSM=Beyond the Standard Model, FTS=First Target Station, HE=High Energy, LBLO=Long Baseline Oscillations, MI=(FNAL) Main Injector, LE=Low Energy, NSI=Non-Standard Neutrino Interactions, STS=Second Target Station. Table from Neutrino Frontier (L. Fields).

Further Proposed Beam Facilities

		Secondary beam					Primary beam				
Project	Primary Physics Goal	Particle	Purity	Energy [GeV]	Spatial characteristics	Timing	Particle	Energy [GeV]	Power [MW]	Timing	Ref.
PIP2-BD(PIP-II Beam Dump Experiment)	Dark matter and Sterile ν search	ν_e, ν_μ, $\overline{\nu_\mu}$, BSM		$\mathcal{O}(0.01$–$1)$	Beam dump	Low duty factor	p	$\mathcal{O}(1)$	0.1–1	Low duty factor	AF092, AF185, RF099, [2]
SBN-BD (SBN Beam Dump Experiment)	Dark matter and Sterile ν search	ν_e, ν_μ, $\overline{\nu_\mu}$, BSM		$\mathcal{O}(0.01$–$1)$	Beam dump	Low duty factor	p	8	0.1–1	Low duty factor	AF092, RF084, [2]
IsoDAR	Sterile ν search, BSM	$\overline{\nu_e}$	100%	0.000–0.015	Beam dump	CW	p	0.06	0.6	CW	AF092, RF084
ESSνSB	CP viol.	ν_μ		2–2.5	Pulsed Horn Forward Beam	14 Hz	p (H^-)	2.5	5 (5)	1.3 µs duration	NF062
ESSνSB-LEνSTORM	cross sections, sterile ν	ν_μ, ν_e	50% /50%	0.4		14 Hz	p (H^-)	2.5	5 (5)	1.3 µs duration	NF062
TeV Muon collider	BSM, energy frontier discoveries	μ^+/μ^-		0.2	high efficiency collection system	5–15 Hz	p (H^-)	4–8	2–4	1–12×1–2 ns bunches	AF081
νSTORM	Sterile ν search	ν_e,$\overline{\nu_e}$, ν_μ,$\overline{\nu_\mu}$	Precise mix	1–4	Relativistic μ decay		p	100	0.156	10 µs every 3.6 s	NF067. Requires μ storage ring
Moment	?	?	?	?	?	?	p	1.5	15	CW	IPAC18, C. Meng et al
ENUBET	ν cross sections, sterile ν using a beam with well known normalization	charged π, K	K is 5/10% of π	4-9	after collimation and focusing $\mathcal{O}(10 \times 10)$ cm^2	$\mathcal{O}(10^{10}$–$10^{11})$ π^+/K^+ over 2–4 s or a sequence of $\mathcal{O}(1)$ ms bursts with ≈10 Hz for horn focusing	p	30–120–400	>0.1	$\mathcal{O}(10^{13})$ p.o.t. over 2–4 s or a sequence of $\mathcal{O}(1)$ ms bursts with ≈10 Hz for horn focusing	[3]

Table 2: New requirements. BSM=Beyond the Standard Model. Table from Neutrino Frontier (L. Fields).

Existing Accelerator Facilities

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Accelerator	Kin. Energy [GeV]	Particle	Power [MW]	Timing (Pulse length, rep. rate, RF freq.)	Type	Comments
CERN LINAC4	0.16	H^-	0.0021	600 µs @ 0.83 Hz (352 MHz)	Linac	Rep. rate could be increased with some upgrade
CERN PSB	1.4–2	p	0.02/0.026	2 µs @ 0.83 Hz (4 bunches)	Synch. (4 rings)	
CERN PS	20	p	0.027	20 ns @ 0.83 Hz (1 bunch)	Synch.	
CERN SPS (FX)	400	p	0.57	23.1 µs (or 2×10.5 µs @ 0.17 Hz (200 MHz)	Synch.	Could be possibly increased
CERN SPS (SX)	400	p	0.36	$\approx$ 1 s @ 0.14 Hz (debunched)	Synch.	
CERN LHC	7000 (FT eq.=1.04×10^8)	p/p	36.8	Hours @ 40 MHz	Collider	The luminosity considered is 2×10^{34} $cm^{-2}s^{-1}$
CSNS-Phase I	1.6	H^-	0.1	550 ns @ 25 Hz (2.44 MHz, 2 bunches)	Linac (80MeV) +RCS	
FNAL Linac	0.4	H^-	0.012	50 µs @ 15 Hz (162.5 MHz)	Linac	
FNAL Booster	8	p	0.04	1.6 µs @ 7 Hz (52.8 MHz)	RCS	
FNAL MI	120	p	0.7?	9.4 µs @ 0.45 Hz (53.1 MHz)	Synch.	
J-PARC linac	0.4	H^-	0.33	0.5 ms @ 25 Hz (324/ 972 MHz)	Linac	
J-PARC RCS	3	p	0.8	1 µs @ 25 Hz (2 bunches)	RCS	
J-PARC MR (FX)	30	p	0.52	5 µs @ 0.4 Hz (8 bunches)	Synch	
J-PARC MR (SX)	30	p	0.05	2 s @ 0.19 Hz (debunched)	Synch.	
LANSCE area A	0.8	H^-	$\approx$0.8	625 µs @ $\leq$100 Hz (805 MHz)	Linac	Presently inactive. Linac feeding the 805 MHz structure operates at 201.25 MHz
LANSCE isotope production line	0.1	p	0.25	625 µs @ 40 Hz (xxx MHz)	Linac	
ISIS	0.8	H^-	0.2	0.5 µs @ 40 Hz to TS1 (1.3–6.2 MHz) and 0.5 µs @ 10 Hz to TS2 (1.3–6.2 MHz)	Linac + RCS	160 kW to TS-1,40 kW to TS-2
PSI	0.59	p	1.4	CW (50 MHz)	Cyclotron	
SNS	1	p	1.4	700 ns @ 60 Hz (1 MHz)	Linac+accumulator	
TRIUMF	0.52	p	0.1	CW (23 MHz)	Cyclotron	

Table 3: Present capabilities (FT=Fixed Target, FX=Fast extraction, h=harmonic number, MI=Main Injector, MR=Main Ring. RCS=Rapid Cycling Synchrotron, Synch.=Synchrotron, SX=Slow Extraction, TS=Target Station). Power is quoted for exclusive operation in a certain mode. The frequency refers to the main bunch repetition frequency. The beam power quoted for the LHC is the power of a fixed target beam with a current corresponding to the number of interactions per second at one LHC IP and having an energy giving a center of mass energy of 14 TeV

Planned Upgrades

Accelerator	Kin. Energy [GeV]	Particle	Power [MW]	Timing (Pulse length, rep. rate, RF freq.)	Type	Comments/Timescale
BNL BLIP	200	H^-	50–60	880 µs @ 6.67 Hz (200 MHz)	Linac	**Timescale?**
BNL BLIP–BLAIRR	>1	H^-	0.25–0.3	880 µs @ 6.67 Hz (200 MHz)	Linac	**Timescale?**
CSNS-Phase II	1.6	H^-	>0.5	550 ns @ 25 Hz (2.44 MHz, h=2)	Linac (300 MeV) +RCS	End of 2028
ESS	2	p	5	2.86 ms @ 14 Hz (352 MHz)	Linac	2023 (projected user operation)
ESSν	2.5	H^-/p	10	2.86 ms @ 28 Hz (352 MHz)	Linac with compressor ring to compress to 1.3 µs	Potential compressor ring upgrade for ν physics
FNAL PIP-II LINAC	0.8	H^-	0.017	540 µs @ 20 Hz (650 MHz)	Linac	2024
FNAL PIP-II Booster	8	p	0.166	1.6 µs @ 20 Hz (52.8 MHz)	Linac+RCS	2024
FNAL PIP-II MI	120	p	1.2	9.4 µs @ 0.83 Hz (53.1 MHz)	Linac+RCS+Synch.	2024
IsoDAR	0.06 GeV/u	$H2^+$	0.6	CW **(xxx MHz)**	Cyclotron	**Timescale?**
Daeδalus	0.8 GeV/u	$H2^+$	3 stations (1+2+5) MW	1 ms @ 200 Hz **(xxx MHz)**	Cyclotron (IsoDAR injector)	5 emA peak current (10 mA peak protons on target)/ **Timescale?**
HL–LHC	7000 (FT eq.=1.04 × 10^8)	p/p	92	Hours @ 40 MHz	Collider	See comment for LHC in Table 3. The luminosity considered is 5 × 10^{34} cm^{-2}s^{-1}. 2029
ISIS	0.8	H^-	0.5	0.5 µs @ 40 Hz to TS3 0.5 µs @ 10 Hz to TS2	Linac + RCS	400 kW to TS3, 100 kW to TS2, 30 MeV/c μ from graphite target in proton beam line to TS1. 2030.
ISIS–II	1.2	H^-	up to 2.4	0.5 µs @ 30 Hz to TS1 0.5 µs @ 15 Hz to TS2	Linac + (RCS or AR or FFA)	Up to 1.6 MW to TS1, up to 800 kW to TS2, 30 MeV/c μ from graphite target in proton beam line to TS1 or directly from linac. 2040.
J-PARC RCS	3	p	1	1 µs @ 25 Hz (2 bunches)	RCS	2024 JFY
J-PARC MR (FX)	30	p	1.3	5 µs @ 0.86 Hz (8 bunches)	Synch	2028 JFY
SNS / PPU upgrade	1.3	p	2.8	700 ns @ 60 Hz	Linac+accumulator	Energy increase by 30%, current increase by 50%, 2024

Table 4: Planned Upgrades and Facilities (AR=Accumulator Ring, FFA=Fixed-Field Alternating Gradient Accelerator, FT=Fixed Target, FX=Fast extraction, h=harmonic number, JFY=Japanese fiscal Year, MR=Main ring, RCS=Rapid Cycling Synchrotron, Synch.=Synchrotron, SX=Slow Extraction, TS=Target Station). Power is quoted for exclusive operation in a certain mode. The frequency refers to the main bunch repetition frequency. The beam power quoted for the LHC is the power of a fixed target beam with a current corresponding to the number of interactions per second at one LHC IP and having an energy giving a center of mass energy of 14 TeV