Panel on Small-to-Medium Experiments: RPF

captions go here

R. Bernstein
for the
Rare and Precision Frontier

And when I leave out your work, remember incompetence is usually a better explanation than conspiracy

What Did We Learn at Snowmass?

- Rare and Precision Frontier
  - has a shared vision that unites much of Frontier: physics of flavor and generations
  - tremendous range of experiments, theory techniques, and ideas
  - will cover small to medium experiments
    - that isn't precisely defined!

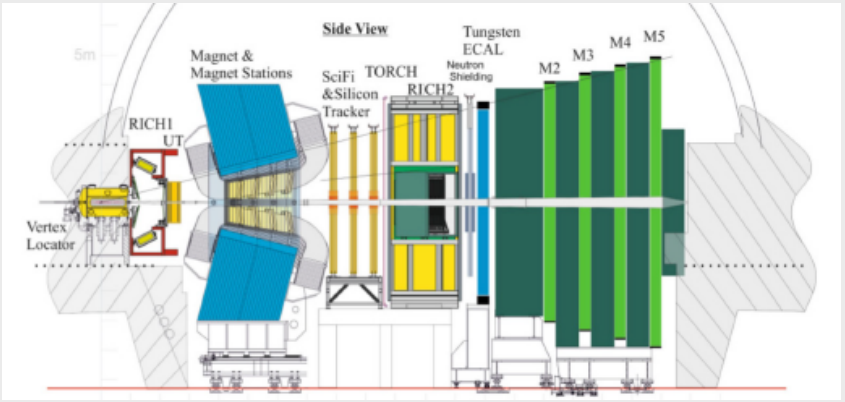
RPF Small/Medium Projects

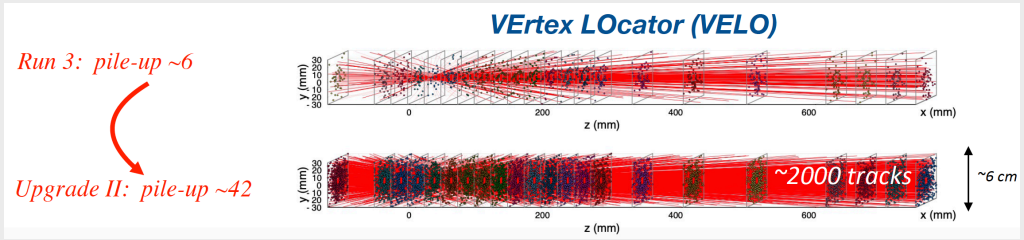
WG	Expt's	Goals (next decade)	Goals (10-20 years)
RF1: *b* and *c*	LHCb, BELLE-II	physics and phased upgrades	CKM tests; lepton universality; dark sector
RF2: light quarks	REDTOP η/η' factory	R&D	*C,P,T* violation; DM; LFV
RF3: small experiments	srEDM	Advanced proposal	10^{-29} e-cm, 300 TeV mass scale, 10 μrad CP
	AMO	choose overlap	EDMs,symmetry violation
RF5: CLFV	Mu2e-II	design	x10 Mu2e at PIP-II; possible change to Ti from AL
RF6: DM	DMNI	select/design experiments; LDMX can run	x10-100 progress in range of portals

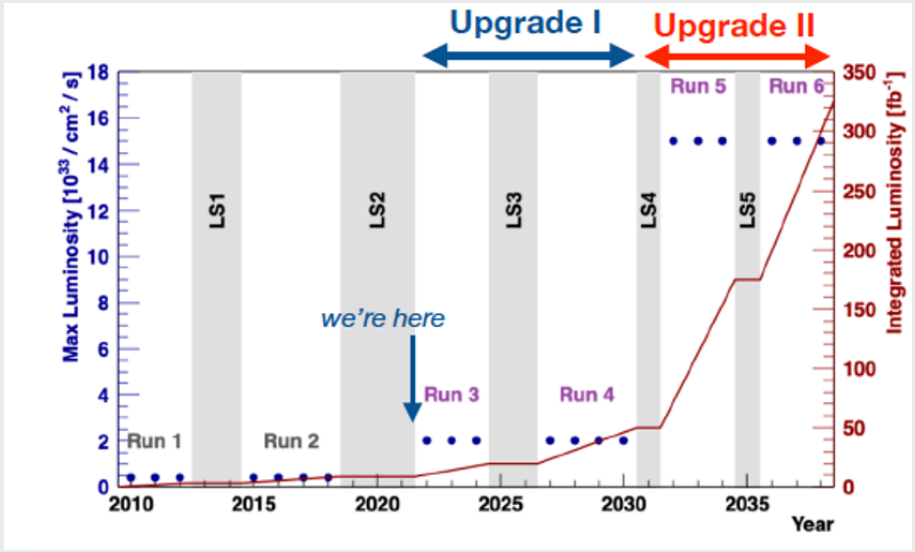
jargon: srEDM = storage ring proton EDM; AMF = advanced muon facility for muon CLFV and related physics; DMNI = dark matter new initiatives

RF1: *b* and *c* Weak Decays

- LHCb Phase II Upgrades: general purpose detector in forward region; spectroscopy, precision EW, dark sector and exotics; unprecedented CKM tests
- Granularity; Fast Timing; Radiation Hardness
  - Upgrade 1: purely software trigger: transformative!
    - and improved magnet chambers for lower momentum tracks, 2026, US leads!
  - Upgrade 2: same performance but with pileup ~40 vs ~6







R&D with TDRs in LS3 (2026); main installation in LS4 (2033-34)

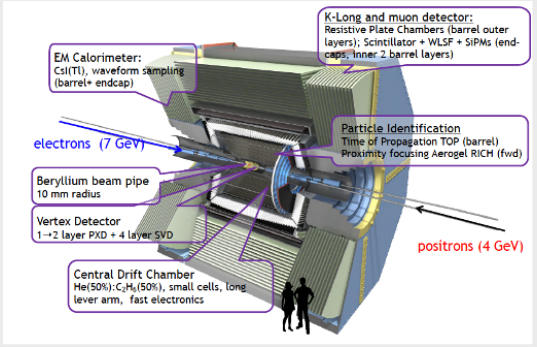
RF1: *b* and *c* Weak Decays

- BELLE-II
  - LS1: 2026-7; LS2> 2032
  - Intensity and Polarization
    1. ->1.2×10^{35} cm^{-2} s^{-1}
    2. ->6.5×10^{35} cm^{-2} s^{-1}
    3. polarization 70%
    4. Ultra-high 4×10^{36} cm^{-2} s^{-1}

beyond current programs

Observable	2022 Belle(II), BaBar	Belle-II 5 ab^{-1}	Belle-II 50 ab^{-1}	Belle-II 250 ab^{-1}
$\sin 2\beta/\phi_1$	0.03	0.012	0.005	0.002
γ/ϕ_3 (Belle+BelleII)	11°	4.7°	1.5°	0.8°
α/ϕ_2 (WA)	4°	2°	0.6°	0.3°
$\lvert V_{ub}\rvert$ (Exclusive)	4.5%	2%	1%	< 1%
$S_{CP}(B \to \eta' K^0_S)$	0.08	0.03	0.015	0.007
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	0.07	0.025	0.018
$S_{CP}(B \to K^{*0}\gamma)$	0.32	0.11	0.035	0.015
$R(B \to K^* \ell^+ \ell^-)^\dagger$	0.26	0.09	0.03	0.01
$R(B \to D^* \tau\nu)$	0.018	0.009	0.0045	<0.003
$R(B \to D \tau\nu)$	0.034	0.016	0.008	<0.003
$\mathcal{B}(B \to \tau\nu)$	24%	9%	4%	2%
$B(B \to K^* \nu\bar{\nu})$	–	25%	9%	4%
$\mathcal{B}(\tau \to \mu\gamma)$ UL	42×10^{-9}	22×10^{-9}	6.9×10^{-9}	3.1×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	3.6×10^{-9}	0.36×10^{-9}	0.073×10^{-9}

Table 2: Projected precision (total uncertainties, or 90% CL upper limits) of selected flavour physics measurements at Belle II.(The † symbol denotes the measurement in the momentum transfer squared bin $1 < q^2 < 6$ GeV/c^2.)



Subdector	Function	upgrade idea	time scale
PXD	Vertex Detector	2 layer installation	short-term
		new DEPFET	medium-term
SVD	Vertex Detector	thin, double-sided strips, w/ new frontend	medium-term
PXD+SVD	Vertex Detector	all-pixels: SOI sensors	medium-term
		all-pixels: DMAPS CMOS sensors	medium-term
CDC	Tracking	upgrade front end electronics	short/medium-term
		replace inner part with silicon	medium/long term
		replace with TPC w/ MPGD readout	long-term
TOP	PID, barrel	Replace conventional MCP-PMTs	short-term
		Replace not-life-extended ALD MCP-PMTs	medium-term
		STOPGAP TOF and timing detector	long-term
ARICH	PID, forward	replace HAPD with Silicon PhotoMultipliers	long-term
		replace HAPD with Large Area Picosecond Photodetectors	long-term
ECL	γ, e ID	add pre-shower detector in front of ECL	long-term
		Replace ECL PiN diodes with APDs	long-term
		Replace CsI(Tl) with pure CsI crystals	long-term
KLM	K_L, μ ID	replace 13 barrel layers of legacy RPCs with scintillators	medium/long-term
		on-detector upgraded scintillator readout	medium/long-term
		timing upgrade for K-long momentum measurement	medium/long-term
Trigger		firmware improvements	continuos
DAQ		PCIe40 readout upgrade	ongoing
		add 1300-1900 cores to HLT	short/medium-term

Table 1: Known short and medium-term Belle II subdetector upgrade plans, starting from the radially innermost. The current Belle II subdetectors are the Silicon Pixel Detector (PXD), Silicon Strip Detector (SVD), Central Drift Chamber (CDC), Time of Propagation Counter (TOP), Aerogel Rich Counter (ARICH), EM Calorimeter (ECL), Barrel and Endcap K-Long Muon Systems (BKLM, EKLM), Trigger and Data aquistion (DAQ). DAQ includes the high level trigger (HLT).

https://arxiv.org/pdf/2203.11349.pdf

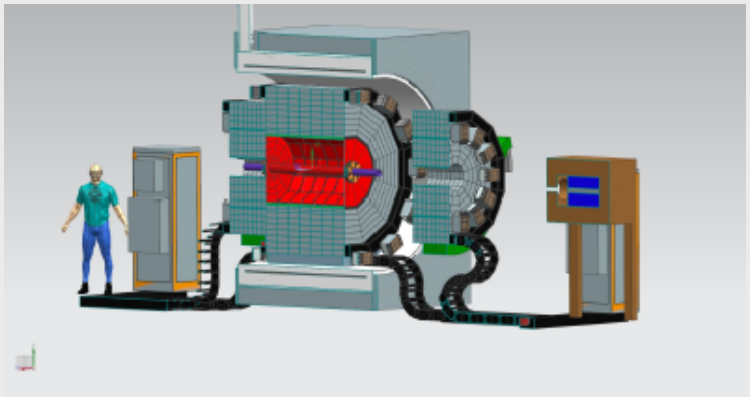
https://confluence.desy.de/display/BI/Snowmass+2021

A. Sibidanov et al., https://arxiv.org/abs/2203.07189

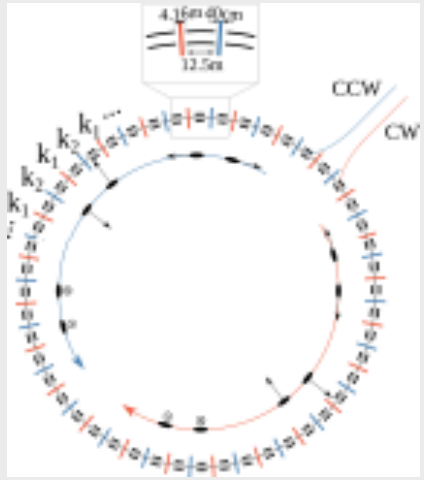
RF2: Strange and Light Quarks

https://arxiv.org/pdf/1910.08505.pdf

- η/η' factory (REDTOP). This has been suggested since at least the last P5 and proponents deserve a clear answer
  - *C*, *T, CP* violation
  - Discrete symmetries: LFV and LNV
  - DM in $\eta \to A'\gamma$



RF3:Fundamental Physics in Small Experiments



- proton EDM at 10^{-29} e·cm
  - mass scale at 10^3 TeV
  - sensitivity to θ_{QCD} (axions) at $10\,\mu$rad

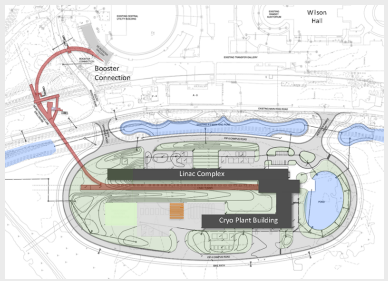
https://arxiv.org/abs/2205.00830

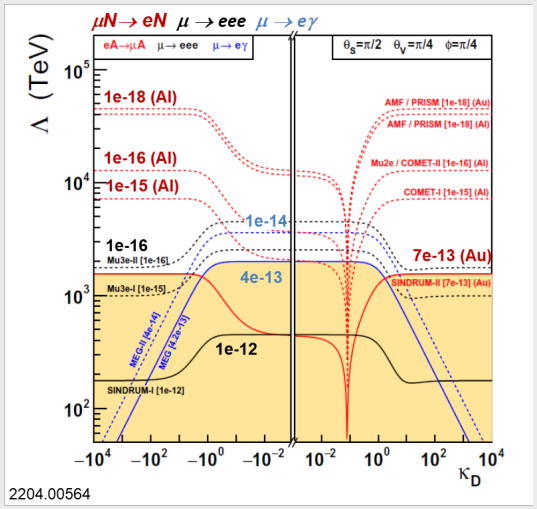
  - ***at Snowmass!*** we talked with proponents and BNL and the proponents are being encouraged to submit a technically advanced proposal.

- AMO physics: lots of possibilities for cross-disciplinary work. And ***at Snowmass!*** learned there are funding streams at DOE

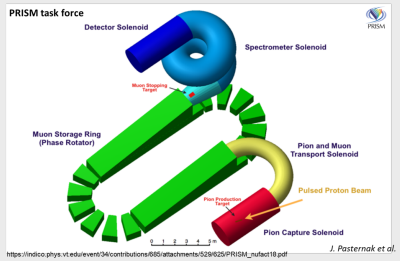
RF5:Charged Lepton Flavor Violation

- Enormous range across machines and channels
- Addresses deep questions in flavor and generations
- Game-changing opportunities in muons:
  - *Mu2e-II at FNAL: x10 Mu2e at PIP-II*
    - start to probe *Z* with Ti (x2)
    - re-use much of Mu2e
    - R&D already underway on tracker and cosmic ray veto
  - *AMF at PIP-II: broad muon program*
    - all muon modes, x100 Mu2e and explore *Z* dependence





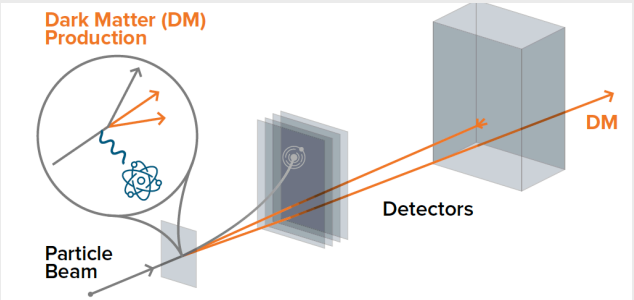
Davidson/Echenard
written as a result of Snowmass!

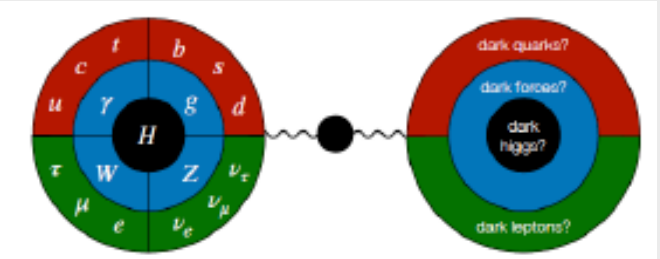


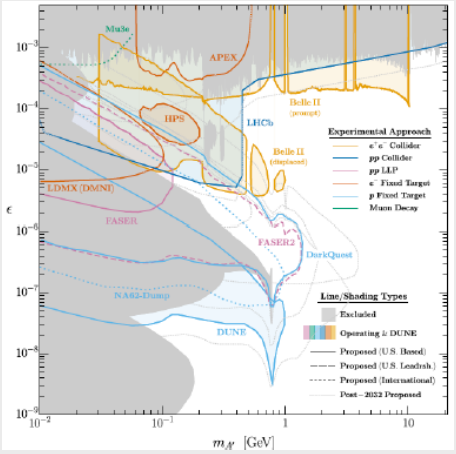
RF6: Dark Sector At High Intensities

- 1 MeV-1 GeV range
- many different experiments with different techniques, covering well-motivated models in unique ways
- *potential for discoveries that will change the direction of large-scale projects*
  - *for example: if LDMX saw a signal, DUNE could confirm!*
  - *analyze CODEX-b events in LHCb; and remember software trigger so could adapt!*
- ***message to P5 and DOE: let's start a program!***

range of small-to-medium scale

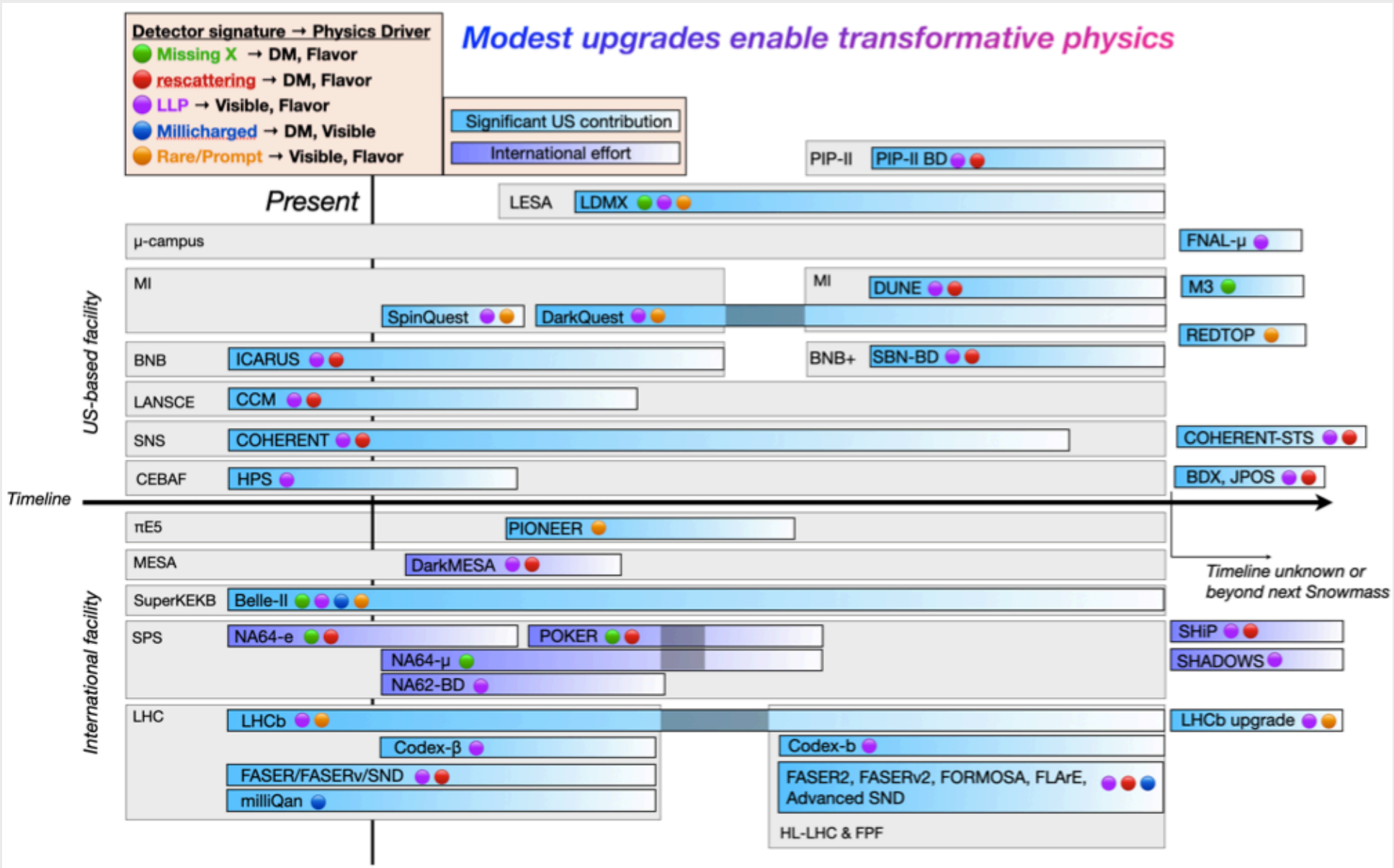






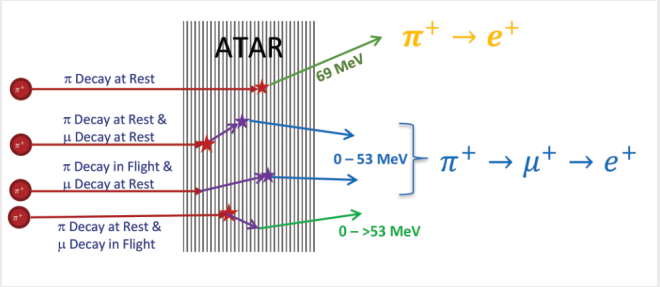
https://science.osti.gov/-/media/hep/pdf/Reports/Dark_Matter_New_Initiatives_rpt.pdf

Possible Experiments



Apologies

- RF2:
  - *K* decays because no “projects” in US
  - programs at J-PARC and CERN
- PIONEER at PSI
  - $R_{e\mu} = \mathcal{B}(\pi^+ \to e\nu_e)/\mathcal{B}(\pi^+ \to \mu\nu_\mu)$ to 10^{-4}; sophisticated active target. DM as well: $\pi^+ \to l^+\nu_l X$ where X is an ALP, and more



- RF4: BLV: DUNE, HyperK for $0\nu 2\beta$ https://arxiv.org/pdf/2203.01981.pdf
- RF7: Hadron Spectroscopy
  - largely research funding with experiments at other programs

Summary

- Wide opportunities for transformative physics across RPF
- We can change directions for other Frontiers:
  - discovery in RPF can inform colliders or DUNE where to look (*b/c/*light, DM, CLFV)
- Small to medium investments in RPF can change the field: focused, intense probes can make profound discoveries