U.S. Particle Physics Strategic Planning

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T RIUMF Science Week

July 2022

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

The U.S. High Energy Physics program is guided by the strategic plan laid out in the 2014 P5 report

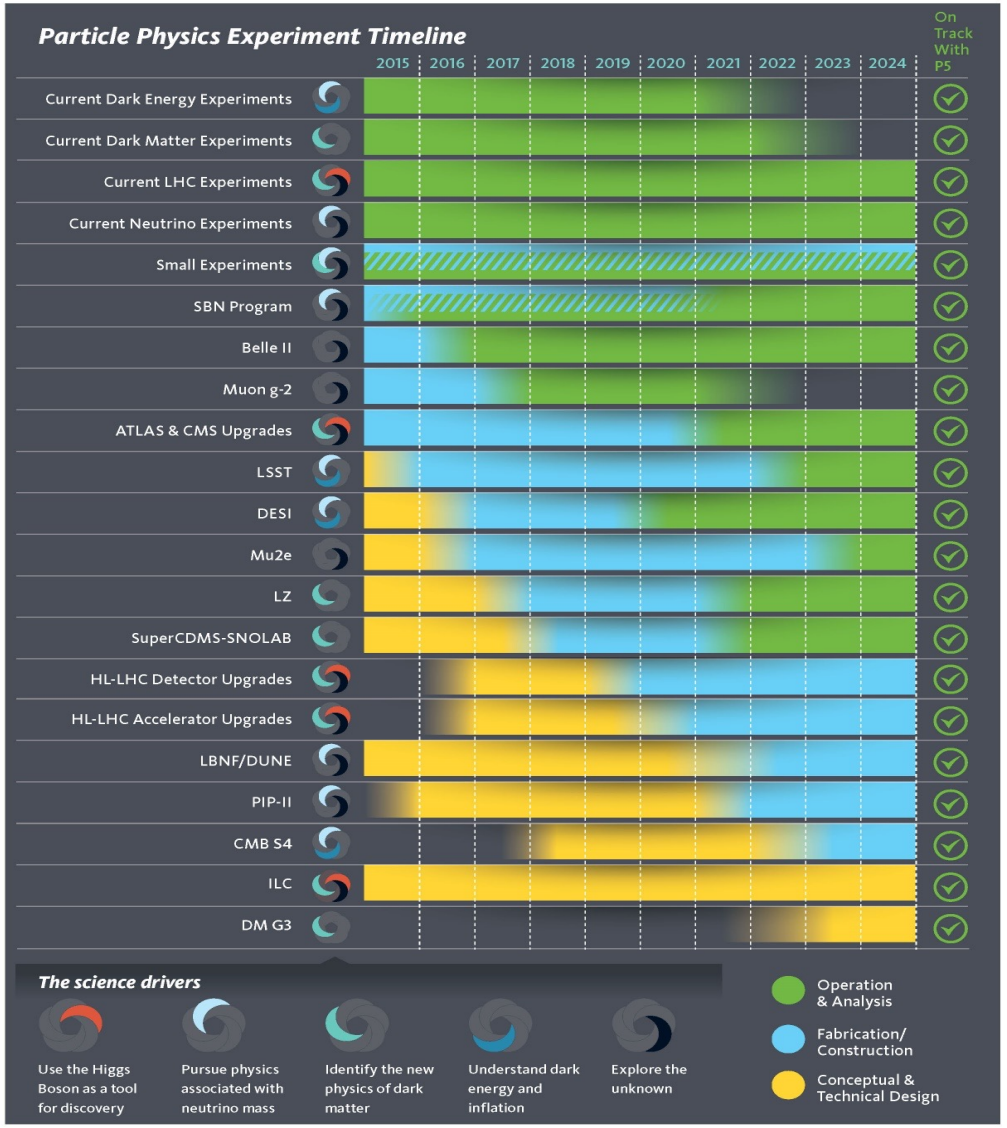
Community Driven Strategic Process

- "Snowmass" 2013: A year-long community-wide study of science opportunities, organized by the Division of Particles and Fields of the American Physical Society
- Particle Physics Project Prioritization Panel (P5) 2014: High Energy Physics Advisory Panel (HEPAP) subpanel, prioritized scientific opportunities outline in the Snowmass study within a budget framework

Dovetailed with

- 2010 Astronomy & Astrophysics Decadal Survey
- 2013 European Strategy for Particle Physics

2014 P5 Plan at a glance



Particle physics is global

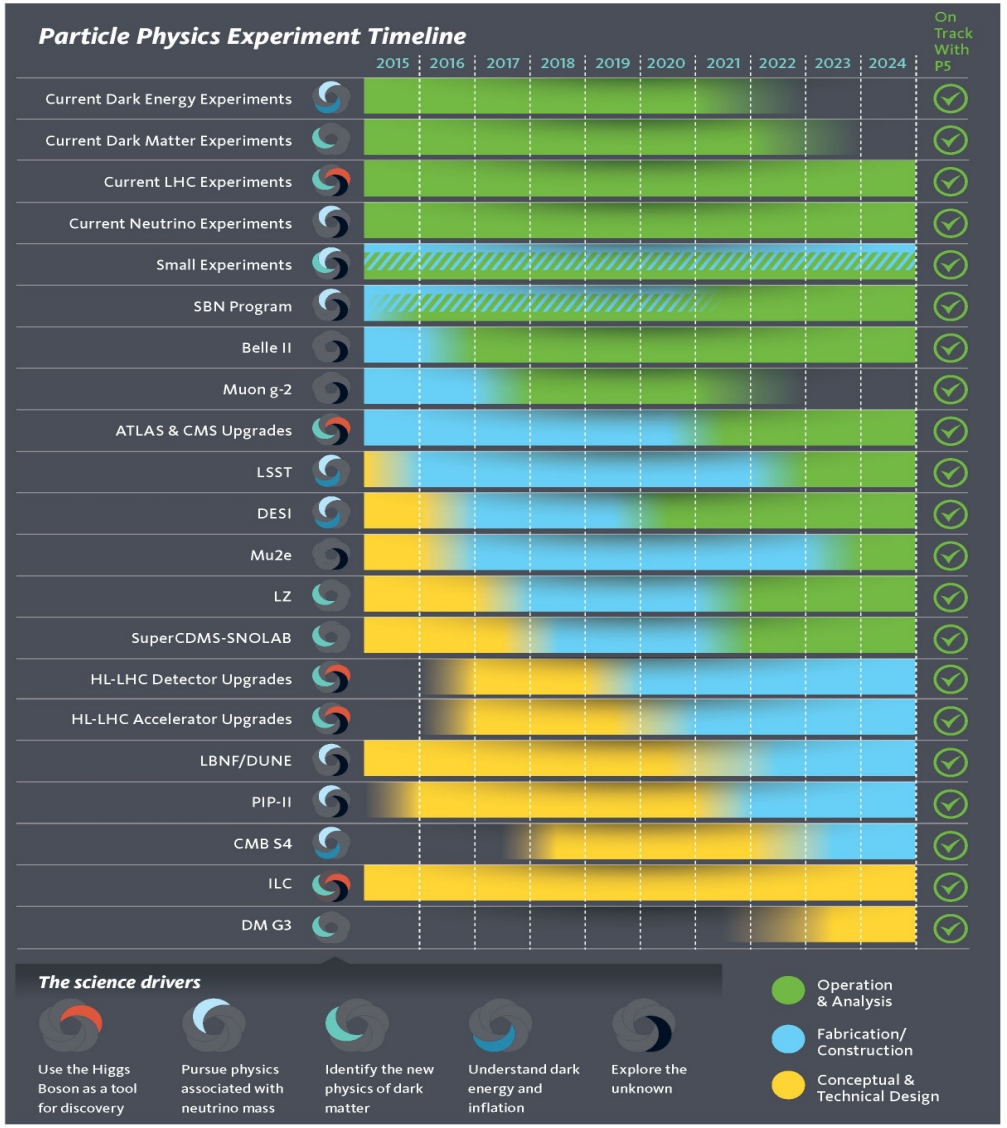
Centered on 5 Science Drivers

- Higgs Boson as a tool for discovery
- Physics associated with Neutrino mass
- Identify the nature of Dark Matter
- Understand Cosmic Acceleration
- Exploring the Unknown

Mix of projects of all scales

Balance Research, Operations & Projects

P5 Plan in 2022: 8 yrs into the Plan



P5 projects report card

8 Projects have been completed (and transitioned to commissioning & operations)

- Belle-2, Muon g-2, Phase I ATLAS, Phase I CMS
- CD-4 in 2020: DESI and LZ
- CD-4 in 2021: FACET-II and LSSTCamera

4 Projects at CD-2/3 (Baseline/Construction)

- HL-AUP, Mu2e, PIP-II, Super-CDMS

3 Projects at CD-1 (preparing for baseline)

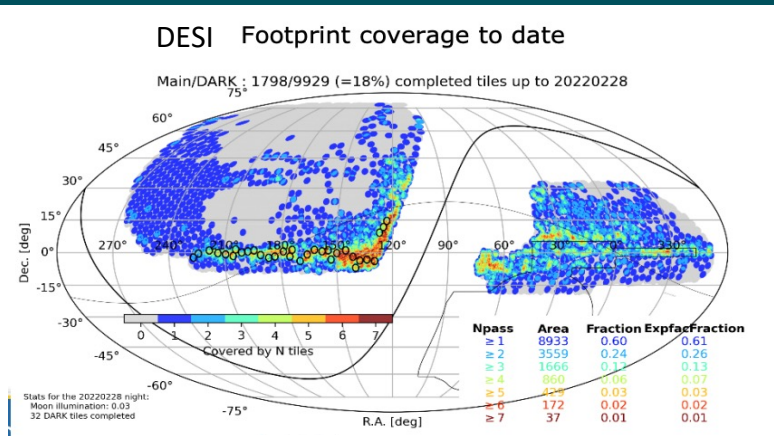
- HL-ATLAS, HL-CMS, LBNF/DUNE

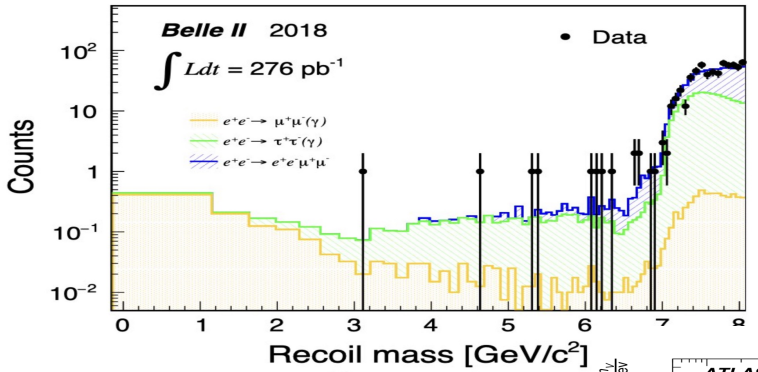
1 Project at CD-0

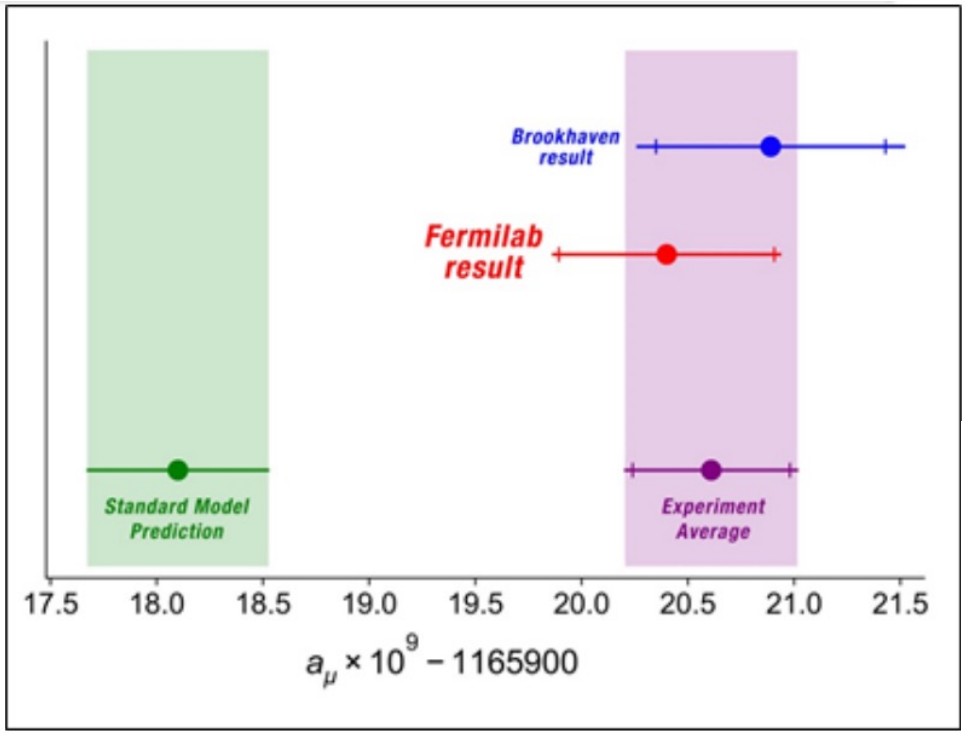
- CMB-S4

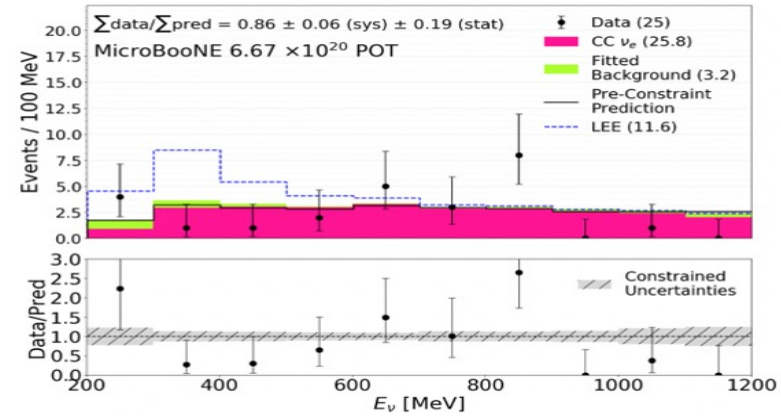
Broad portfolio of small projects from R&D phase to operations

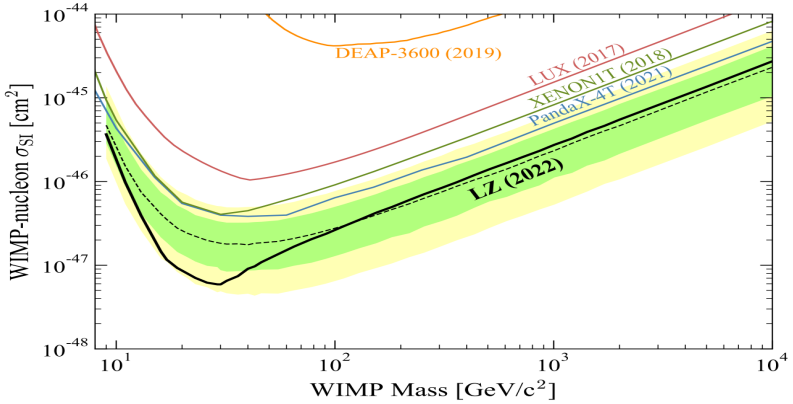
Reaping Science from Recently Completed Projects

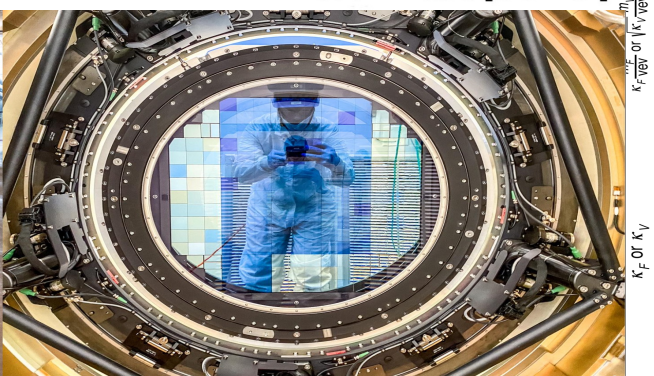


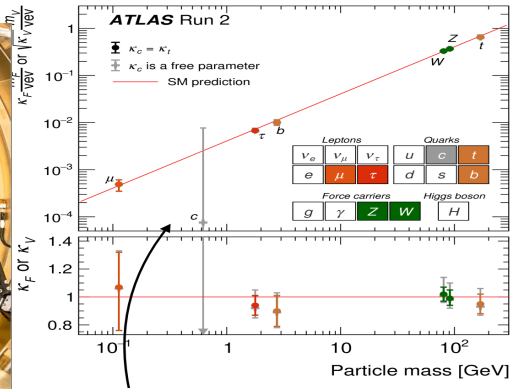


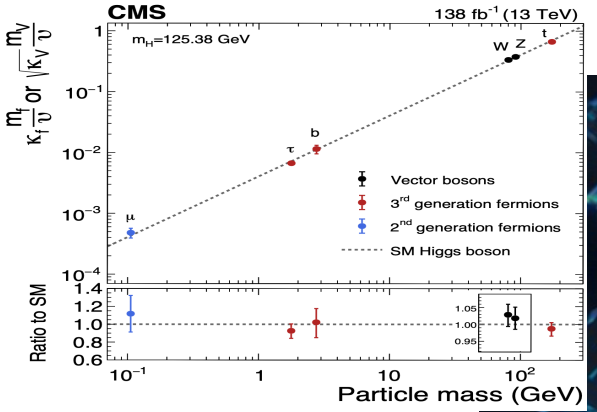




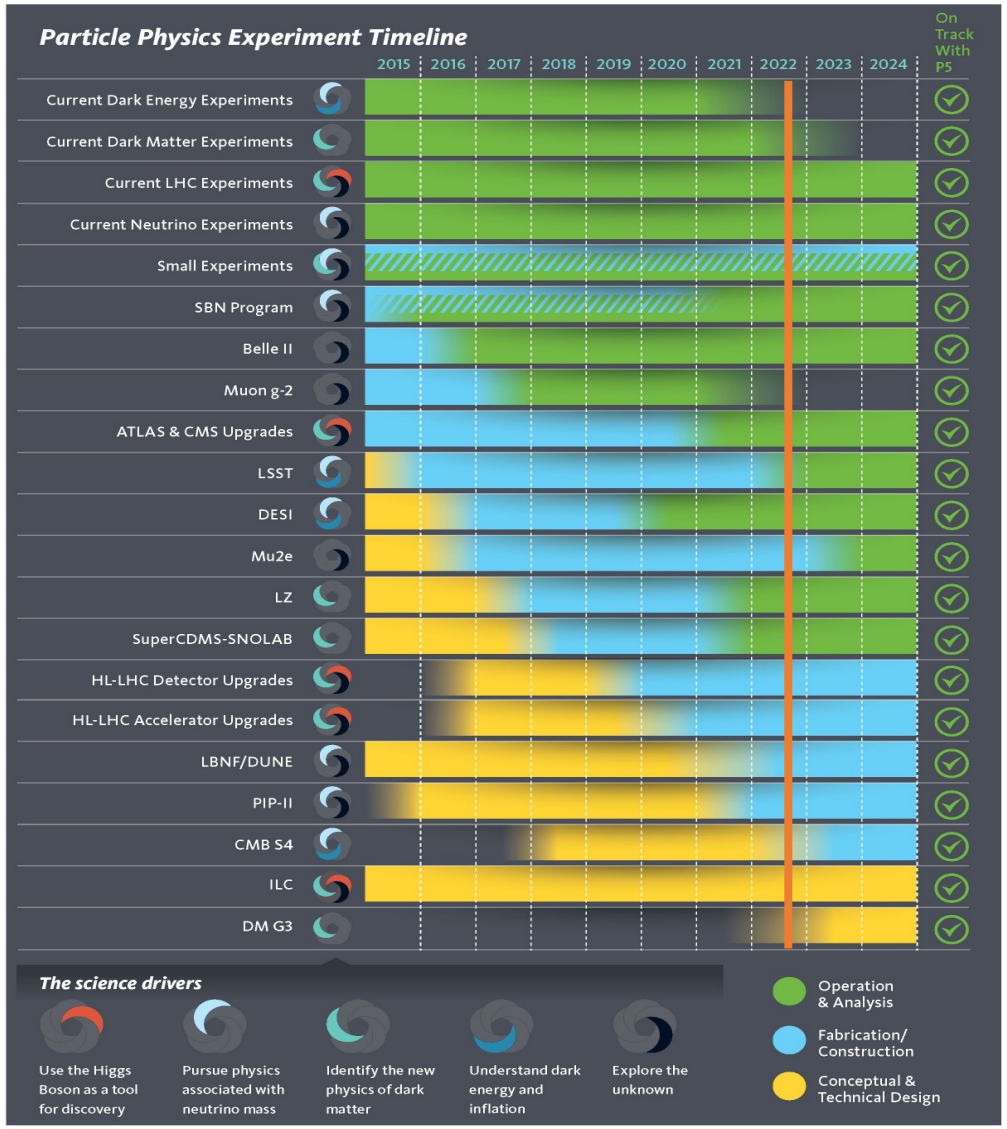








How do we know the time is right for a new strategic plan?



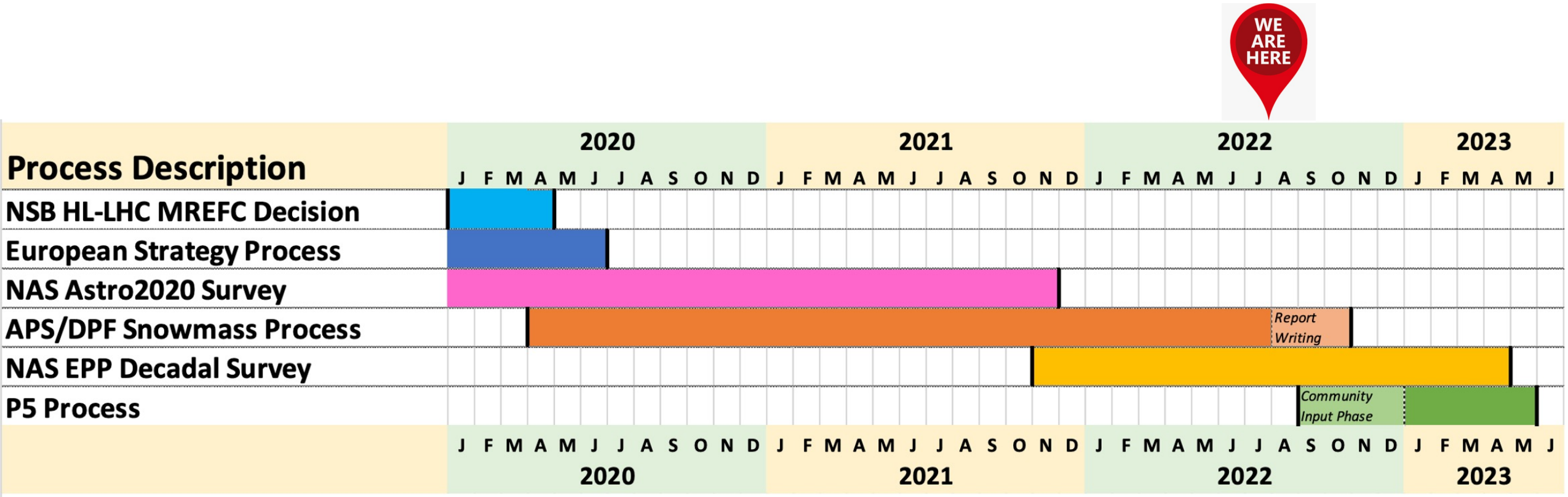
Healthy HEP program requires a mix of project stages

Yesterday's projects lead to today's science

Today's projects lead to tomorrow's science

Planning for the next decade(s)

2020's U.S. Strategic Planning Timeline



There are a lot of moving parts and pieces!

Snowmass is critical piece of U.S. strategic planning

Unique, key elements of Snowmass

- Community driven
- Science driven
- Everyone can contribute
- Full coverage of the field
- Vision of what could be
- Brings science communities together
- Brings different generations of researchers together
- Defines key scientific questions and approaches

Snowmass results guide the direction of the field and are the scientific input to the next P5

1984 DPF Summer Study on the Design and Utilization of the Superconducting Super Collider (SSC) (Snowmass 84)

23 June-13 July 1984. Snowmass, CO, United States (C84-06-23)

Part of the SNOWMASS series

Note: CN changed to QCD184:S7:1984 (SSC), and back to follow Snowmass series

Physics of the Superconducting Supercollider: Proceedings, 1986 Summer Study, June 23 - July 11, 1986, Snowmass, Colorado

R. Donaldson (LBL, Berkeley)(ed.), J.N. Marx (LBL, Berkeley)(ed.)
1986

770 pages

Contribution to: Snowmass '86 Summer Study on the Physics of the Superconc

Published: 1988 in New York by American Institute of Physics

High-energy physics in the 1990s. Proceedings, Summer Study, Snowmass, USA, June 27 - July 15, 1988

Sharon Jensen (SLAC)(ed.)
1989

914 pages

Contribution to: 1988 DPF Summer Study on High-energy Physics in the 1990s (Snowmass 88)

Report number: SLAC-REPRINT-1988-002

Proceedings of the 1996 DPF/DPB Summer Study on New Directions in High-energy Physics

Proceedings of Snowmass 2001

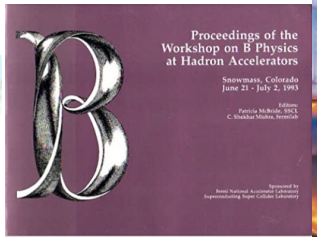
Snowmass Village, Colorado
June 30--July 21

Proceedings, 2005 International Linear Collider Physics and Detector Workshop and 2nd ILC Accelerator Workshop (Snowmass 2005)

Norman A. Graf
Jun 21, 2006

Contribution to: 2005 International Linear Collider Physics and Detector Workshop and 2nd ILC Accelerator Workshop

Report number: SLAC-R-798



Snowmass is finally here!

Snowmass is finally here!

Community Study ("Snowmass"): 2020-2022

- Organized by Division of Particles and Fields of the

  American Physical Society

- Define most important questions in the field
- Identify promising opportunities to address them

- ~700 Whitepapers submitted
- 1328 participants
- Snowmass "Book" finalized in Fall 2022

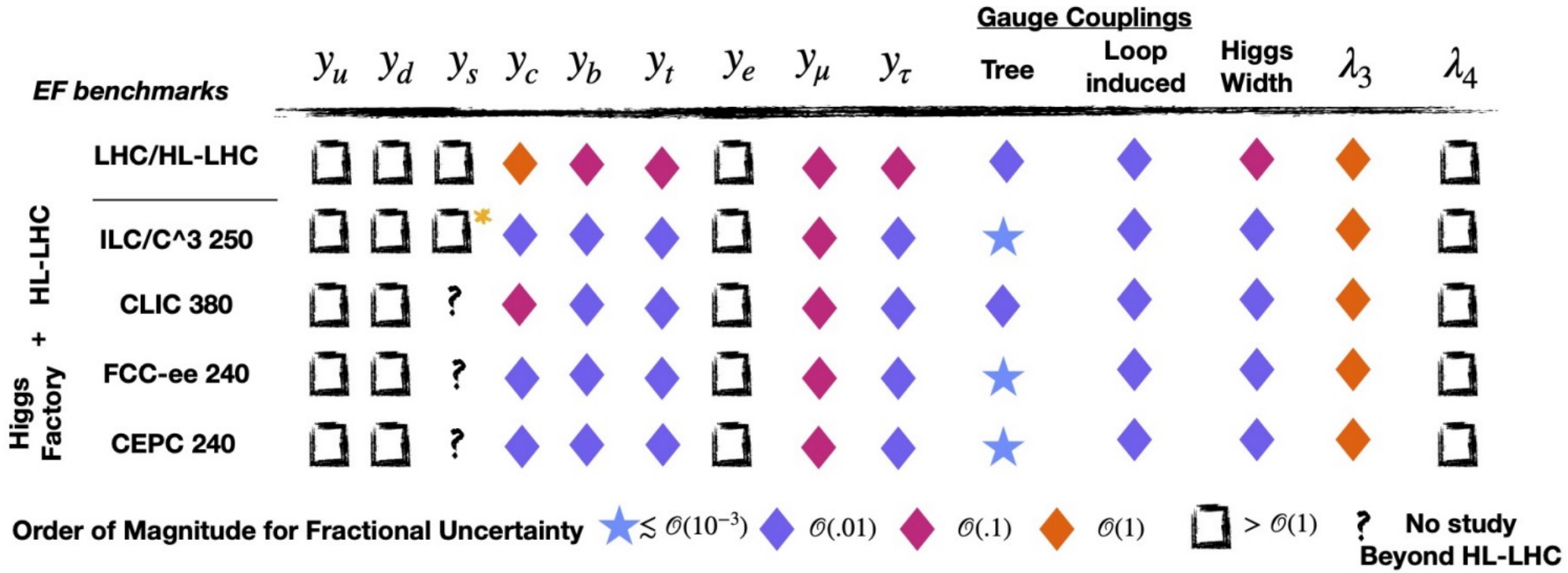
10 Frontiers!

- Energy Frontier
- Frontiers in Neutrino Physics
- Frontiers in Rare Processes & Precision Measurements
- Cosmic Frontier
- Theory Frontier
- Underground Facilities and Infrastructure Frontier
- Accelerator Frontier
- Instrumentation Frontier
- Computational Frontier
- Community Engagement Frontier

Selected Highlights from Snowmass Studies*

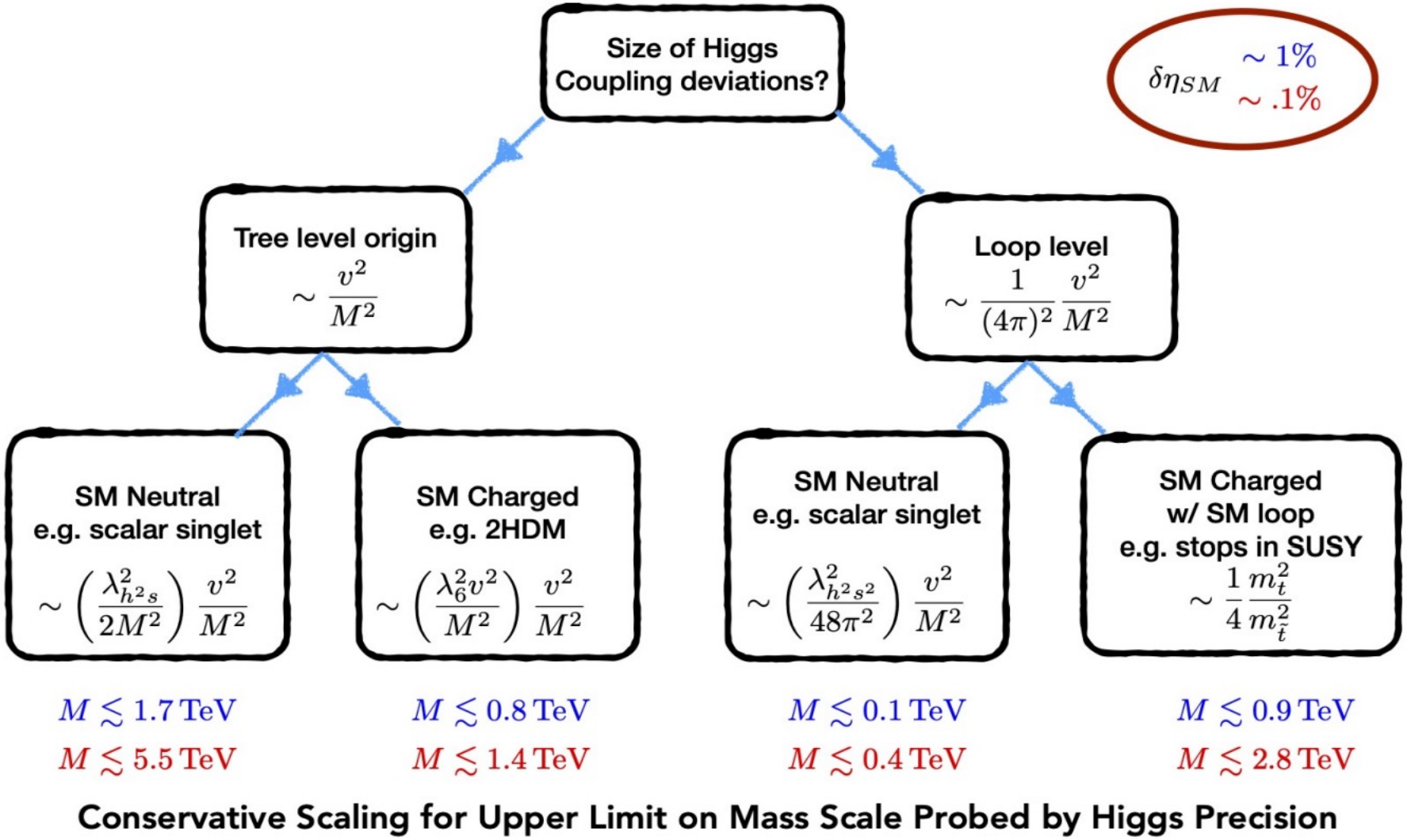
*Preliminary results from preliminary working group reports

Higgs coupling precision measurements



https://snowmass21.org/_media/energy/snowmass2021_higgs_reportv2.pdf

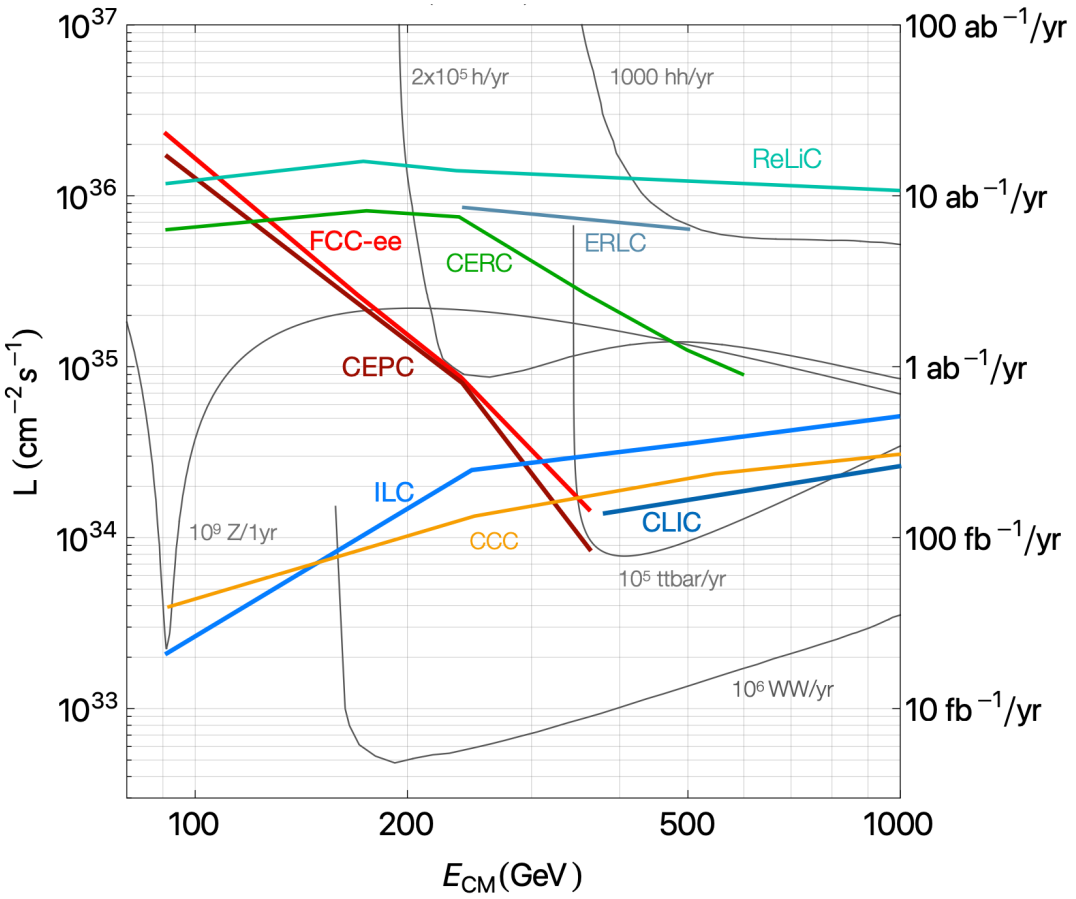
Interplay of Precision Higgs and Direct Searches



Conservative Scaling for Upper Limit on Mass Scale Probed by Higgs Precision

https://snowmass21.org/_media/energy/snowmass2021_higgs_reportv2.pdf

Higgs Factory Concepts



Cost estimates

Project Cost (no esc., no cont.)	4	7	12	18	30	50
FCCee-0.24						
FCCee-0.37						
FNAL eeHF						
ILC-0.25						
ILC-0.5						
CLIC-0.38						
CCC-0.25						
CCC-0.55						
CERC-0.24						
CERC-0.6						
ReLiC-0.25						
ERLC-0.25						
MuColl-0.125						
XCC-0.125						

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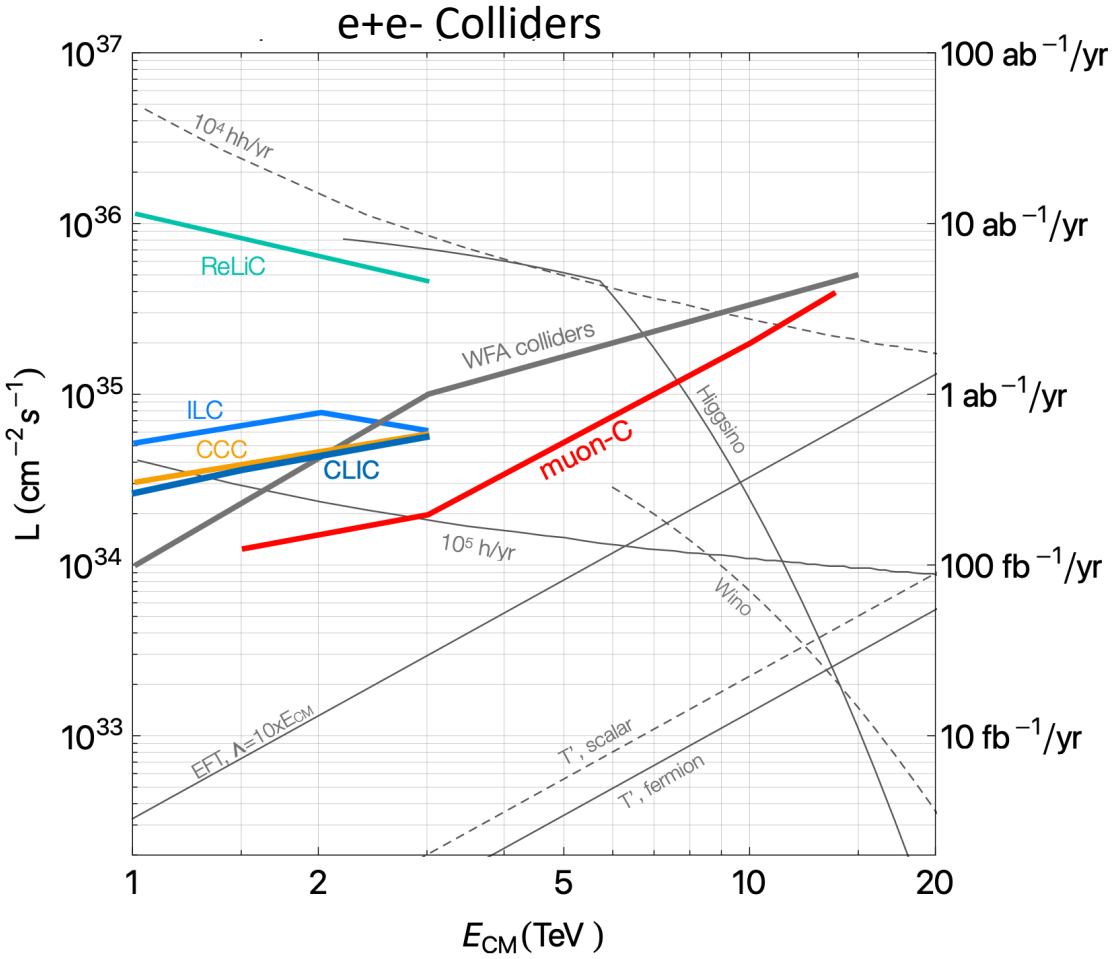
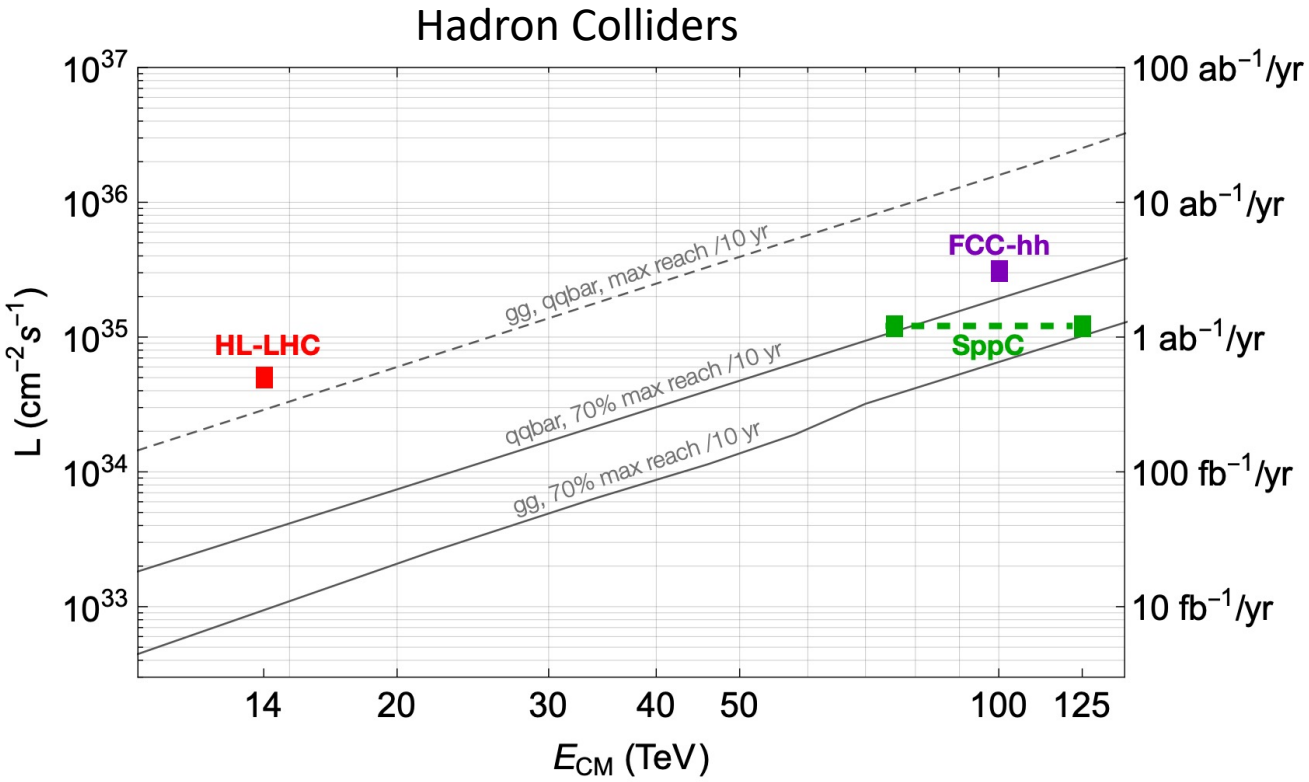
Energy Frontier Accelerator Concepts





https://indico.fnal.gov/event/22303/contributions/245261/attachments/157255/205819/2022%2007%2018%20ITF%20Snowmass%20talk.pdf

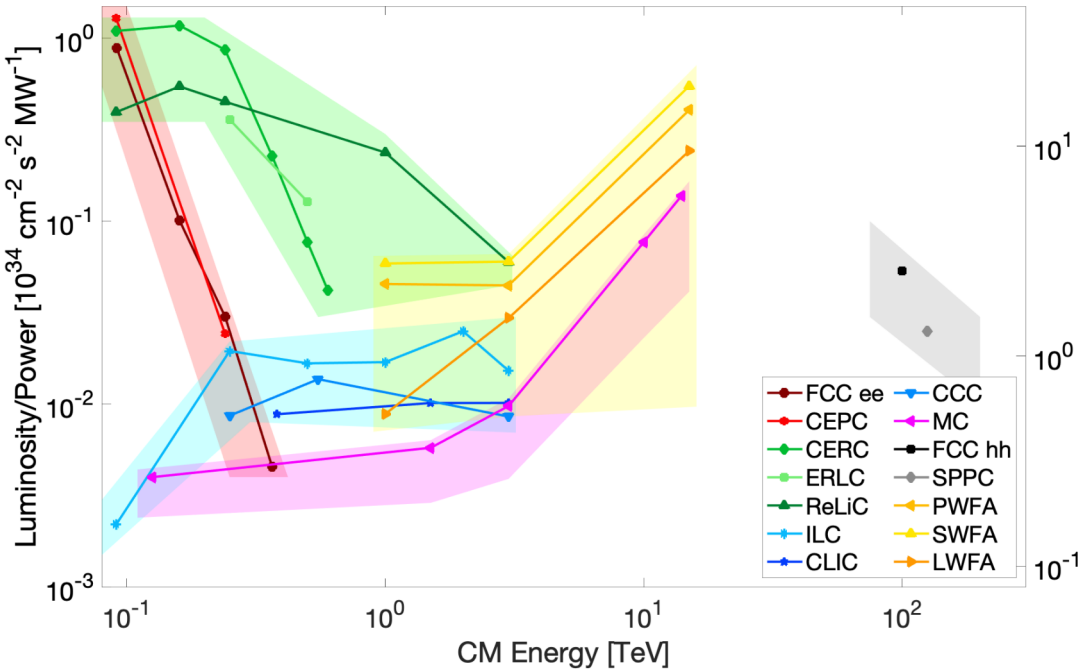
Technical Readiness of Collider Proposals

Technical Risk	Score	Color Code
TRL = 1,2	4	
TRL = 3,4	3	
TRL = 5,6	2	
TRL = 7,8	1	

Proposal Name (c.m.e. in TeV)	Collider Design Status	Lowest TRL Category	Technical Validation Requirement	Cost Reduction Scope	Performance Achievability	Overall Risk Tier
FCCee-0.24	II					1
CEPC-0.24	II					1
ILC-0.25	I					1
CCC-0.25	III					2
CLIC-0.38	II					1
CERC-0.24	III					2
ReLiC-0.24	V					2
ERLC-0.24	V					2
XCC-0.125	IV					2
MC-0.13	III					3
ILC-3	IV					2
CCC-3	IV					2
CLIC-3	II					1
ReLiC-3	IV					3
MC-3	III					3
LWFA-LC 1-3	IV					4
PWFA-LC 1-3	IV					4
SWFA-LC 1-3	IV					4
MC 10-14	IV					3
LWFA-LC-15	V					4
PWFA-LC-15	V					4
SWFA-LC-15	V					4
FCChh-100	II					3
SPPC-125	III					3
Coll.Sea-500	V					4

Environmental Impact

Luminosity per power consumption

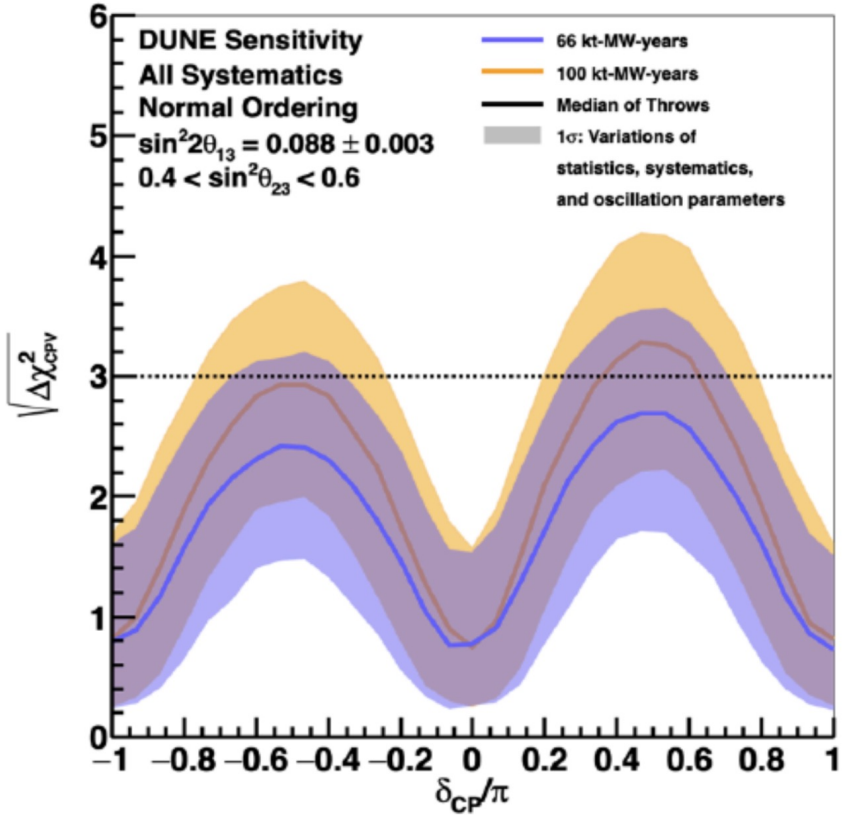


Proposal Name	Power Consumption	Size	Complexity	Radiation Mitigation
FCC-ee (0.24 TeV)	280	91 km	I	I
CEPC (0.24 TeV)	340	100 km	I	I
ILC (0.25 TeV)	140	14 km	I	I
CLIC (0.38 TeV)	170	13.4 km	II	I
CCC (0.25 TeV)	150	3.7 km	I	I
CERC (0.24 TeV)	90	100 km	II	I
ReLiC (0.24 TeV)	370	20 km	II	I
ERLC (0.24 TeV)	250	60 km	II	I
XCC (0.125 TeV)	90	1.4 km	II	I
MC (0.13 TeV)	200	3 km	I	II
ILC (3 TeV)	~400	59 km	II	II
CLIC (3 TeV)	~550	42 km	III	II
CCC (3 TeV)	~700	26.8 km	II	II
ReLiC (3 TeV)	~780	360 km	III	I
MC (3 TeV)	~230	10-20 km	II	III
LWFA (3 TeV)	~340	1.3 km	II	I
PWFA (3 TeV)	~230	14 km	II	II
SWFA (3 TeV)	~170	18 km	II	II
MC (14 TeV)	~300	27 km	III	III
LWFA $\gamma\gamma$ (15 TeV)	~210	6.6 km	III	I
PWFA $\gamma\gamma$ (15 TeV)	~120	14 km	III	II
SWFA $\gamma\gamma$ (15 TeV)	~90	90 km	III	II
FCC-hh (100 TeV)	~560	91 km	II	III
SPPC (125 TeV)	~400	110 km	II	III

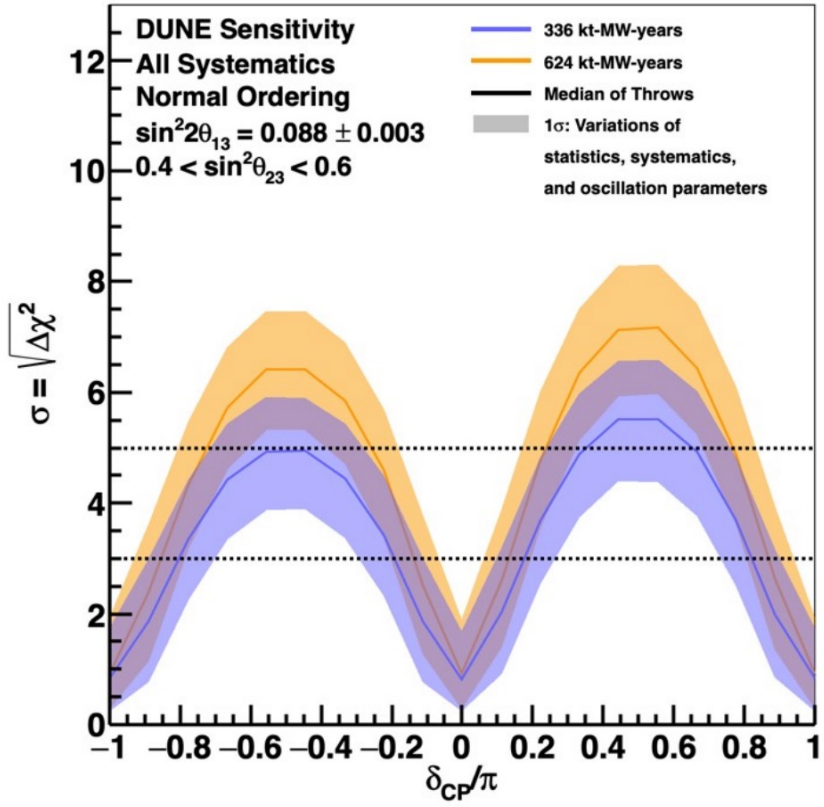
Long-Baseline Neutrino Oscillations: DUNE

Phase I and Phase II sensitivity to CP Violation

Phase I = 2 far detectors, near detector, 1.2 MW beam



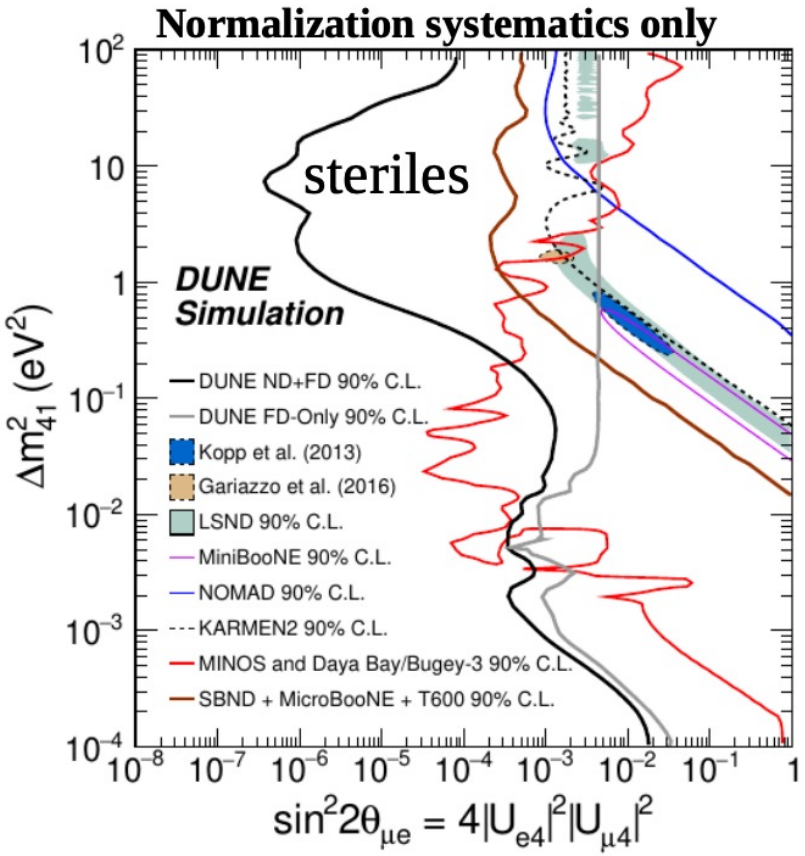
Phase II = 4 far detectors, upgraded near detector, 2.4 MW beam



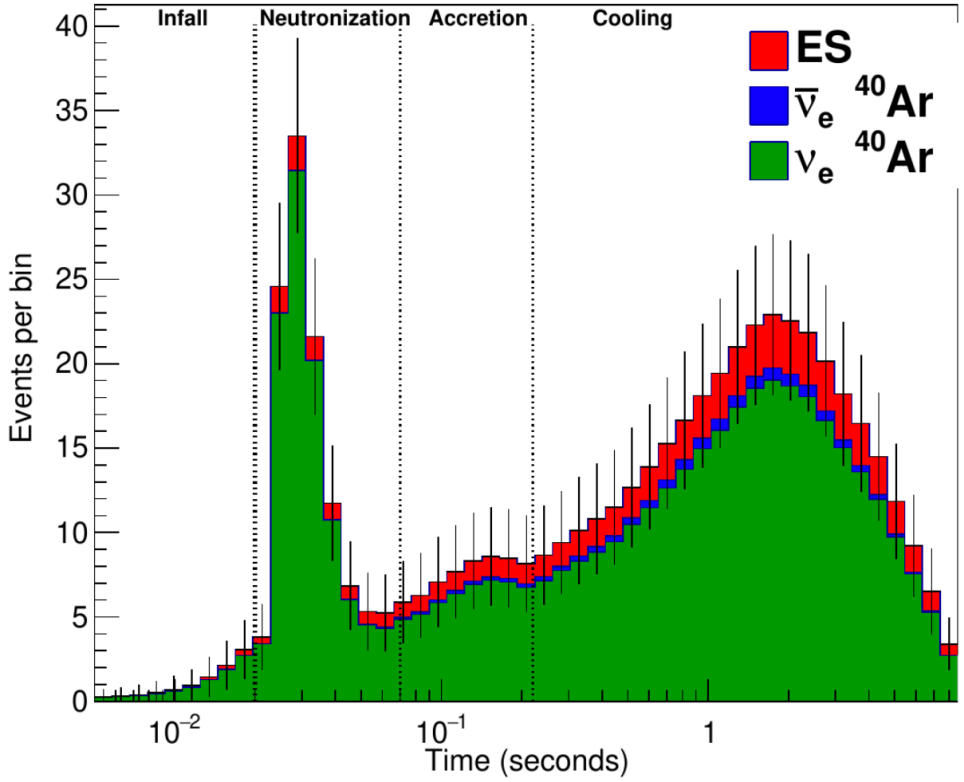
https://drive.google.com/file/d/1nJT0b4paucU2jDv7DMVpDYhXCg01XK_b/view

Other DUNE Science

Sensitivity to non-standard oscillations



Supernova neutrino time distribution, 10 kpc 20 kton fidicial mass



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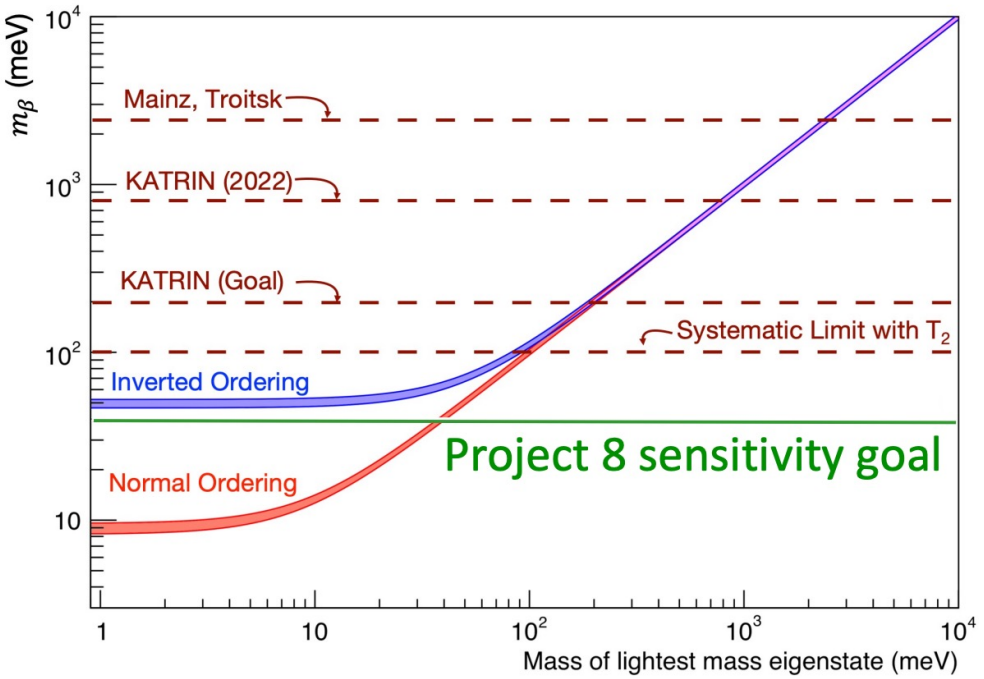
Neutrino Properties

Direct mass measurement

Future path of Project-8 with ultimate goal of 40 meV sensitivity (atomic tritium)



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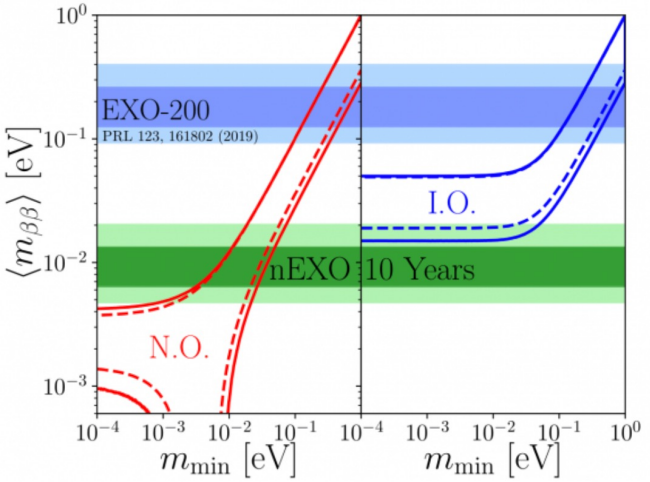
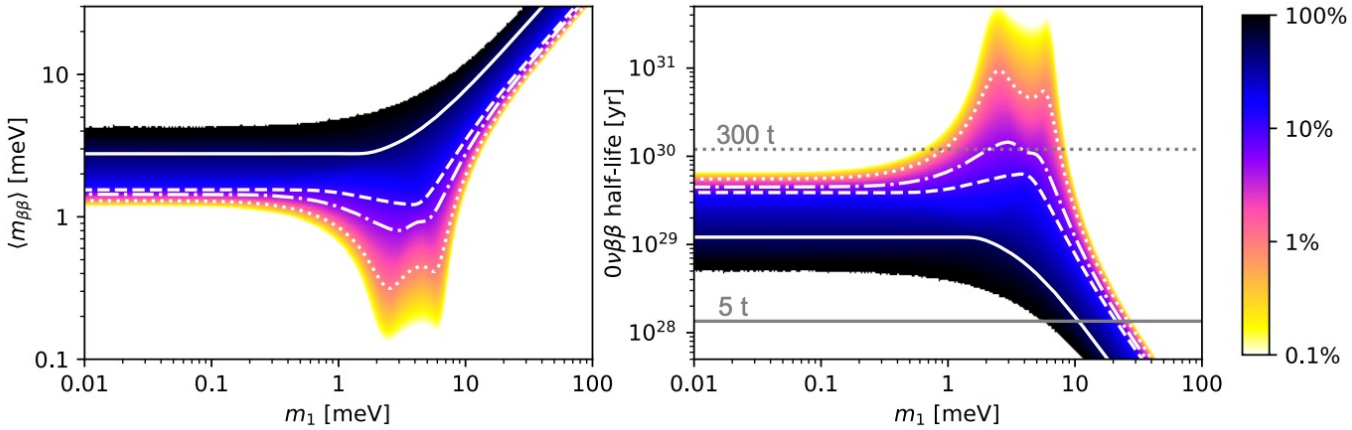
Neutrinoless double beta decay (Liquid Xe)

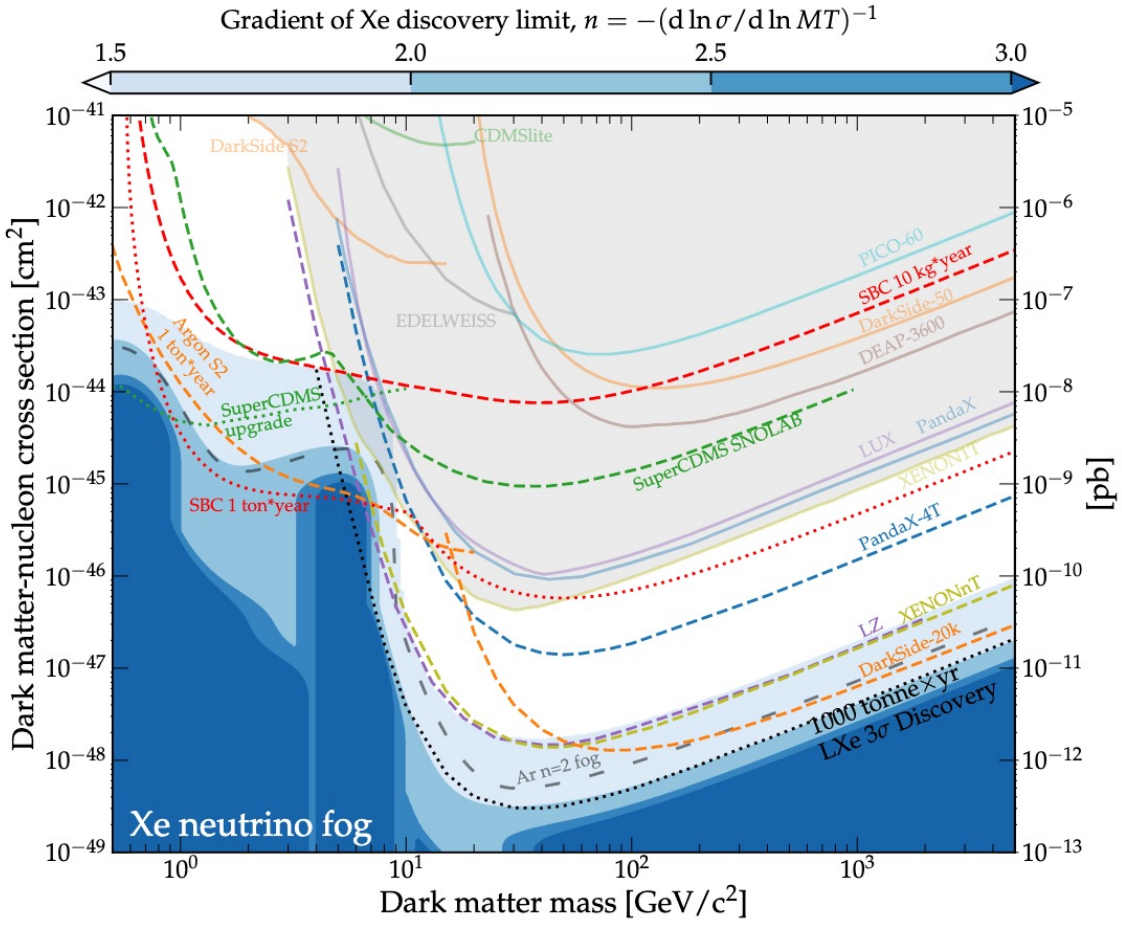


arXiv:2110.01537



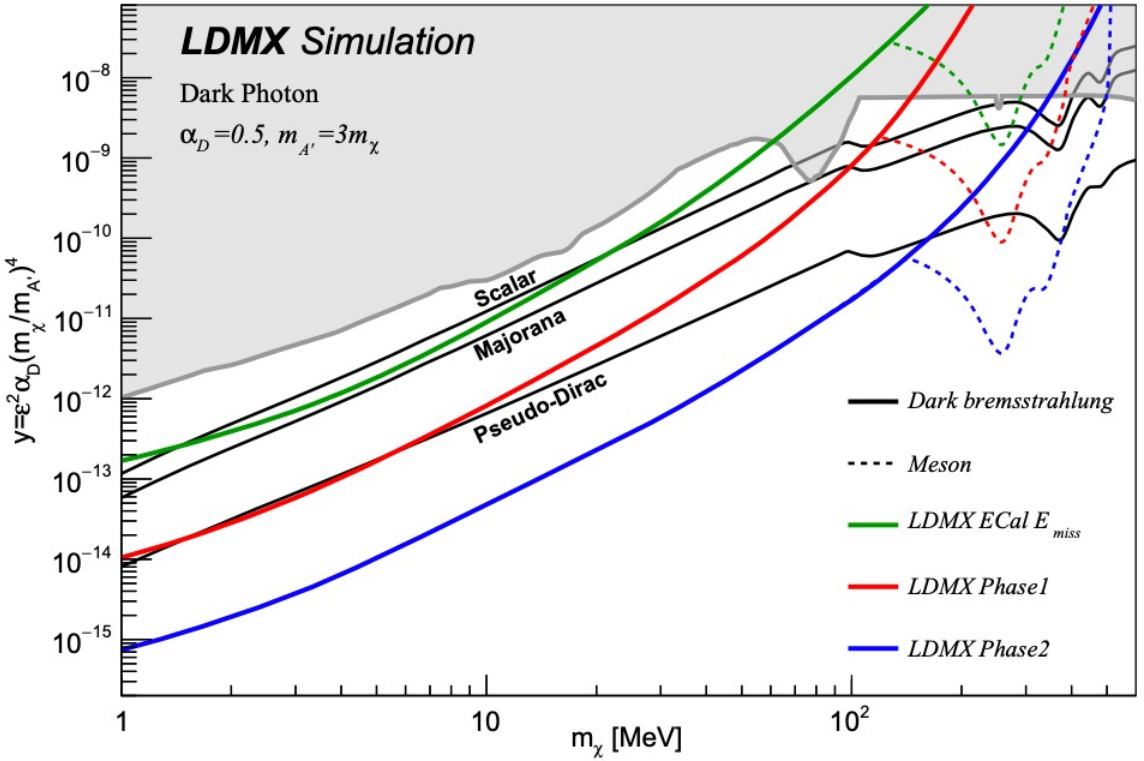
Particle-Like Dark Matter

Direct Detection Generation-3



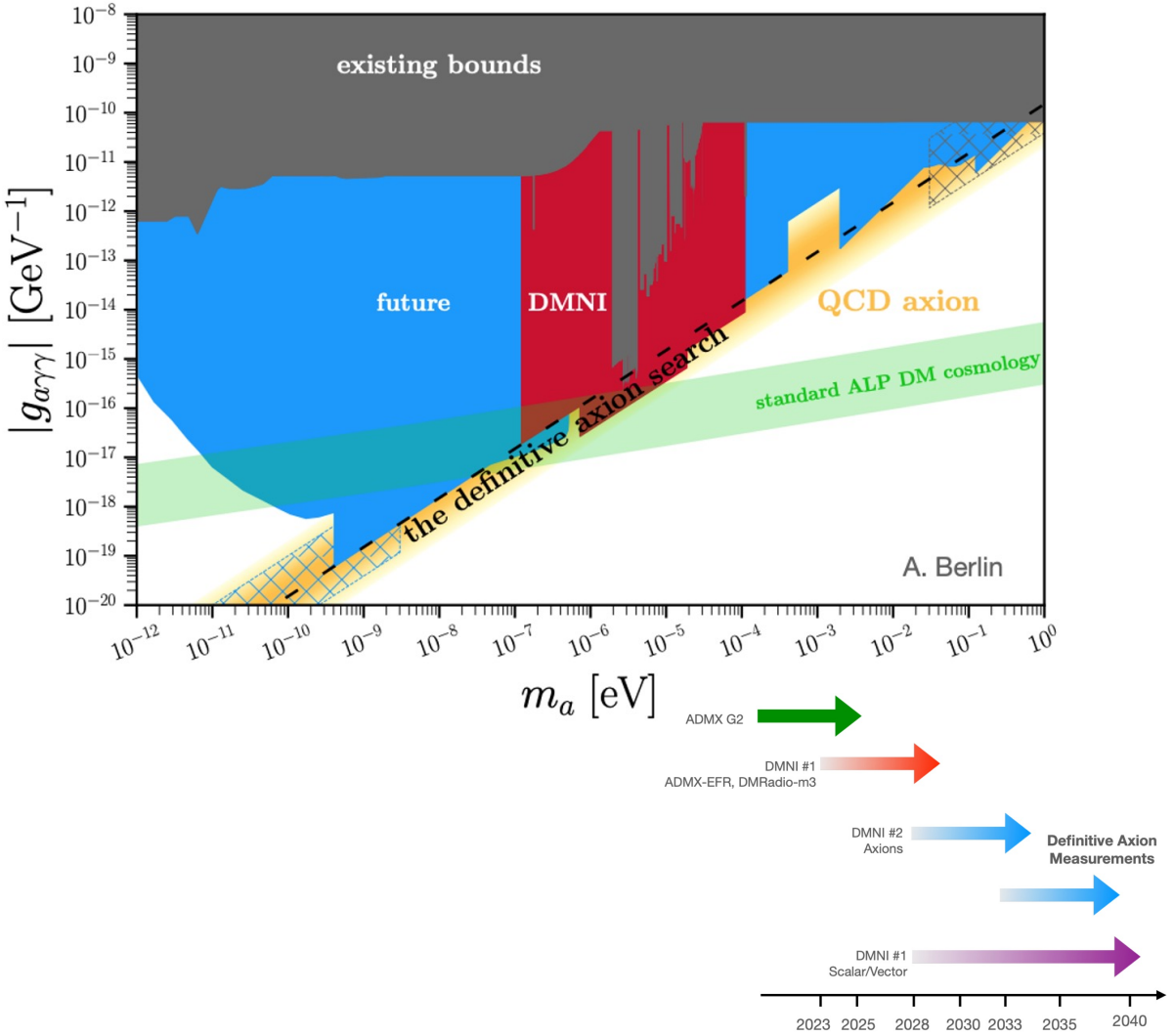
https://www.overleaf.com/project/6230f6d17d45434260f05329

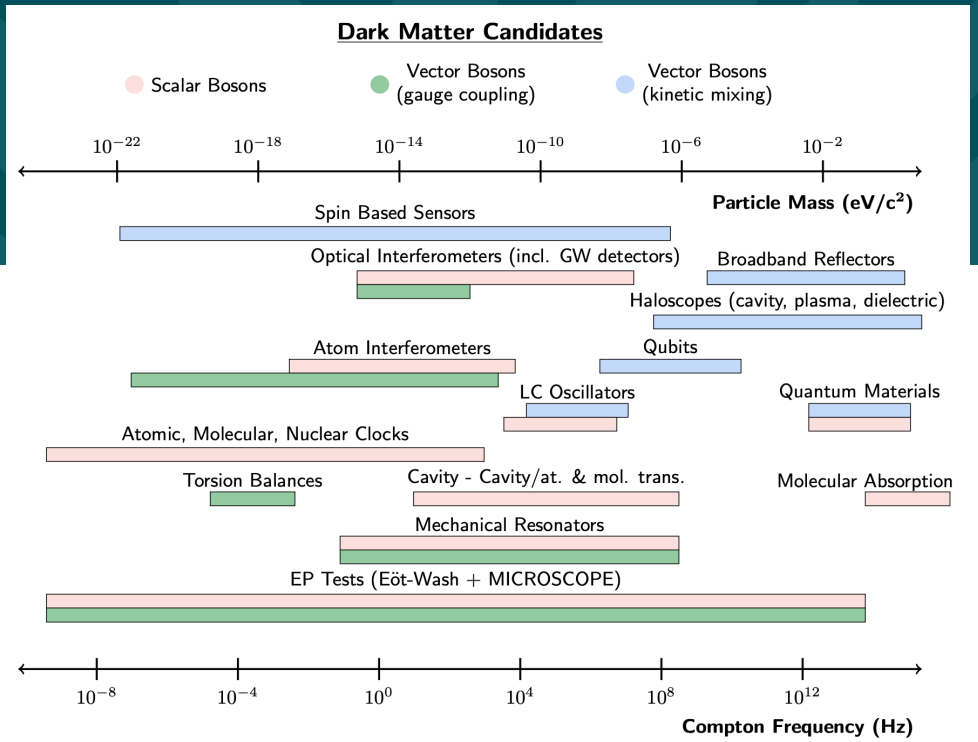
MeV-scale dark matter with intense e- beams

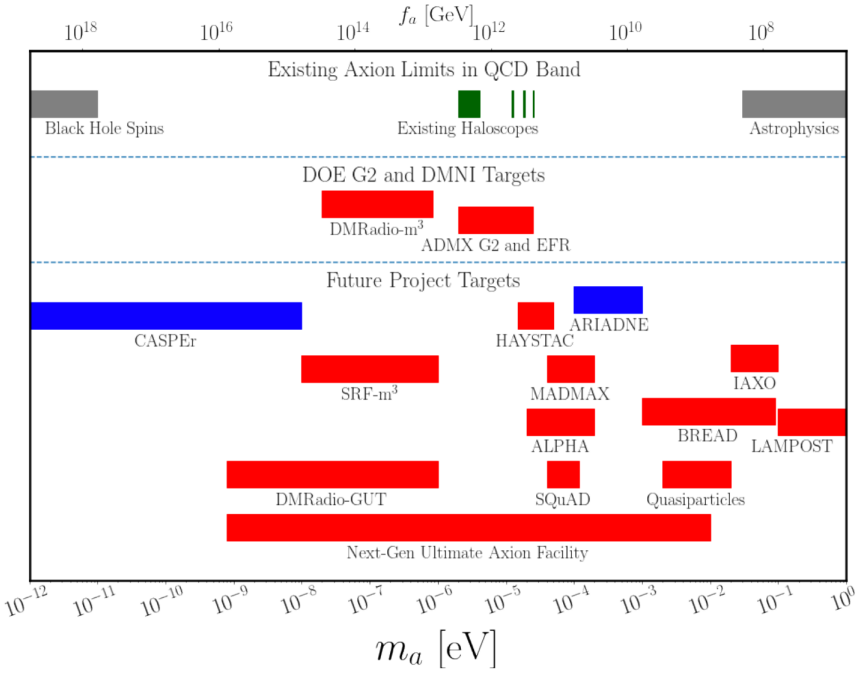


https://arxiv.org/pdf/2203.08192.pdf

Wave-like Dark Matter

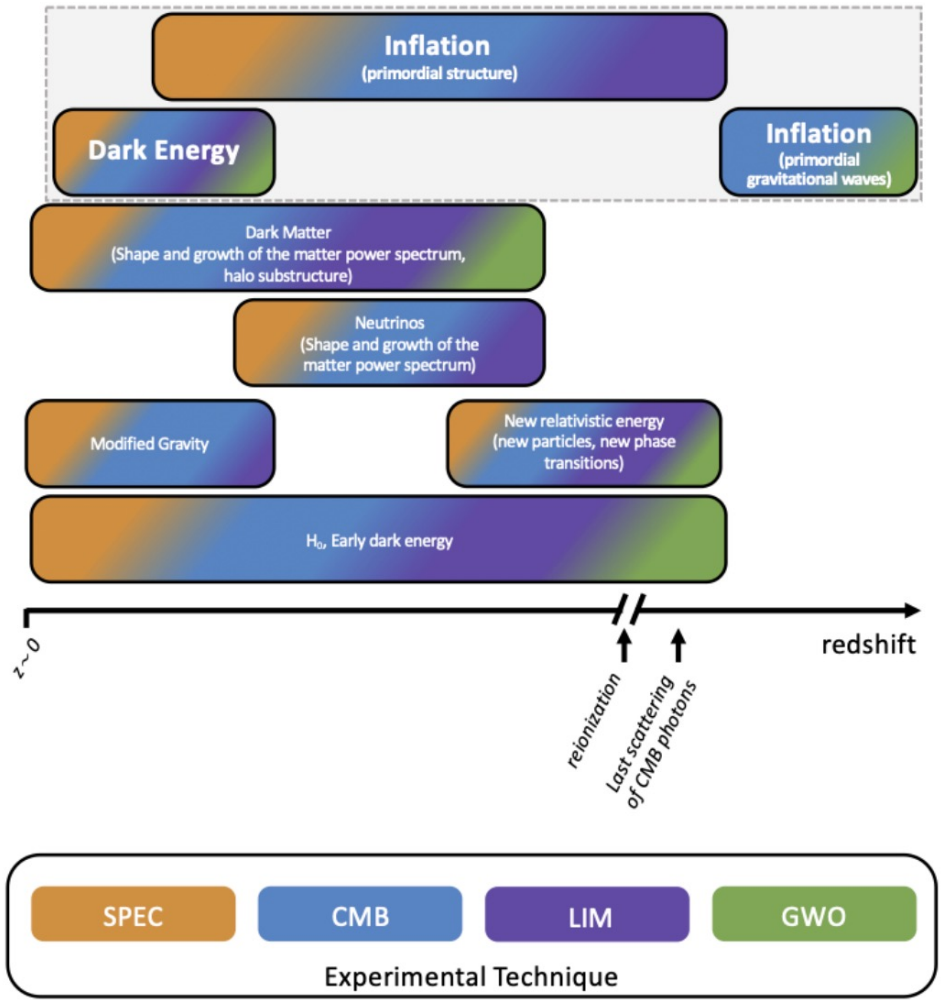


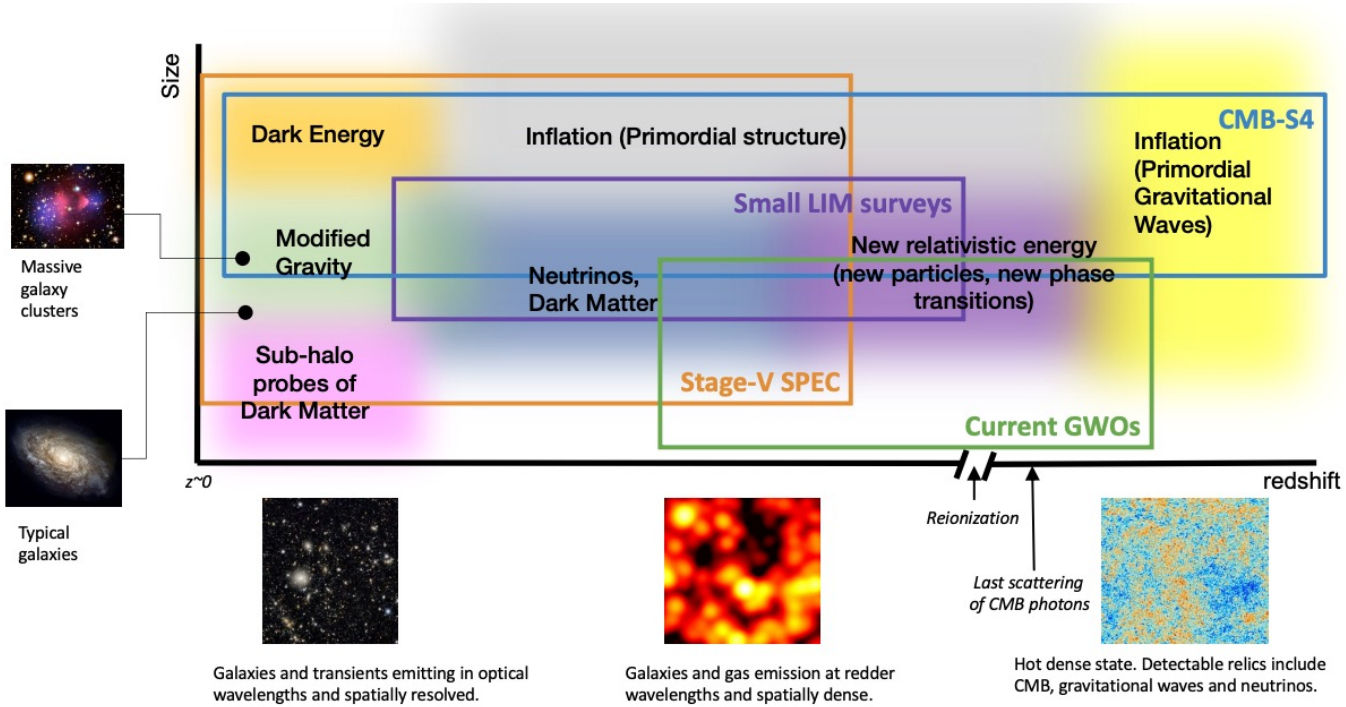




https://snowmass21.org/_media/cosmic/repv1_cf2.pdf

Cosmic Acceleration: Relating Techniques to Science Targets



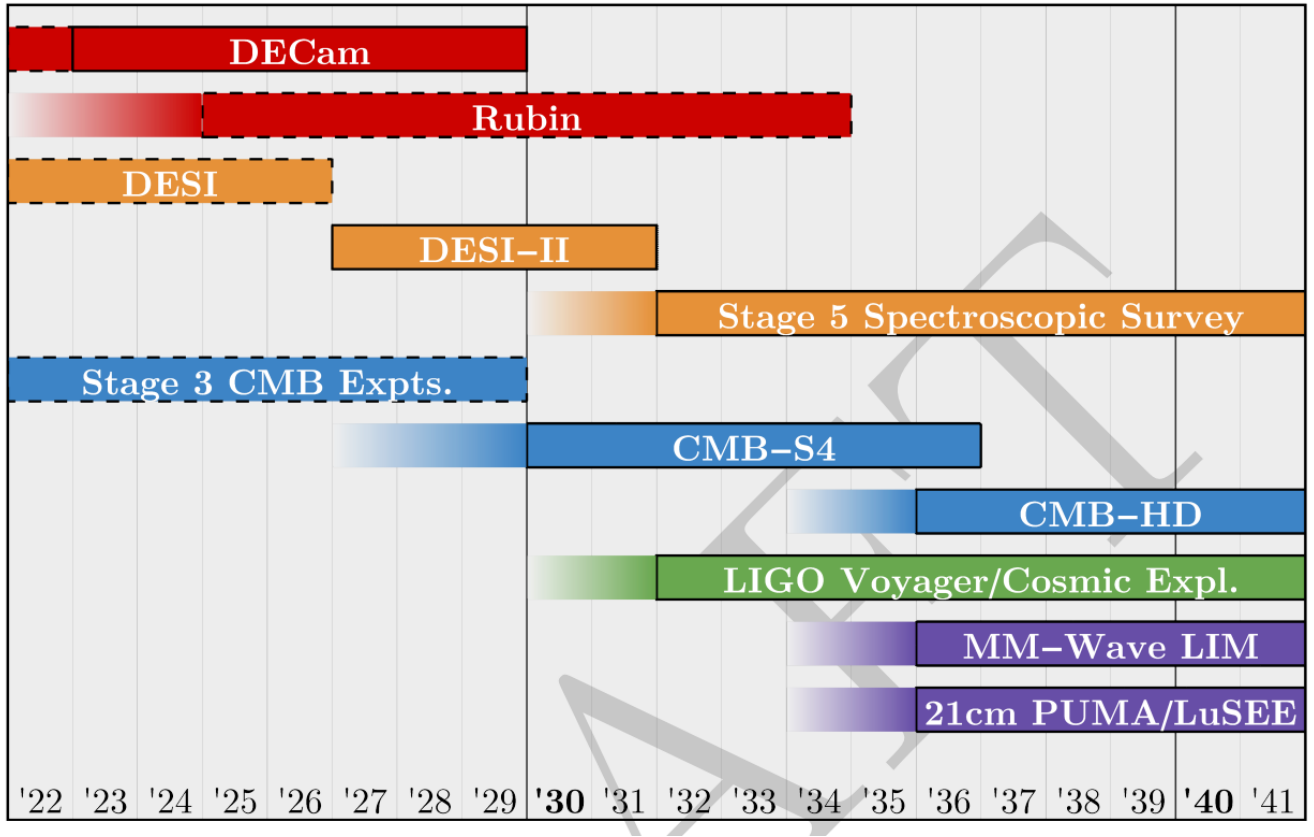


https://snowmass21.org/_media/cosmic/repv1_cf6.pdf, https://snowmass21.org/_media/cosmic/repv1_cf5.pdf

Cosmic Acceleration: Proposed Facilities Roadmap

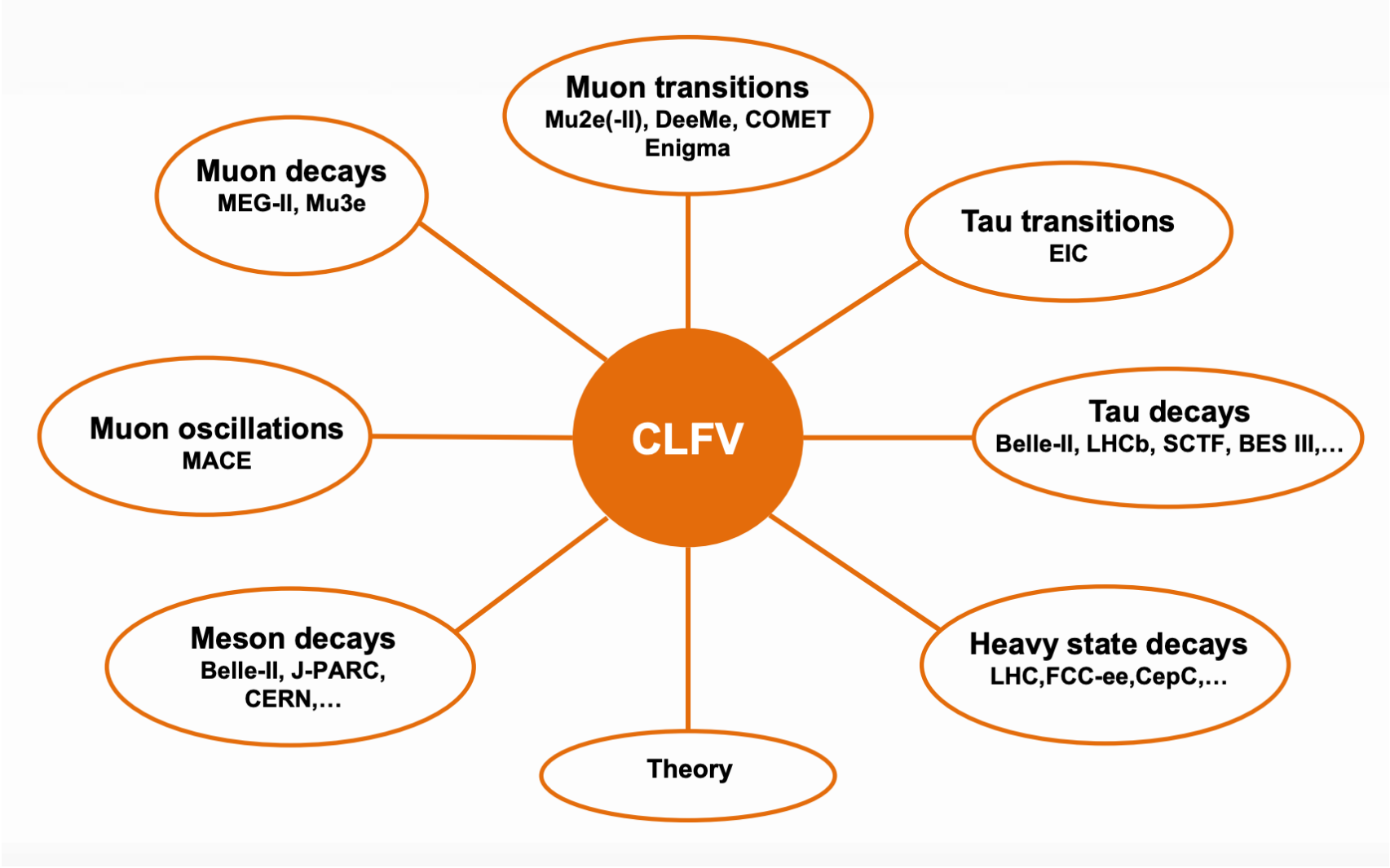
3D Mapping of the universe

	Experiment type	Concept	Redshift Range	Primordial FoM	Time-scale	Technical Maturity	Comments
DESI	spectro	5000 robotic fiber fed spectrograph on 4m Mayall telescope	$0.1 < z < 2.0$	0.88	now	operating	
Rubin LSST	photo	*ugrizy* wide FoV imaging on a 6.5m effective diameter dedicated telescope	$0 < z < 3$	-	2025-2035	on schedule	Targeting survey for next generation spectroscopic instruments
SPHEREx	narrow-band	Variable Linear Filter imaging on 0.25m aperture from space	$0 < z < 4$	-	2024	on schedule	Focus on primordial non-Gaussianity
MSE+[†]	spectro	up to 16,000 robotic fiber fed spectrograph on 11.25 m telescope	$1.6 < z < 4$ (ELG+LBG samples)	< 6.1	2029-	high	
MegaMapper	spectro	20,000 robotic fiber fed spectrograph on 6m Magellan clone	$2 < z < 5$	9.4	2029-	high	Builds upon existing hardware and know-how
SpecTel[†]	spectro	20,000-60,000 robotic fiber fed spectrograph on a dedicated 10m+ class telescope	$1 < z < 6$	< 23	2035-	medium	Potentially very versatile next generation survey instruments
PUMA	21 cm	5000-32000 dish array focused on intensity 21 cm intensity mapping	$0.3 < z < 6$	85 / 26 (32K / 5K optimistic)	2035-	to be demonstrated	Very high effective number density, but $k_\parallel$ modes lost to foregrounds
mm-wave LIM concept	mi-crowave LIM	500-30000 on-chip spectrometers on existing 5-10m telescopes, 80-300 GHz with R∼300-1000	$0 < z < 10$	up to 170	2035 -	to be demonstrated	CMB heritage, can deploy on existing telescopes, signal uncertain, $k_\parallel$ modes lost to foregrounds & resolution



https://snowmass21.org/_media/cosmic/repv1_cf6.pdf

Charged Lepton Flavor Violation



https://indico.fnal.gov/event/51844/contributions/240626/attachments/155112/201925/RPF-TG5-echenard.pdf

Summary

Stay tuned!

- Frontier summary talks next week

Many, many exciting physics opportunities ahead of us!

- Will need guidance from 2022-2023 P5