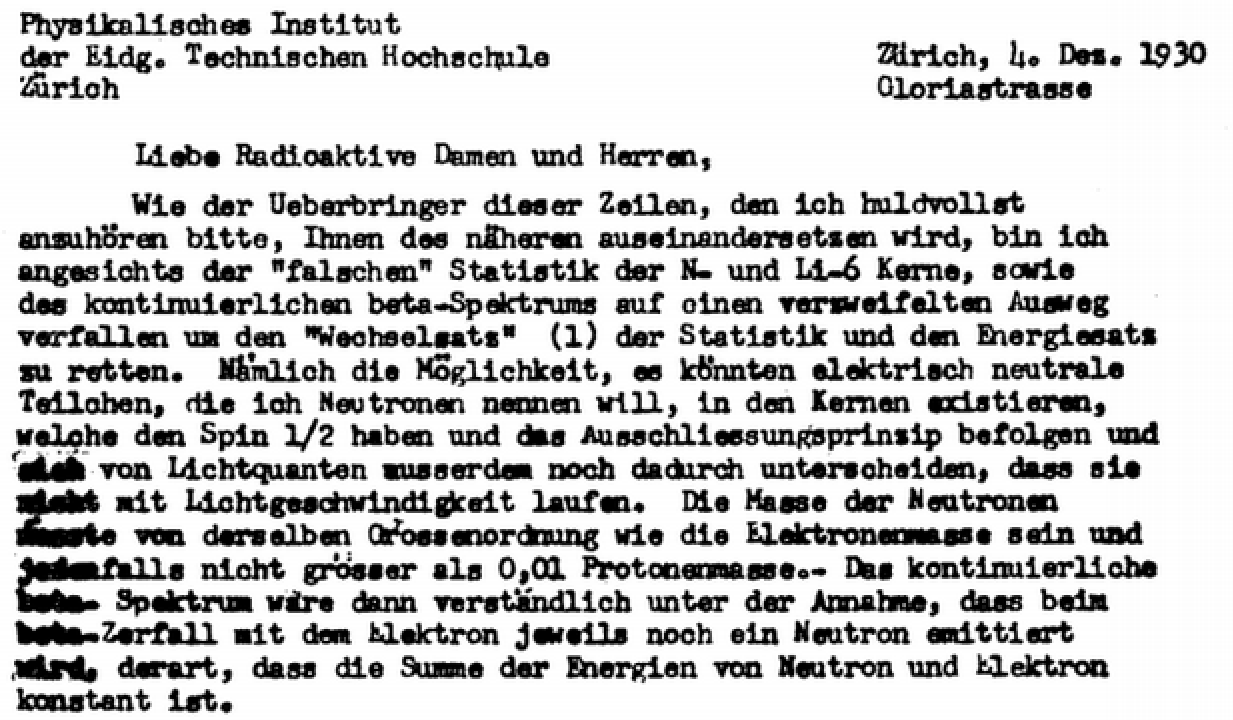
Neutrino Frontier



Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Snowmass 2021

Patrick Huber, Kate Scholberg, Elizabeth Worcester

The science drivers for NF

- What are the neutrino masses?
- Are neutrinos their own antiparticles?

- How are the masses ordered?
- What is the origin of neutrino mass and flavor?
- Do neutrinos and antineutrinos oscillate differently?
- Discovering new particles and interactions
- Neutrinos as messengers

Nuclear Physics funded, small and medium sized

DUNE phase I, large, end of construction by 2030

DUNE phase II, two medium sized detector upgrades a large accelerator upgrade, construction from 2030-2040

Many other projects, most have a small US HEP contribution

NF message

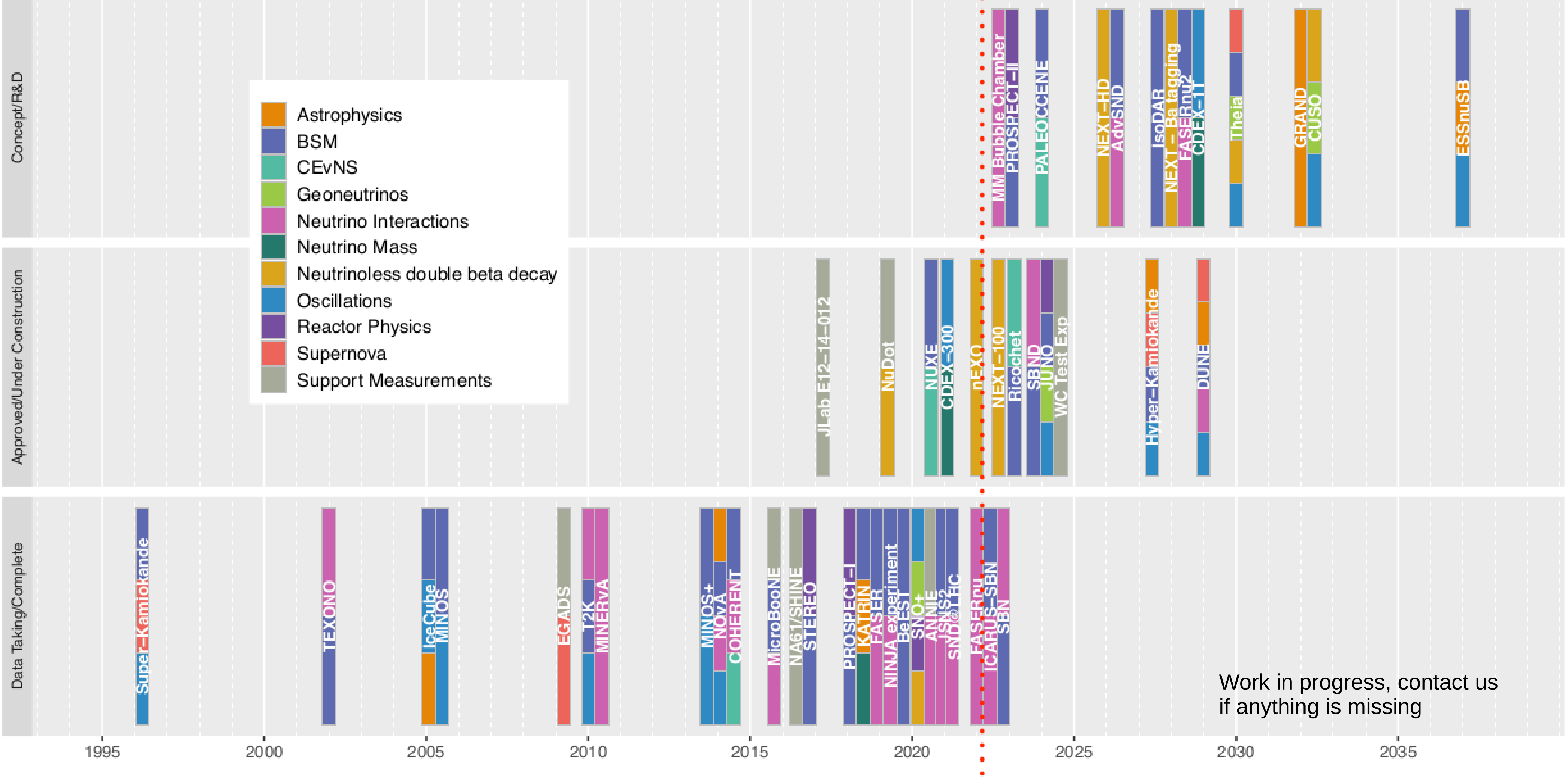
A future program with a healthy breadth and balance of physics topics, experiment sizes, and timescales, supported via a dedicated, deliberate, and ongoing funding process, is highly desirable.

Completion of existing experiments and execution of DUNE in its full scope are critical for addressing the NF science drivers. Both Phase I and Phase II are part of the original DUNE design endorsed by the last P5. DUNE Phase I will be built in the current decade and DUNE Phase II (2 additional FD modules, more capable ND, and use of the 2.4 MW beam power from the FNAL accelerator upgrade) is the priority for the 2030s.

Existing technologies enable the original DUNE physics program for both Phase I and Phase II. However each piece of DUNE Phase II offers broader physics opportunities than originally envisioned. **To exploit these new opportunities directed R&D needs to be supported.**

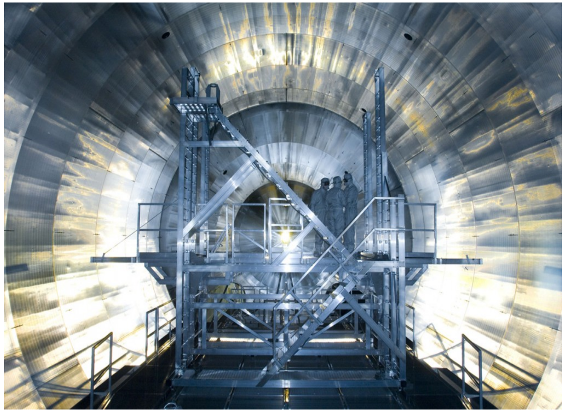
Strong and continued support for neutrino theory is needed.

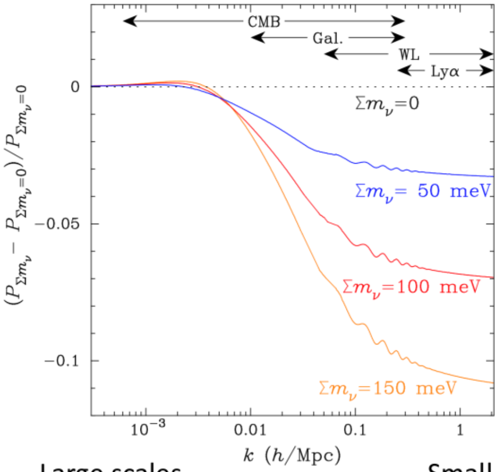
There are unique opportunities for NF to contribute to leadership of a cohesive, HEP-wide strategic approach to DEI and community engagement, which is urgently needed.



Impossible to cover in a close-out, only few of these will individually rise to the P5 level.

Neutrino mass measurements





Large scales

Small scales

Experiments in CF, neutrino mass a by-product and not design drivers

KATRIN current limit is 0.8eV with a future sensitivity of 0.2eV

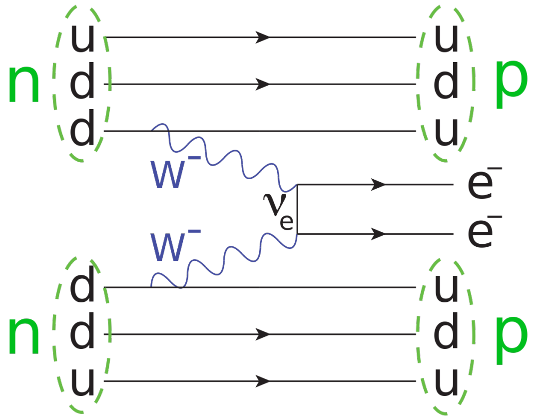
There are ideas beyond KATRIN: Project 8, ECHO, Holmes

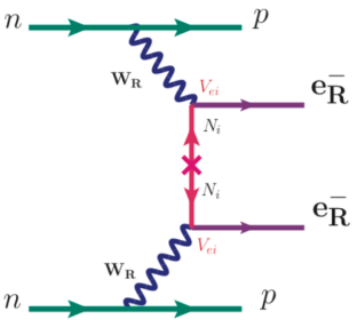
R&D required for <0.1eV

Current limits are order 0.2-0.5eV and will reach << 0.1eV soon

Complementary to direct searches.

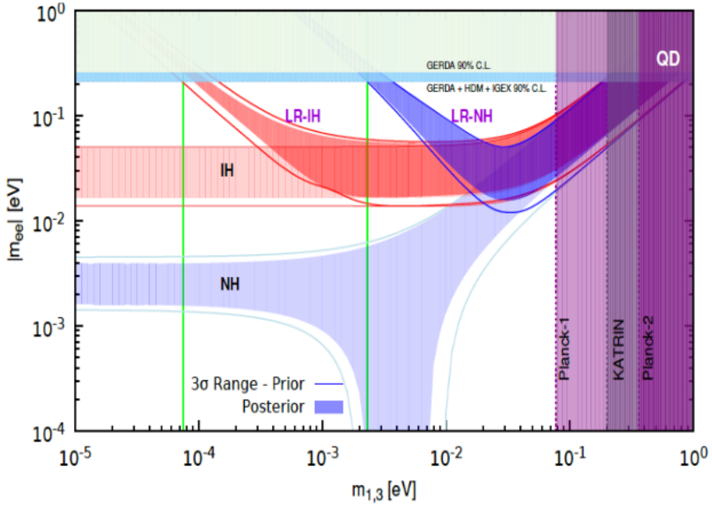
Are neutrinos their own antiparticles?





Left-Right Symmetric Model,
$M_{W_R} \sim 2$ TeV, $M_N = 1$ TeV,
$g_R \sim 2/3\ g_L$

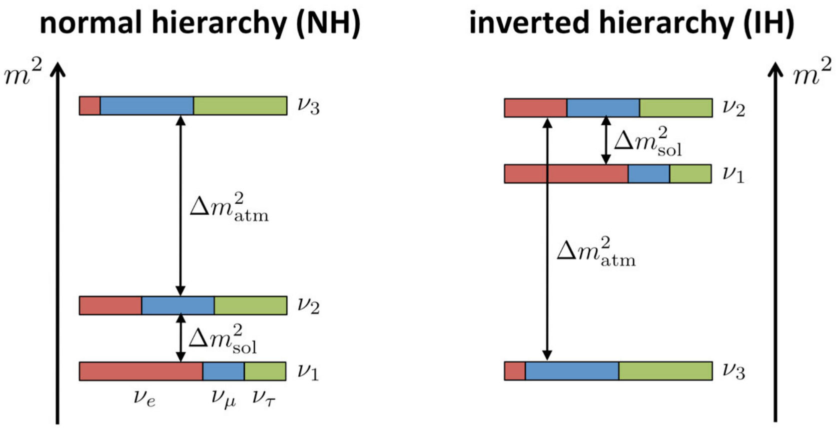
JHEP 10 (2015) 077



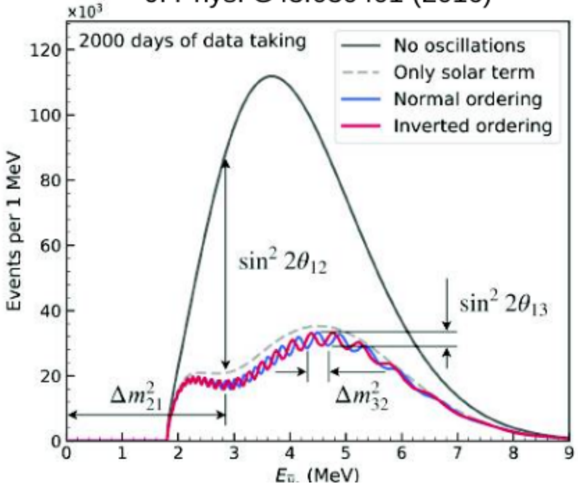
Ton scale 0nuBB experiments will cover the inverted hierarchy by 2035

Medium sized, but funded by Nuclear Physics

How are the masses ordered?

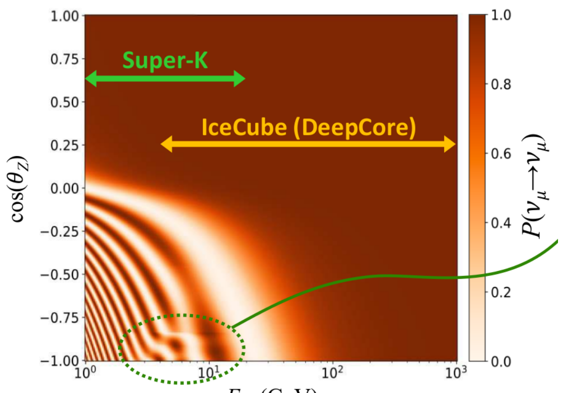


J. Phys. G43:030401 (2016)



JUNO also will improve the precision on a number of oscillation parameters, which is critical for testing the oscillation framework.

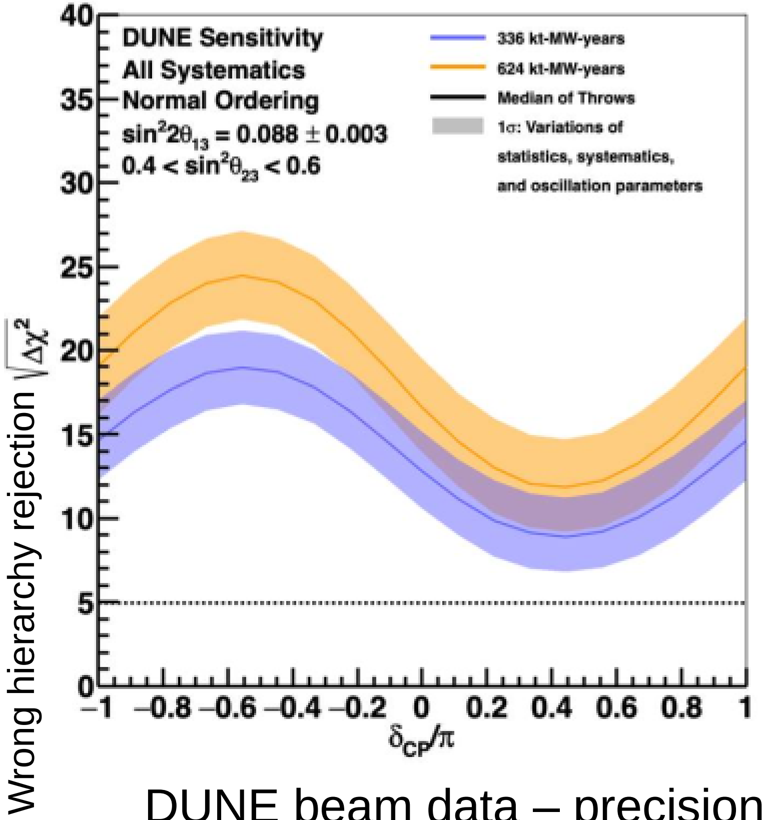
- Mass searches (beta decay, 0nuBB, cosmology)
- Matter effects (long-baseline oscillation, atmospheric neutrinos)
- Vacuum oscillation (reactor oscillation experiments)



Atmospheric neutrinos in the 1-10GeV exhibit the MSW resonance, requires very large detectors

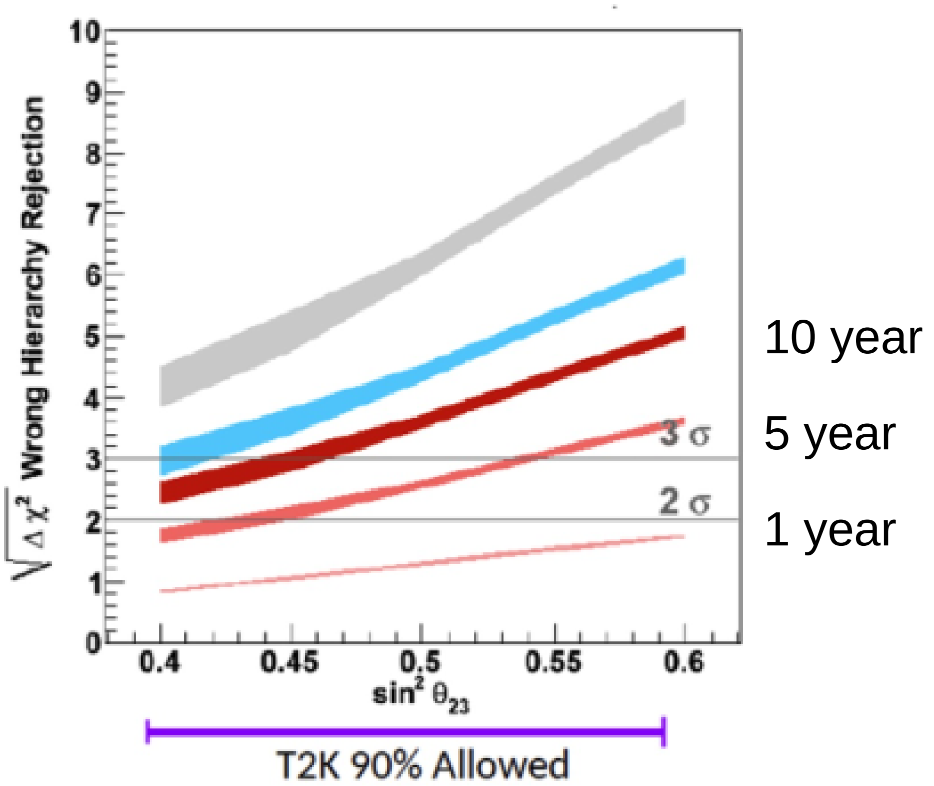
→ neutrino telescopes

How are the masses ordered?



EPJC 80 (2020) 978

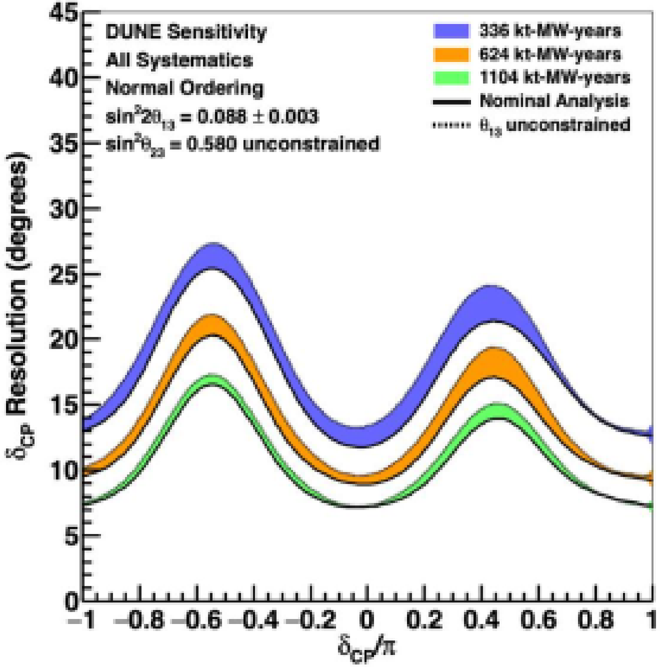
DUNE beam data – precision study of matter effects



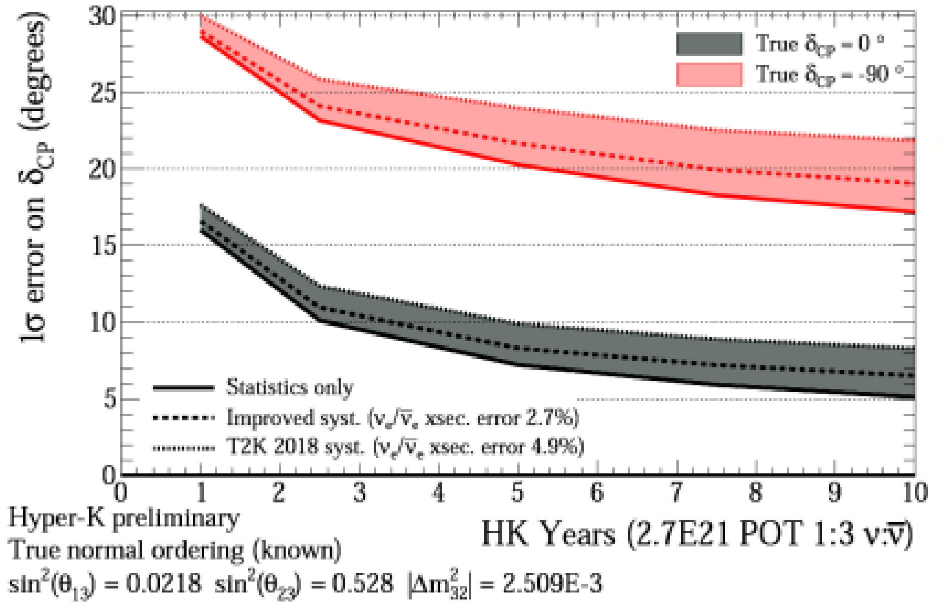
Hyper-K atmospheric data

Figures from SNOWMASS neutrino colloquium by C. Wilkinson

CP violation in oscillation



Snowmass year = 10^7 s

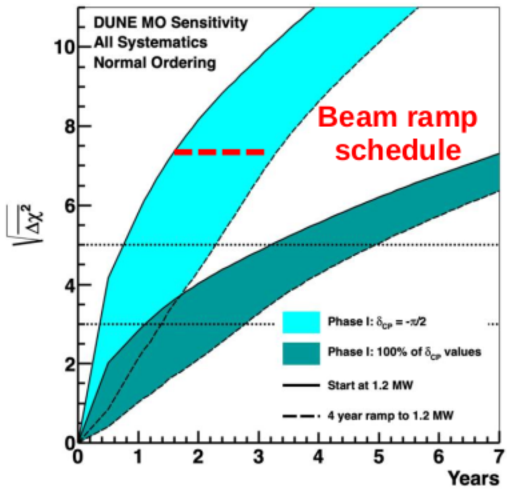


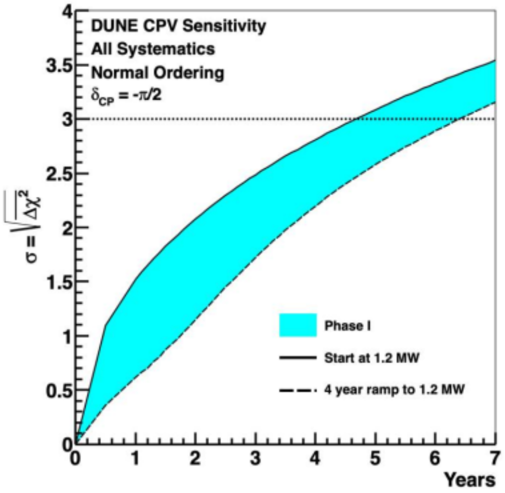
Comparable sensitivities

– but very complementary systematics

Figures from SNOWMASS neutrino colloquium by C. Wilkinson

DUNE staging





Phase I:

Construction ends around ~2030

✔ Unambiguous MO

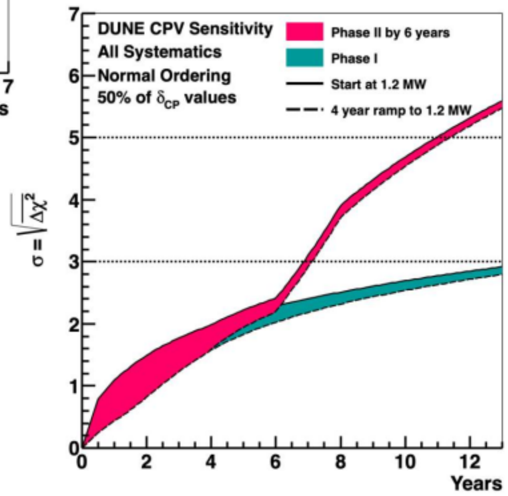
✔ 3σ CPV at maximal δ_{CP}

Phase II:

✔ P5 goal of 5σ CPV for 50% of δ_{CP}

✔ Precision δ_{CP}, Δm^2_{32}, θ_{23}, θ_{13}

Requires 2.4 MW, 40 kt and full ND



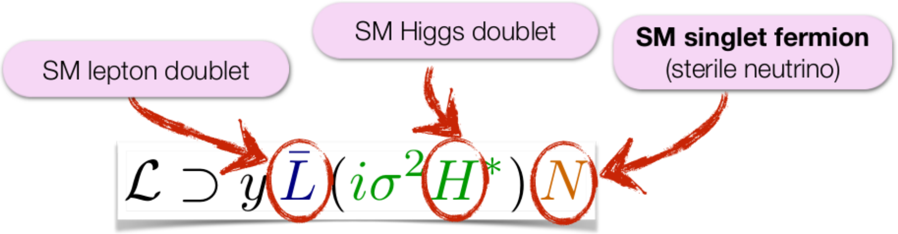
Construction should start around ~2030:

FD mass
ND upgrade
Beam upgrade

Figures from SNOWMASS neutrino colloquium by C. Wilkinson

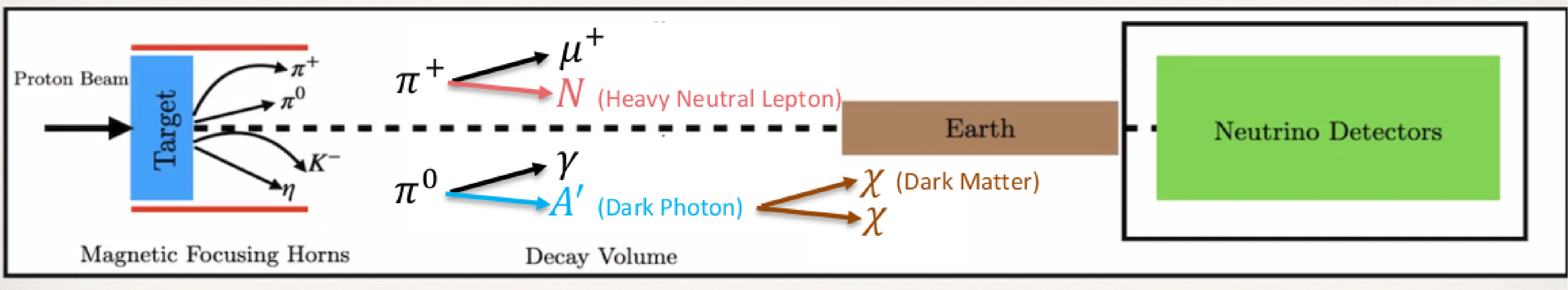
Discovering new things

- New neutrinos or new neutrino interactions

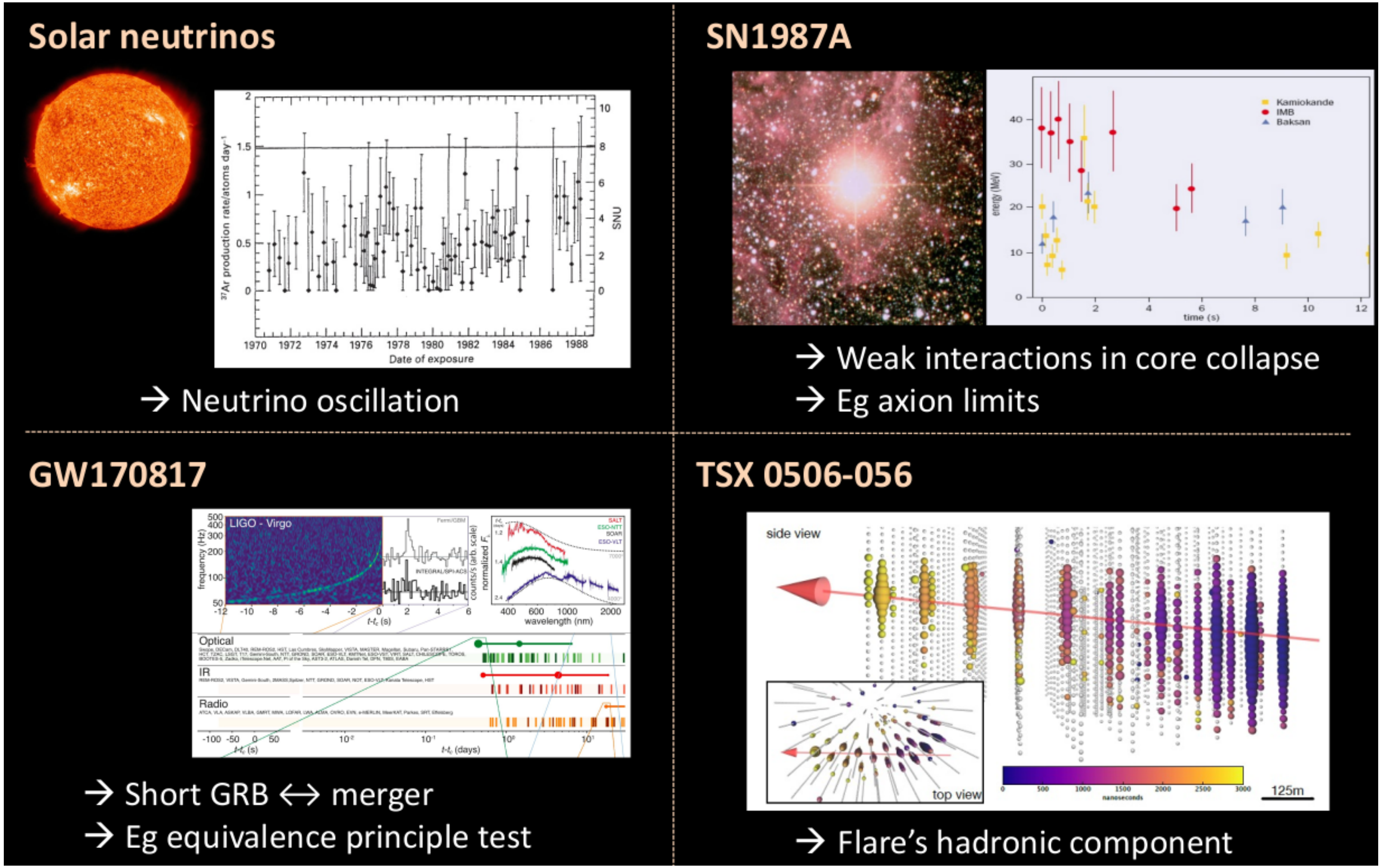


- New light states not related to neutrinos

Figures from SNOWMASS neutrino colloquia by J. Kopp and Z. Tabrizi



Neutrinos as messengers

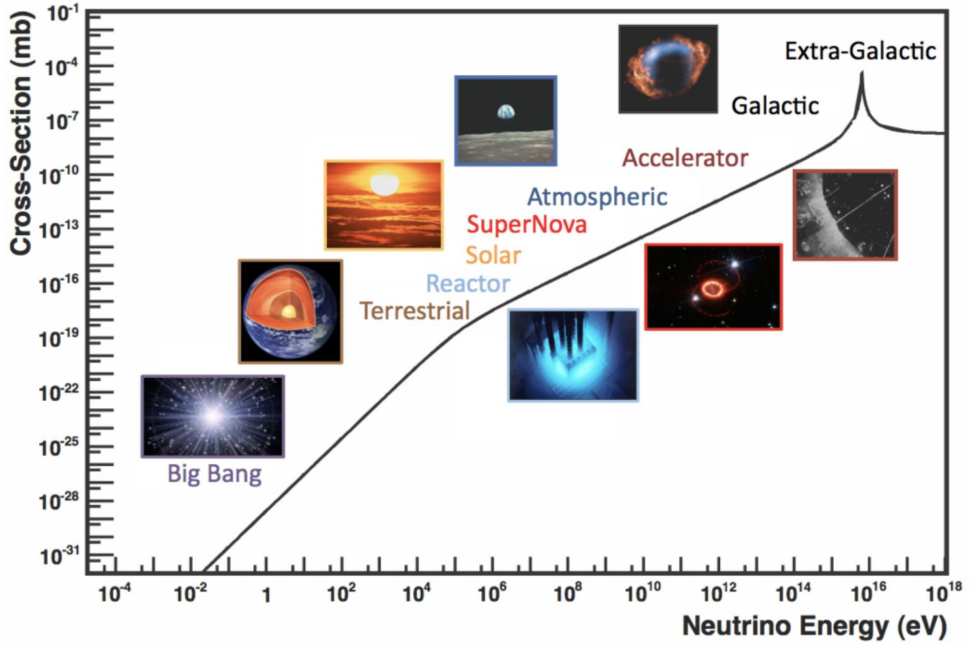


Neutrinos are one leg of multi-messenger astronomy

Combination with photons from radio to gamma rays
and gravitational waves

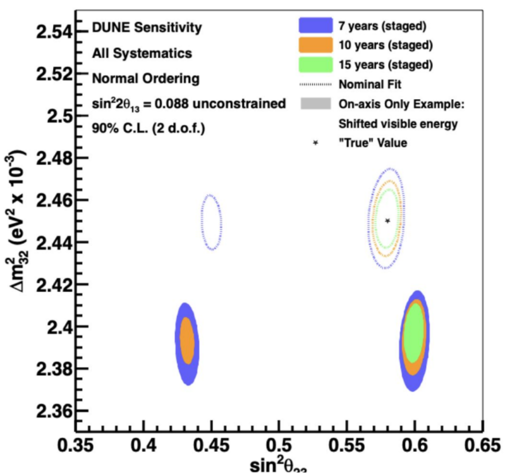
Figures from SNOWMASS neutrino colloquium by S. Horiuchi

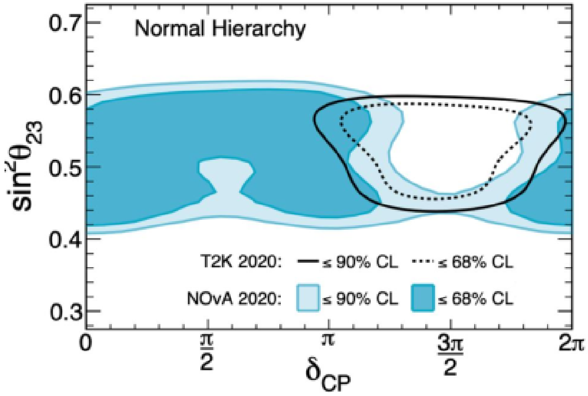
Enabling program: Neutrino interactions



Measuring SM processes

DUNE Physics TDR arxiv. 2002.03005





New physics or cross section mismodeling?

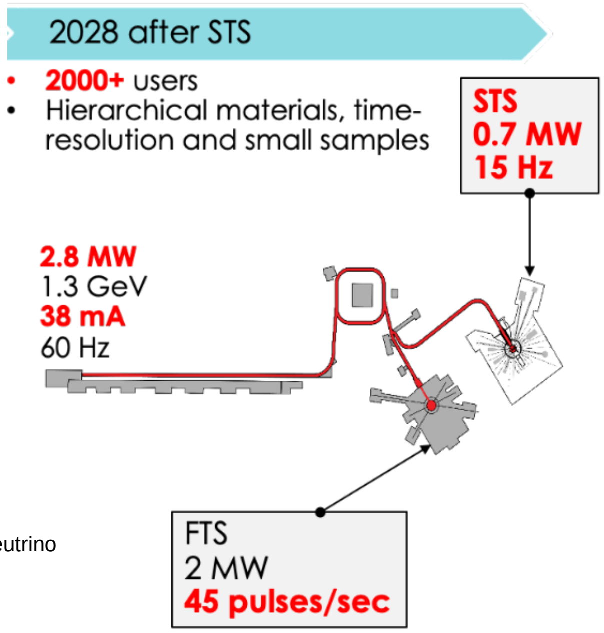
Robust program at many energy scales underway (small experiments) – essential to do physics, theory & nuclear physics.

Figures from SNOWMASS neutrino colloquium by K. Mahn

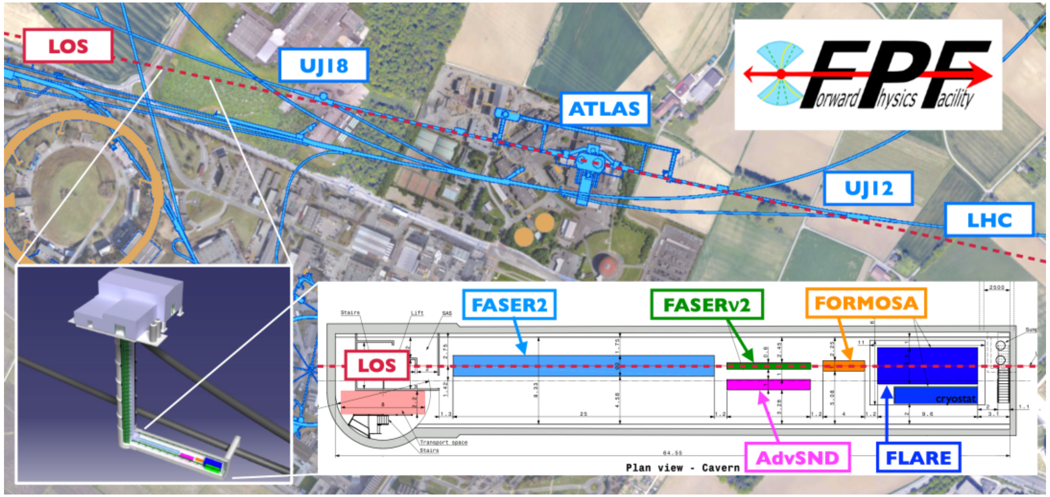
Synergies at the machine level as well as physics

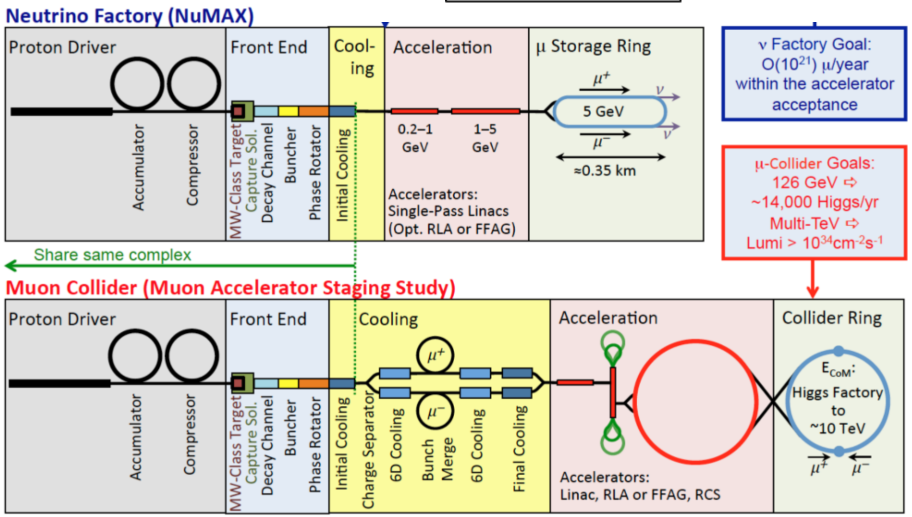
Experiment	Dark Sectors	ν Physics	CLFV	Precision tests	R&D
Lepton flavor violation: μ-to-e conversion					
Lepton flavor violation: μ decay					
PIP2-BD: ~GeV Proton beam dump					
SBN-BD: ~10 GeV Proton beam dump					
High energy proton fixed target					
Electron missing momentum					
Nucleon form factor w/ lepton scattering					
Electron beam dumps					
Muon Missing Momentum					
Muon beam dump					
Physics with muonium					
Muon collider R&D and neutrino factory					
Rare decays of light mesons					
Ultra-cold neutrons					
Proton storage ring for EDM and axions					
Tau neutrinos					
Proton irradiation facility					
Test-beam facility					

Booster replacement (beam upgrade)



Figures from SNOWMASS neutrino colloquium by M. Toups





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Significant growth in activity since last Snowmass