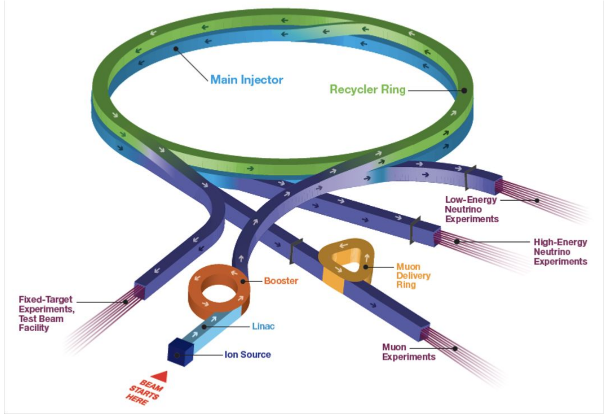
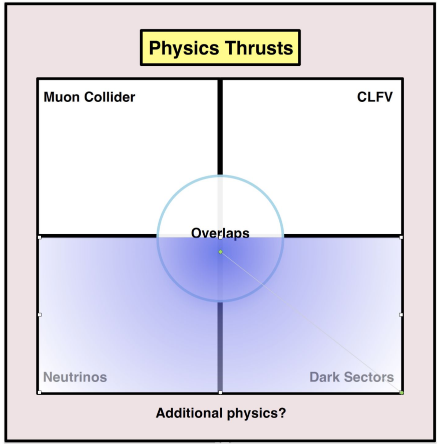




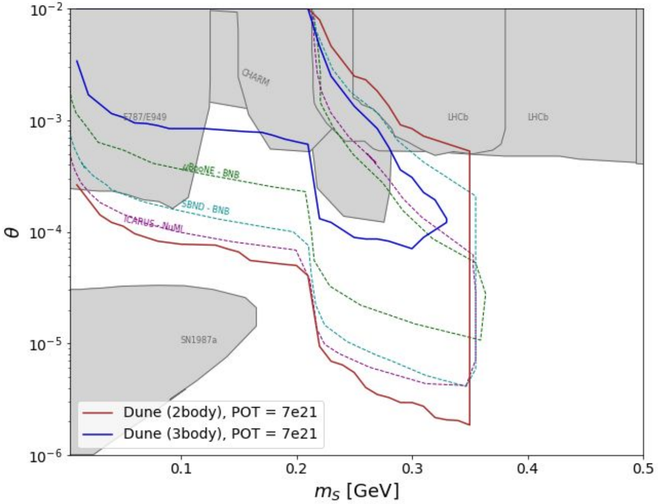
Discussion Session - Dark Sectors and Neutrinos - Summary

[1]Bhaskar Dutta, [2]Alexandre Sousa, [3]Jacob Zettlemoyer

[1]Texas A&M, [2]Cincinnati, [3]Fermilab

ACE Science Workshop, Fermilab, June 15, 2023

- How do we maximize complementarity of the accelerator options under the ACE plan with existing/proposed experiments probing dark sector and neutrino physics?
  - Considering proton energies, detection thresholds, detector locations (i.e. on-axis or off-axis), and baselines?
  - Large swathes of dark photon, ALP, g-2, etc., parameter spaces remain unexplored. How do we probe them?



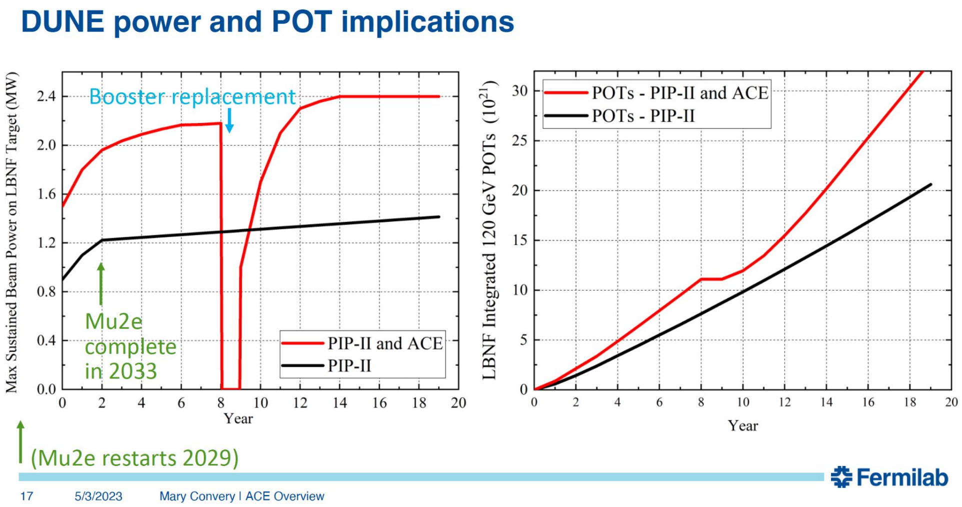
- Key to expand coverage of parameter space is to increase kaon production
  - High-Z target (tungsten, tantalum)
  - Higher beam energy
  - Detector location

A. Karthikeyan, TAMU

- Searching for new physics is done directly by producing the mediator from various meson decays. Are we missing any important physics ideas or production/detection channels?
  - LDM, ALP, HNL, tau neutrino appearance, tridents, millicharged particles, etc.; electron/proton bremsstrahlung, photon conversions, Primakoff, Compton, etc. and detection via mediator scattering, DM scattering, decays, neutrino scattering…

- New possibilities should be considered for example:
- Resonant $\pi 0$ production in neutrino detectors for complementary regions of parameter space

- Which ACE upgrades before and during DUNE running might enable expansion of DUNE's Physics Scope?



- Why do we cap DUNE at 2.4 MW. Could you go beyond that?
  - Limited by target+absorber capabilities

- Could ACE provide a 4 MW beam for DUNE?
  - Yes, potentially limited by space charge effects

- What could the Booster replacement provide for DUNE physics?

- What physics could we access with micro-bunch structure knowledge of the beam

- What are the most impactful detector media to search for physics in the dark and neutrino sectors?
  - Water-based Liquid scintillator (low-energy extension)
  - LiquidO (opaque scintillator), high resolution
  - Need excellent tracking detectors (LArTPC can bee too slow for highly intense sources)
  - Optical tracking in LAr detectors (large photodetection coverage) - CEvNS type of detectors
  - Fully pixelated detectors like 3D Scintillator Tracker (3DST)
  - Which detector would we use for physics benefitting from sub-nano second bunch structure beam precision?
    - Potentially help with HNL time-of-flight measurements

- What are the New Physics probes enabled by proton (beam-dump) runs at neutrino beam facilities?
    - Remove neutrino decay-in-flight backgrounds by sending beam to proton dump
        - Thick dump can also help remove neutron backgrounds
    - SBND dump mode might be even better, because of short distance, but you have lower energy than say DUNE, so it covers complementary parameter space
    - What other beam-dump style experiments can we build utilizing other parts of PIP-II and ACE?
        - Some experimental concepts such as PIP2-BD (J. Zettlemoyer’s talk) can take advantage of the powerful beam timing capabilities of an accumulator ring attached to PIP-II
    - With BNB, there's potential for running alternatively with beam on and off-target during regular operations. With enough physics motivation a dedicated beam dump facility can be built

- What possibilities exist beyond the upcoming DUNE program to continue leading in this science?
    - Partially discussed at André's talk yesterday
    - DUNE Phase II discussions are the current priority, beyond that will need further reflection at future ACE workshops

From J. Eldred's talk yesterday

PIP-II and ACE Options

PIP-II nominal physics "spigots"

S0A: 0.8 GeV PIP-II Linac, experiments which require CW linac

S0B: 0.8 GeV PIP-II Linac, experiments which can use pulsed linac beam.

S0C: 0.8 GeV PIP-II, with Accumulator Ring program.

S0D: 8 GeV Booster Experiments

S0E: 8 GeV Recycler & Delivery Ring Experiments.

S0F: 120 GeV Main Injector Slow-Extraction program.

ACE upgrade "spigots"

S1: O(1) GeV High Duty-Factor Beamline

(like S0A and S0B 0.8 GeV PIP-II Linac, but higher energy)

S2: O(1) GeV Low Duty-Factor Beamline

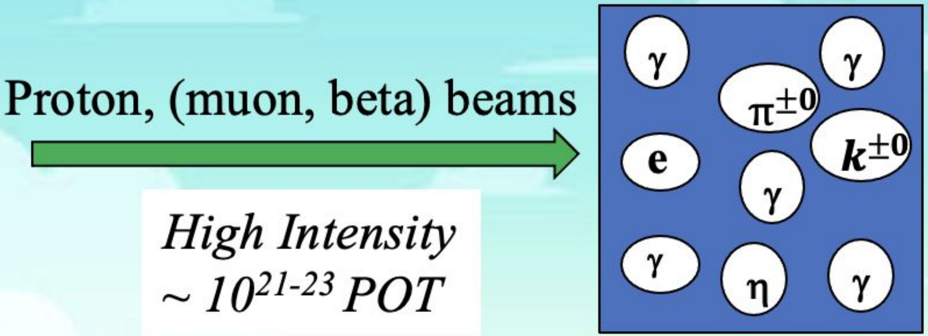
(like S0C 0.8 GeV PIP-II with AR program, but higher energy)

S3: O(10) GeV Low Duty-Factor Beamline

(like S0D 8 GeV Booster Experiments, but much higher power).

Supplements

Theory Landscape



What lives in the “blue sky”?

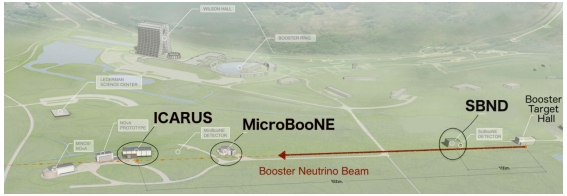
- HNL
- HPS
- LDM
- Dark sector
- mCP
- ALP
- Anomalies g-2, MB
- Inelastic Processes
- NSI
- Your Ideas!

Present and Near-Future Experimental Landscape

- Listing accelerator-based experiments only!

Pion/Kaon/Isotope Decay-at-Rest:
60 MeV - 8 GeV proton beams
PIP2-BD, KPIPE (Fermilab), COHERENT (ORNL), CAPTAIN-Mills (LANL), JSNS^2 (JPARC), IsoDAR (Yemilab)

Short-Baseline Pion Decay-in-Flight:
8 GeV BNB on-axis + 120 GeV NuMI off-axis, 400 GeV SPS proton beams
SBN Program (Fermilab), SHiP (CERN)

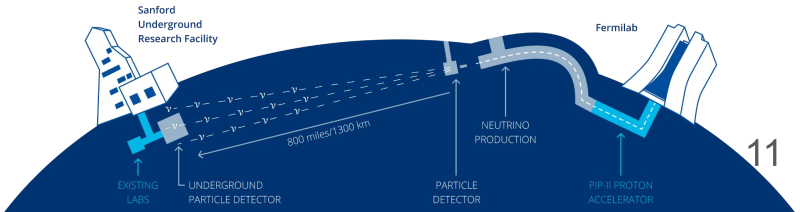


Detector Tech.
Ar, WCh, CsI, NaI, Ge, Scint., Emulsion, etc.

Colliders:
Up to 14 TeV CM proton collisions
FASERnu, FLArE (CERN)

Long-Baseline Pion Decay-in-Flight:
2.5 GeV - 120 GeV proton beams
NOvA, DUNE (Fermilab), T2K, HyperK (JPARC), ESSnuSB (ESS Lund)

Muon Decay-in-Flight:
1 - 6 GeV muon beams
nuSTORM (CERN)



ACE and Longer-Term Expt. Efforts

Experiment	Experiment type	Proton Beam: Energy [GeV]	Proton Beam: Power [kW]	Proton Beam: Time Structure	Uses existing or new beamline?
Proton Storage Ring: EDM and Axion Searches	Precision tests Dark Matter	0.232	1e11 polarized protons per fill	Fill the ring every 1000s	new
Physics with Muonium	Precision tests	0.8	1e(13+/-1) POT per second	CW	new
REDTOP Run I	Precision tests	1.8 - 2.2	0.03-0.05	slow extraction	Muon Campus
REDTOP Run II	Precision tests	0.8 - 0.92	200	CW,	new
REDTOP Run III	Precision tests	1.7	>1,000	CW,	new
Ultra-cold Neutron Source for Fundamental Physics Experiments, Including Neutron-Anti-Neutron Oscillations	Precision tests	0.8-2	1,000	quasi-continuous	new
CLFV with Muon Decays	CLFV	Not critical 0.8 to a few GeV	100 or more	continous beam on the timescale of the muon lifetime i.e. proton pulses separated by a microsecond or less. The more continuous the better	new
Mu2e II	CLFV	1 to 3	100	pulse width 10s of ns or better separated by 200 to 2000 ns. Flexible time structure	new
Fixed Target Searches for new physics with O(1 GeV) Proton Beam Dump	Dark Sector, Neutrino	0.8 to 1.5 GeV	100 or more	<O(1 micro s) pulse width for neutrino measurements, <O(30 ns) pulse width for dark matter searches, 10^{-5} or better duty factor	new
PRISM-like Charged Lepton Flavor Violation	CLFV	1 -3 GeV	up to 2 MW	15ns pulses at a rep rate of about 1 kHz	new
Proton Irradiation Facility	R&D	Energy is not very important	1e18 protons in a few hours	Pulsed beam (duty factor not specified)	new
SBN	Neutrino	8	32	20Hz	BNB
Fixed Target Searches for new physics with O(10 GeV) Proton Beam Dump	Dark Sector, Neutrino	8	up to 115	Beam spills less than a few microsec with separation between spills greater than 50 microsec	BNB
Muon beam dump	Dark Sector	8 (producing 3 GeV muons)	3e14 muons in total on target for the whole run	CW	Muon Campus
Muon Collider R&D	R&D	8 - 16GeV	4e13 to 1.2e14 protons per bunch	5 - 20 Hz rep rate and bunch length 1-3 ns	new
Muon Missing Momentum	Dark Sector	few 10s of GeV	10^{10} muons per experimental	Pulsed beam (duty factor not specified)	new
High Energy Proton Fixed Target	Dark Sector, Neutrino	O(100 GeV)	1e12 POT/s therefore ~20 kW	CW via resonant extraction. "IF we could up the duty factor that woul dbe even better"(?)	Switchyard or new
Test-Beam Facility	R&D	120, lower energies would also be beneficial	10 to 100 kHz on the testing	Pulsed beam (duty factor not specified)	Switchyard or new
Tau Neutrinos	Neutrino	120	1200 or higher	MI time structure	LBNF

Options proposed in the Proton Intensity Upgrade - Central Design Group Report. How do we expand on this using the options presented within ACE and beyond?

Proposed Questions for Discussion - 1

- How do we maximize complementarity of the accelerator options under the ACE plan with existing/proposed experiments probing dark sector and neutrino physics?
  - Considering proton energies, detection thresholds, detector locations (i.e. on-axis or off-axis), and baselines
  - Large swathes of dark sector, g-2, etc., parameter spaces remain unexplored. How do we probe them?

- Searching for New Physics is done directly by producing the mediator from various meson decays. Are we missing any important physics ideas or production/detection channels?
  - LDM, ALP, HNL, tau neutrino appearance, tridents, millicharged particles, etc.; electron/proton bremsstrahlung, photon conversions, Primakoff, Compton, etc. and detection via mediator scattering, DM scattering, decays, neutrino scattering…

- Which ACE upgrades before and during DUNE running might enable expansion of DUNE's physics scope?

Proposed Questions for Discussion - 2

- What are the most impactful detector media to search for physics in the dark and neutrino sectors?

- What are the New Physics probes enabled by proton (beam-dump) runs at neutrino beam facilities?

- What possibilities exist beyond the upcoming DUNE program to continue leading in this science?

- Other questions / points to discuss