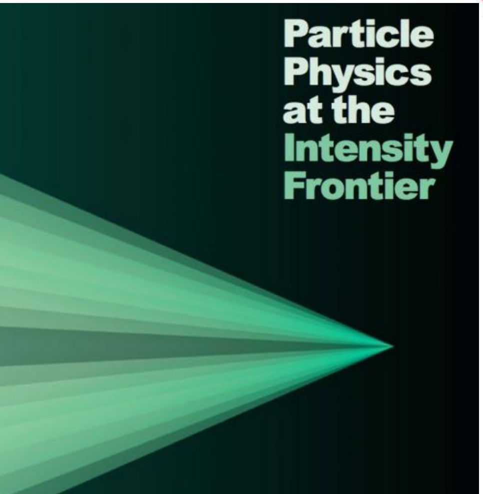
Intensity Frontier Overview



J. Hewett, H. Weerts

CSS13 Intensity Frontier Working Groups

Quark Flavor Physics: Joel Butler, Zoltan Ligeti, Jack Ritchie	K, D & B Meson decays/properties
Charged Lepton Processes Brendan Casey, Yuval Grossman, David Hitlin	Precision measurements with muons, taus
Neutrinos Andre deGouvea, Kevin Pitts, Kate Scholberg, Sam Zeller	All experiments for properties of neutrinos. Accelerator & non-accel.
Baryon Number Violation Kaladi Babu, Ed Kearns	Proton decay, Neutron Oscillation
New Light, Weakly Coupled Particles Rouven Essig, John Jaros, William Wester	"Dark" photons, paraphotons, axions, WISPs
Nucleons, Nuclei & Atoms Krishna Kumar, Z.-T. Lu, Michael Ramsey-Musolf	Properties of nucleons, nuclei or atoms (EDM), as related to HEP

Exploring High Energy Scales

- **Precision measurements @ Intensity Frontier explore high mass scales via indirect effects**

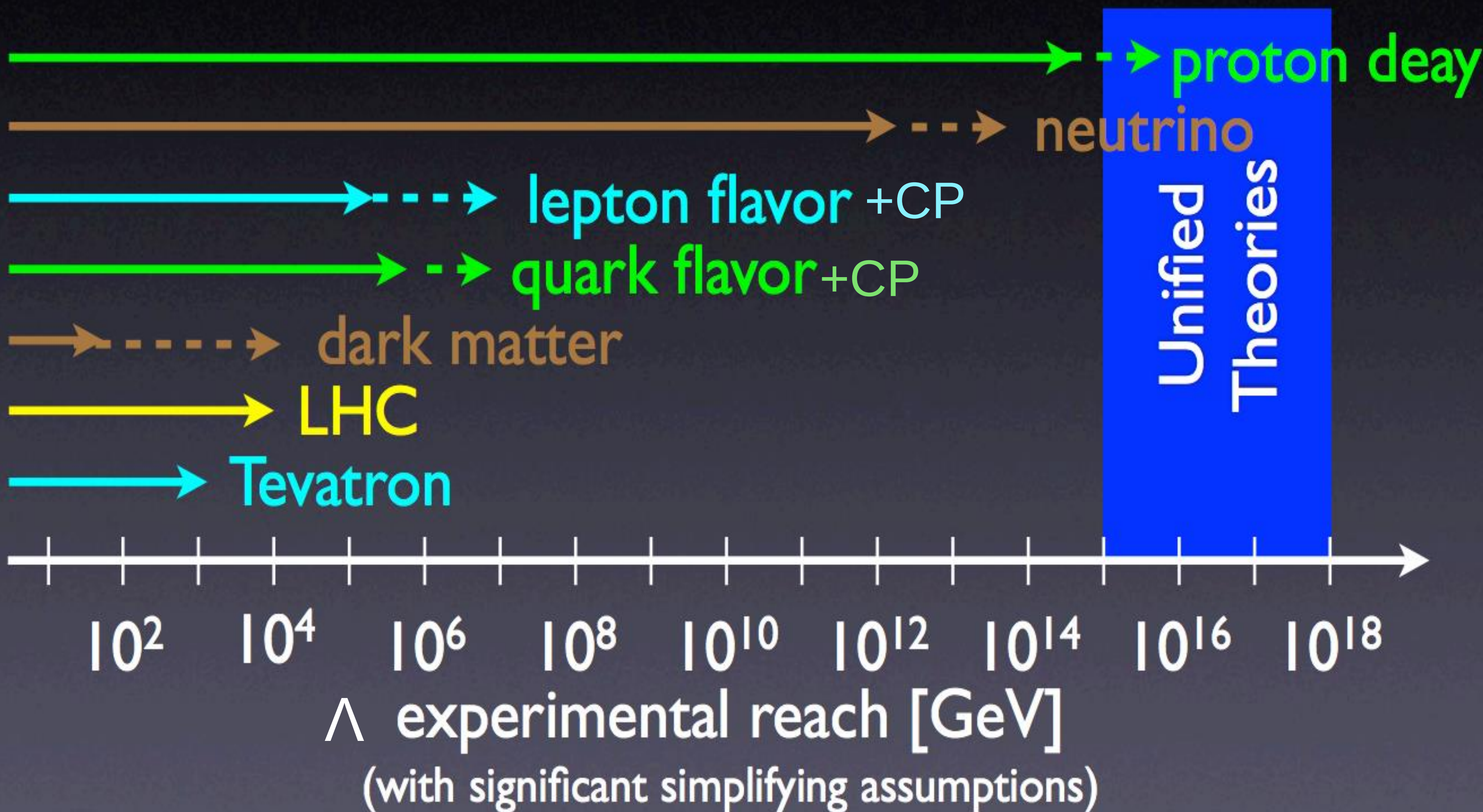
Flavor Physics: New physics & SM both appear @ loop-level

$$\mathcal{A} = \mathcal{A}_0 \left[\frac{c_{SM}}{M_W^2} + \frac{c_{NP}}{\Lambda^2} \right]$$

Neutrinos: Only Dim-5 operator allowed by SM symmetries

$$\frac{1}{\Lambda}(y_\nu L H)(y_\nu L H) + h.c.$$

Power of Expedition



courtesy Ligeti/Murayama

Flavor Physics Summary

- **Flavor observables provide essential probes of new physics**
- **Substantial progress expected this decade**

Quark Flavor Physics:

Belle-II, LHCb upgrades, BES-III going ahead

ORKA can measure K ➔⇨vv with unprecedented precision using Main Injector

Strong collaboration already formed

Would be unique quark flavor exp't in the US

Charged Lepton Processes

g-2 ring is @FNAL, lattice will have precision evaluation of HVP, but HLBL still difficult

Mu2e provides impressive reach, seems on-track

Rare τ decays part of quark flavor program

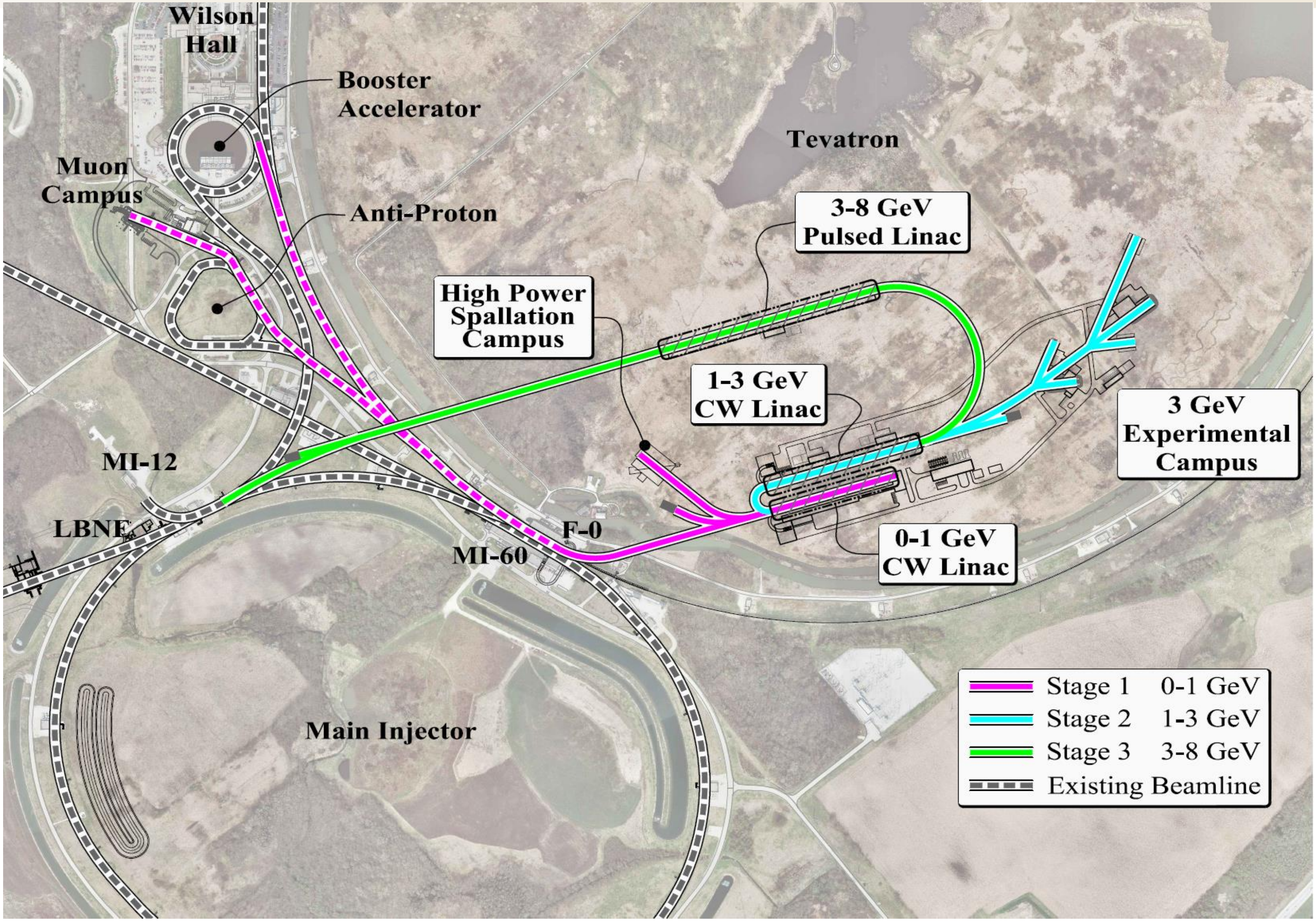
Nucleons, Nuclei & Atoms

Numerous precise measurements of weak mixing angle planned/underway

Project X would provide 2 order of magnitude improvement on edm's

Project X physics case detailed in new physics book

Staging of Project X



The Nature of Neutrinos

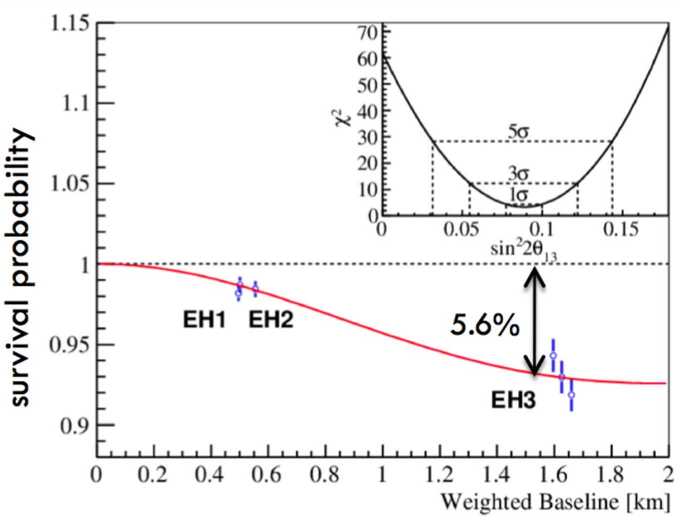
- Our questions are very fundamental
  - *- what is the absolute neutrino mas*
  - *- are neutrinos Majorana or D*
  - *- what is the neutrino ma ing?*
  - *- is CP violated in th io sector?*
  - *- to what exten e 3n paradigm describe nature?*
  - *- are there new physics in existing data?*
  - *- wh nowledge will neutrinos from astrophysical bring?*
- now this information for every other particle!
- We know more about the Higgs than we do about neutrinos

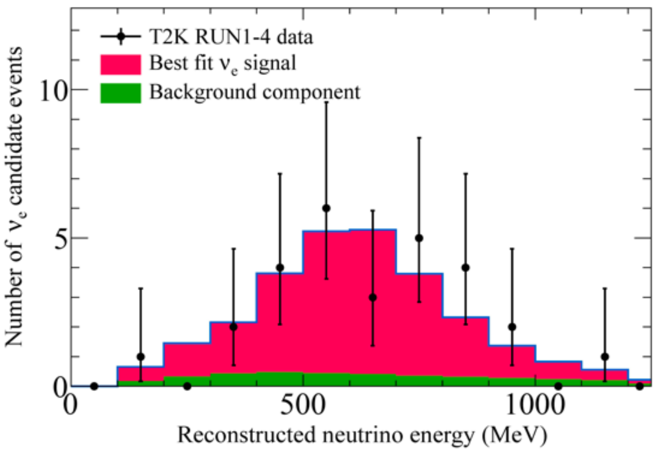
Consensus: Neutrinos pose many important questions that we need to address

This was a sea change of general opinion!

Neutrinos: a clear path forward

Daya Bay & T2K results





- We are entering the era of precision neutrino physics
- Now that θ_{13} is measured, there is a clear path forward for testing the 3ν paradigm
- LBNE uniquely positioned to determine δ
- Phase I LBNE is considered to be underground
- Multi-MW beams will be required in the future
- Many smaller, interesting proposals (PINGU/JUNO)

TRIUMF

U.S. Goal for neutrinos

- The question of CP violation is one of the few major questions that can be addressed with present technologies in a reasonable time scale and investment
  - Positive observation will change our thinking about the world….quark and lepton sectors looking similar
- This opportunity should not miss proton decay
- Supernova and atmospheric neutrinos are interesting providing a broad physics program
- Detector should be larger & underground @ t=0
- Perhaps consensus view is we wish to study neutrino properties in detail

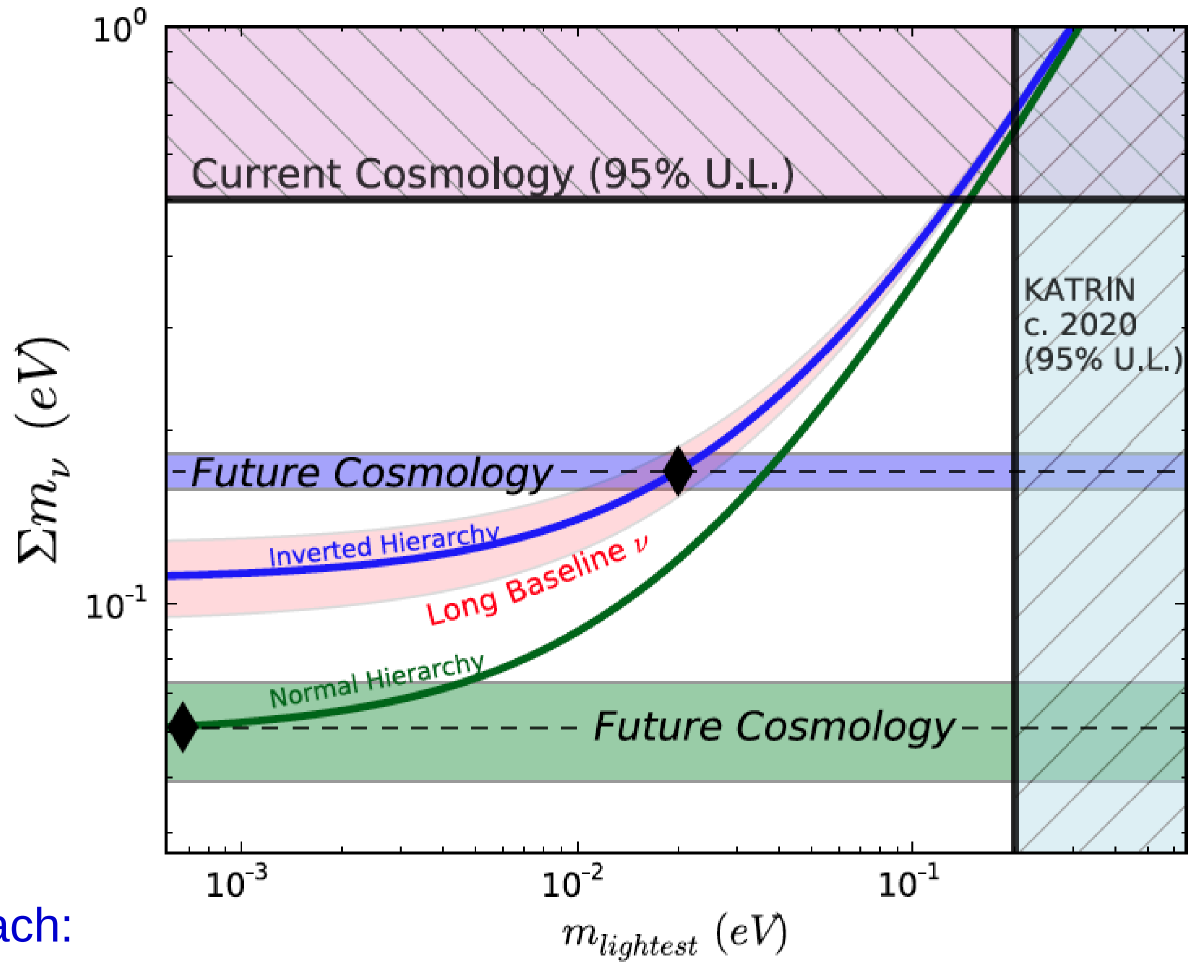
Neutrinoless double beta decay

- Neutrinoless double beta decay ($0\nu\beta\beta$) search experiments are critical as the only realistic way to elucidate a key part of the picture: the question of whether neutrinos are Majorana or Dirac fermions.

- The current generation of 100-kg-class neutrinoless double beta decay search experiments should reach effective masses in the 100 meV range; beyond that, there are opportunities for multi-ton-class experiments that will reach sub 10 meV effective mass sensitivity, pushing below the inverted hierarchy region.

$0\nu\beta\beta$ is crucial element of the neutrino program

Neutrinos and Cosmology are connected

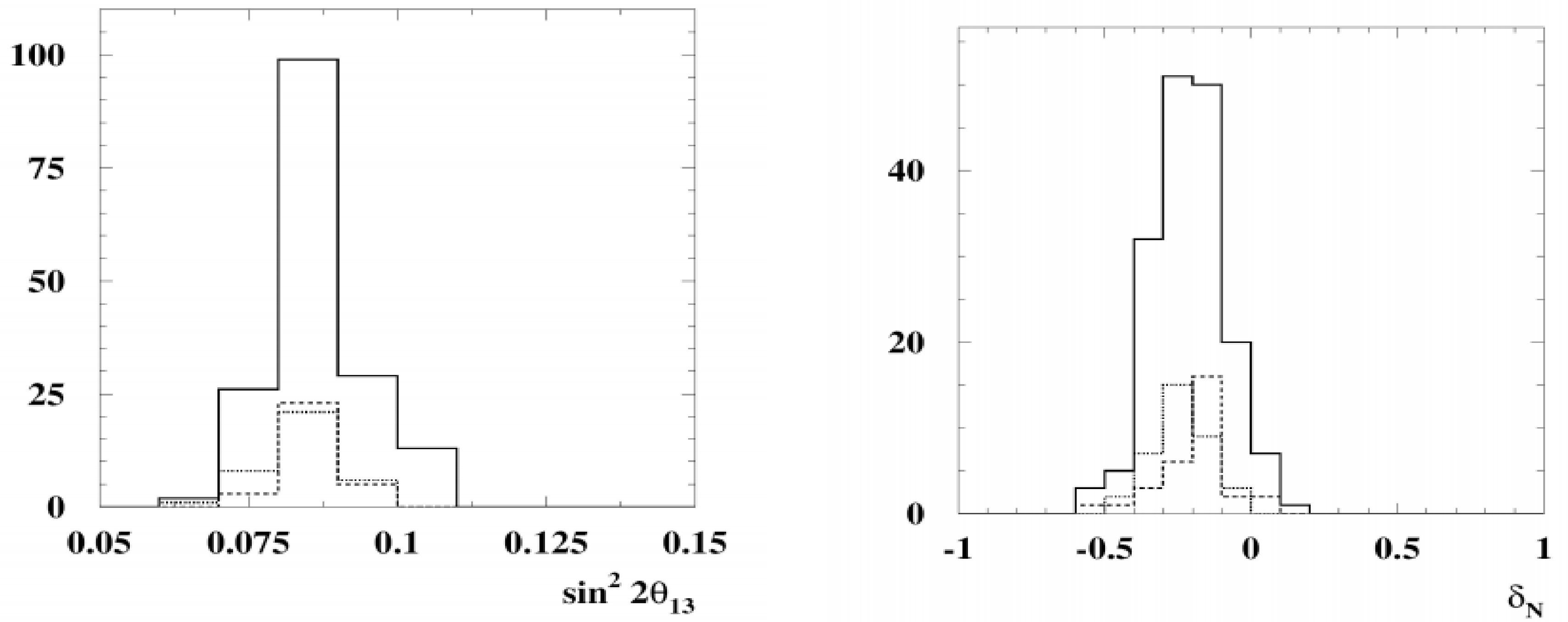


Projected Reach:
2013-2016: Σm_ν ~0.1 eV
2016-2020: Σm_ν ~ 0.06 eV
2020-2025: Σm_ν ~ 16 meV

(S. Dodelson, Wednesday session)
See talk by S. Ritz

Grand Unified Models

Theta(13) in Minimal SO(10)

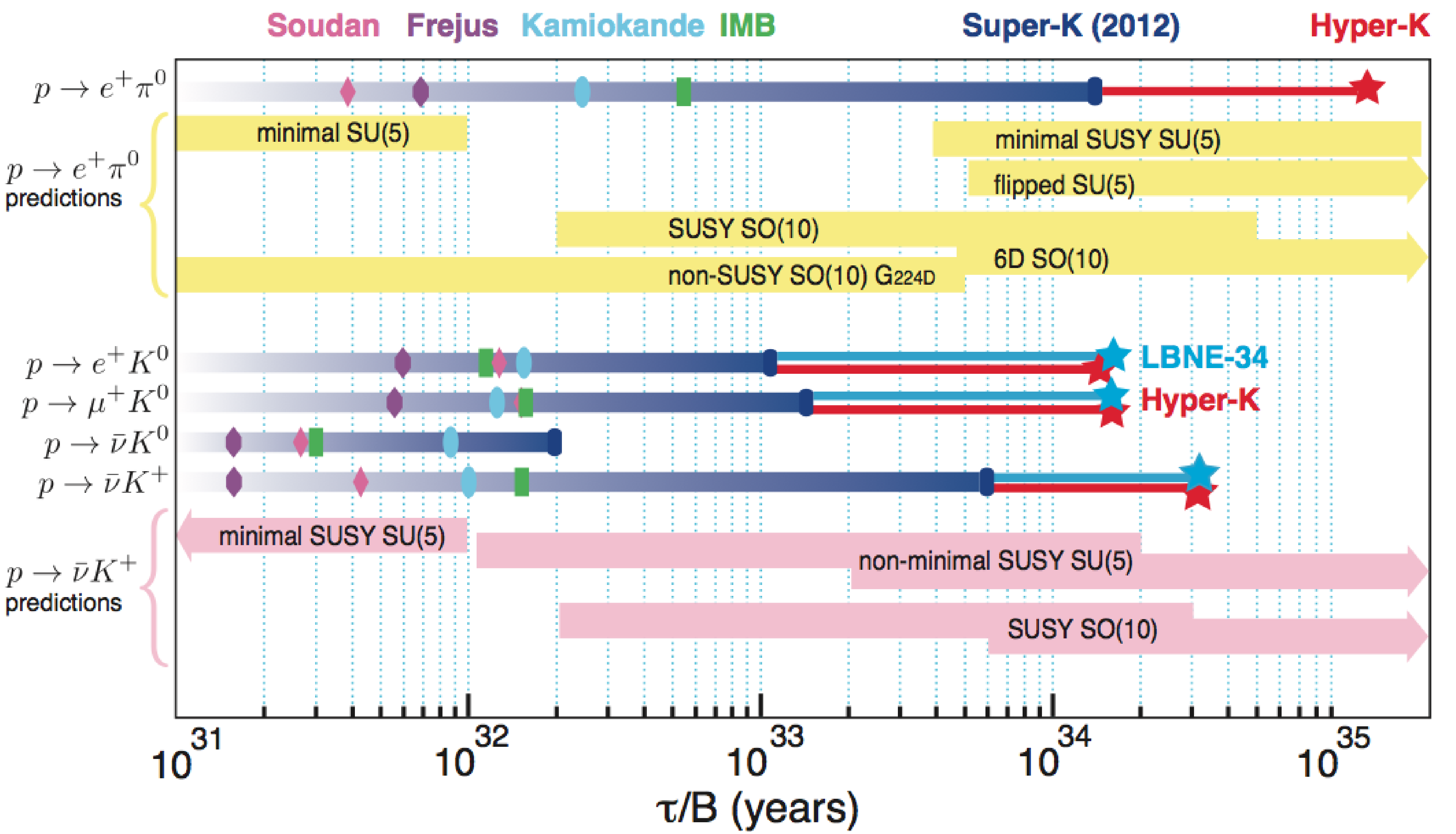


$\sin^2 2\theta_{13}$ and CP violating phase δ_N

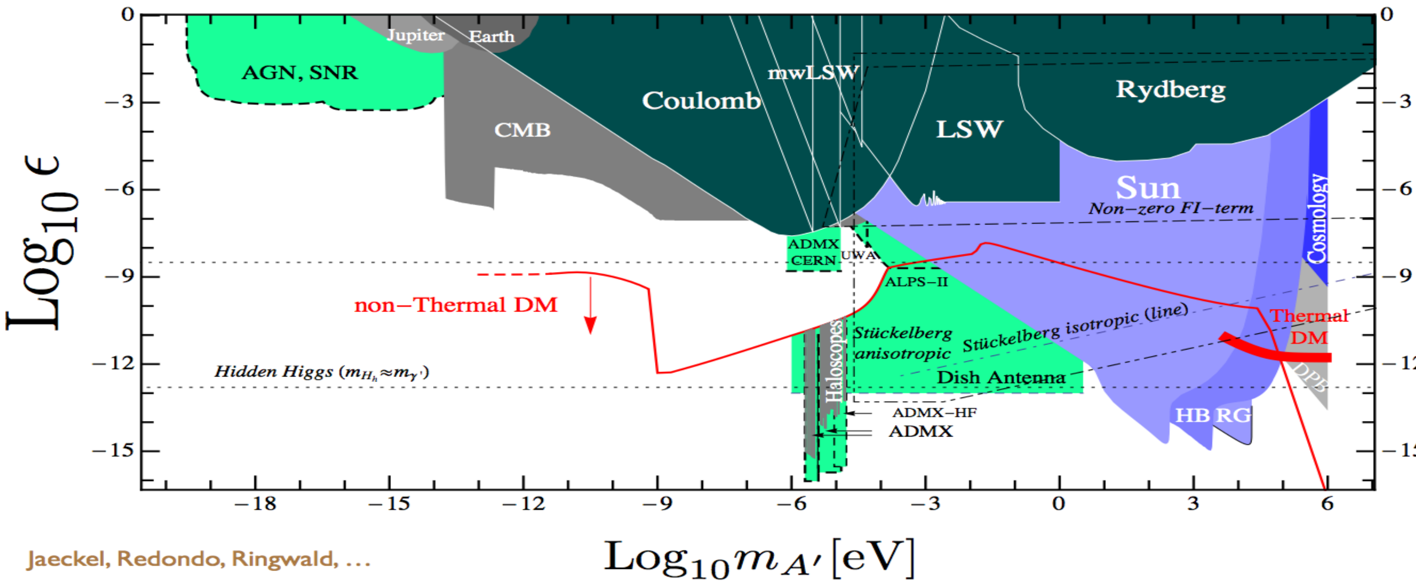
K.S. Babu and C. Macesanu (2005)

$\sin^2 2\theta_{13} = 0.089 \pm 0.010 \pm 0.005$ Daya Bay (2012)

Proton Decay



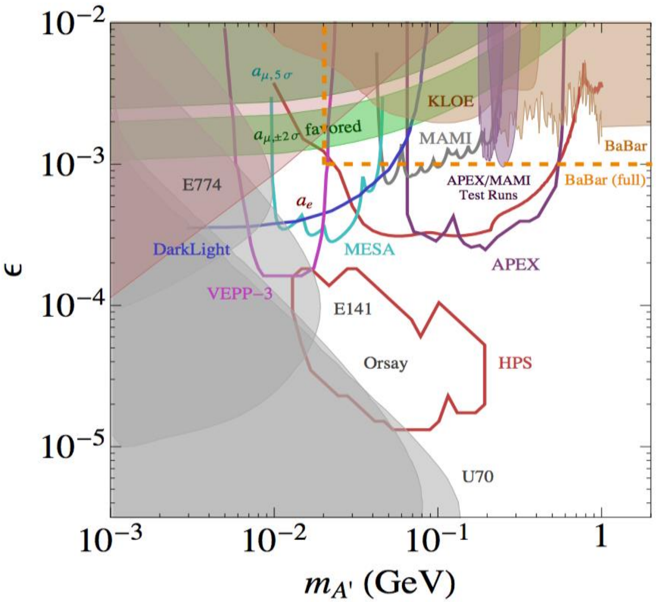
Ultra-weak Hidden Sectors



Effective coupling to SM vs Mass plane

Jaeckel, Redondo, Ringwald, …

$m_{A'} < 1ev$



Hidden Sector Vector Portal:
Couplings to SM small enough to have missed so far, but big enough to find

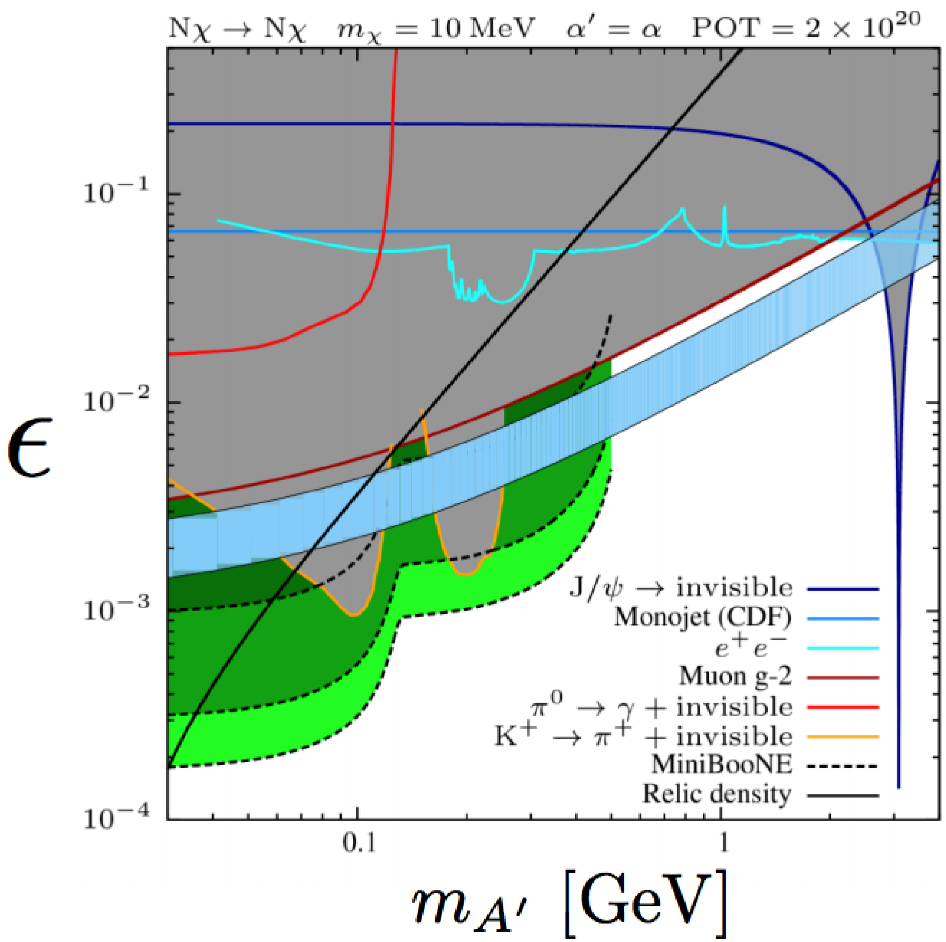
Theories motivated by cosmic frontier
Signatures at Intensity and (Energy) frontiers

$m_{A'} > 1ev$

Proton-beam based searches

MiniBooNE proposal for sub-GeV DM search

Aguilar-Arevalo et.al. (MiniBooNE proposal)



e.g. $m_{\text{DM}} = 10$ MeV

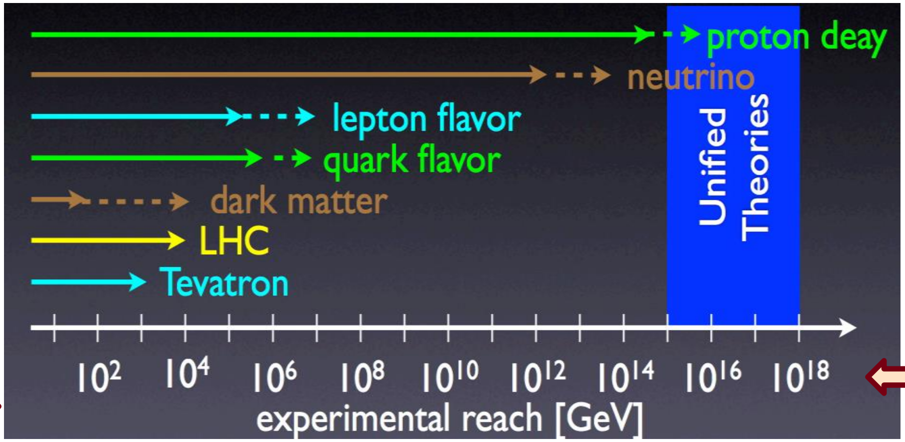
pioneering search for sub-GeV dark matter using a neutrino factory

relatively inexpensive, no new facility

Essig

Intensity Frontier Science Summary

Precision neutrino physics in next two decades



Quark & Charged Flavor experiments

Proton Decay & NNbar oscillations

Electric Dipole Moments (EDMs)

New light, weakly coupled particles

Rapid progress from last 2 years will continue

Intensity & Cosmic Frontiers

Probe mass scales of possible New Physics with multiple approaches

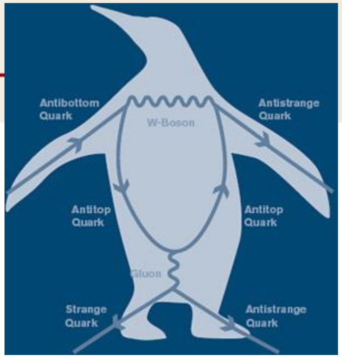
Particle explanation of Dark Sector

Back-up Slides

New Physics Flavor Problem

New physics is constrained by flavor physics observables

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{C_{\text{NP}}}{\Lambda^2} O_{ij}$$



ΔF=2 Operator	Bounds on Λ [TeV] ($C = 1$) Re	Im	Bounds on C ($\Lambda = 1$ TeV) Re	Im	Observables
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	6.6×10^2	9.3×10^2	2.3×10^{-6}	1.1×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	2.5×10^3	3.6×10^3	3.9×10^{-7}	1.9×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.4×10^2	2.5×10^2	5.0×10^{-5}	1.7×10^{-5}	Δm_{B_s}; $S_{\psi\phi}$
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	4.8×10^2	8.3×10^2	8.8×10^{-6}	2.9×10^{-6}	Δm_{B_s}; $S_{\psi\phi}$

If there is new physics at the TeV scale, its flavor sector is unnatural

New Physics in $B_{d,s}$ Mixing

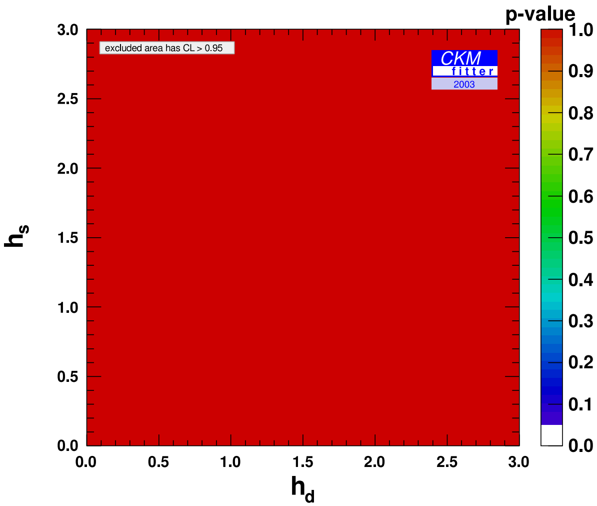
Let $M_{12} = M_{12}^{SM}$ x $(1 + he^{2i\sigma})$

New physics in amplitude

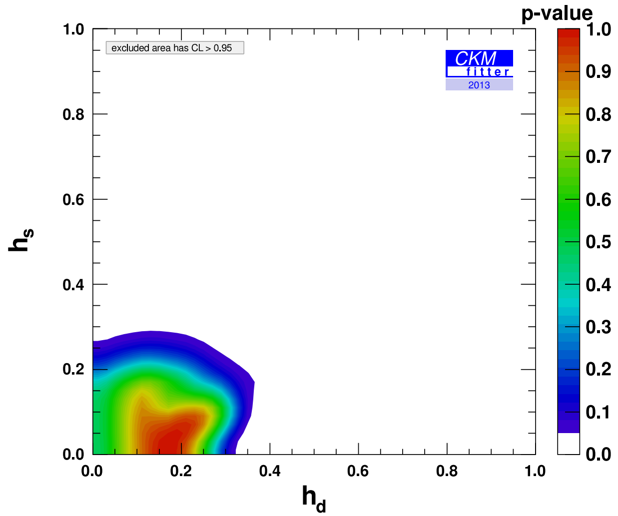
New physics in phase

(Assumes CKM unitarity and SM-dominated tree-level decays)

2003

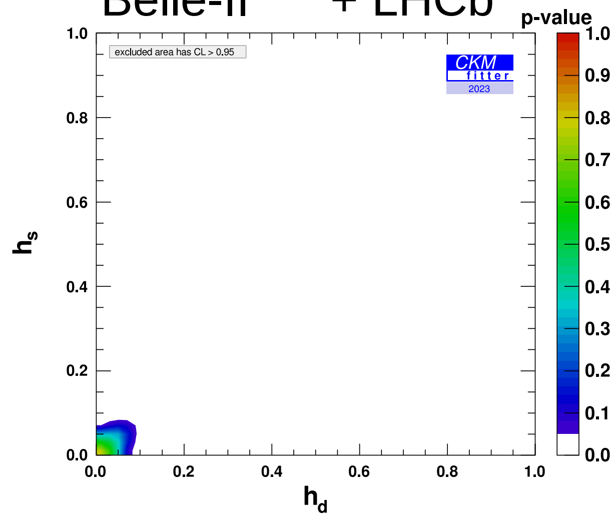


2013



50 ab^{-1} B_d + 50 fb^{-1} B_s

Belle-II + LHCb



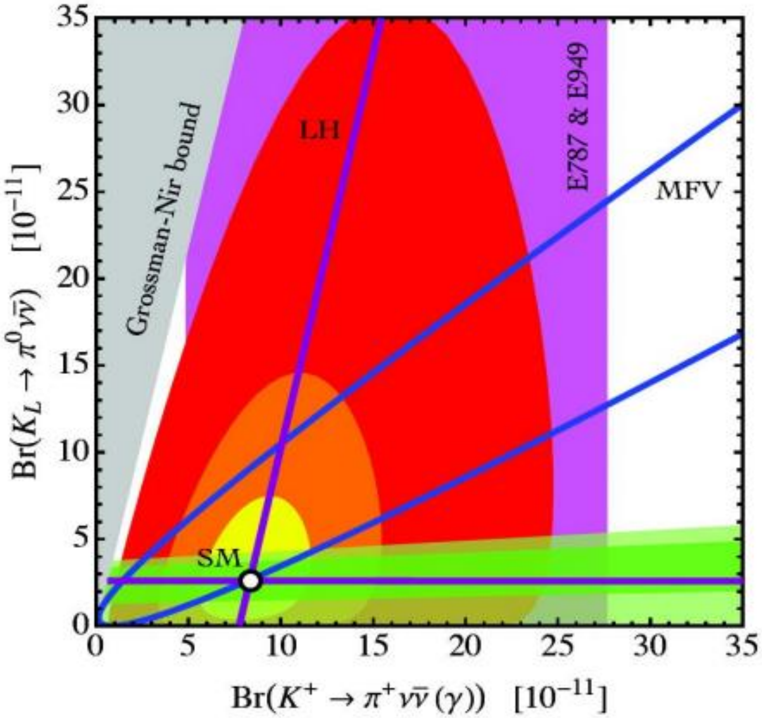
Charles etal

Preliminary

Kaon Program

- Worldwide goal to achieve precision measurements

Sensitivity to new physics



Haisch

SM Prediction:

$$B(K^+ \to \pi^+ \nu\bar{\nu}) = (7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$$

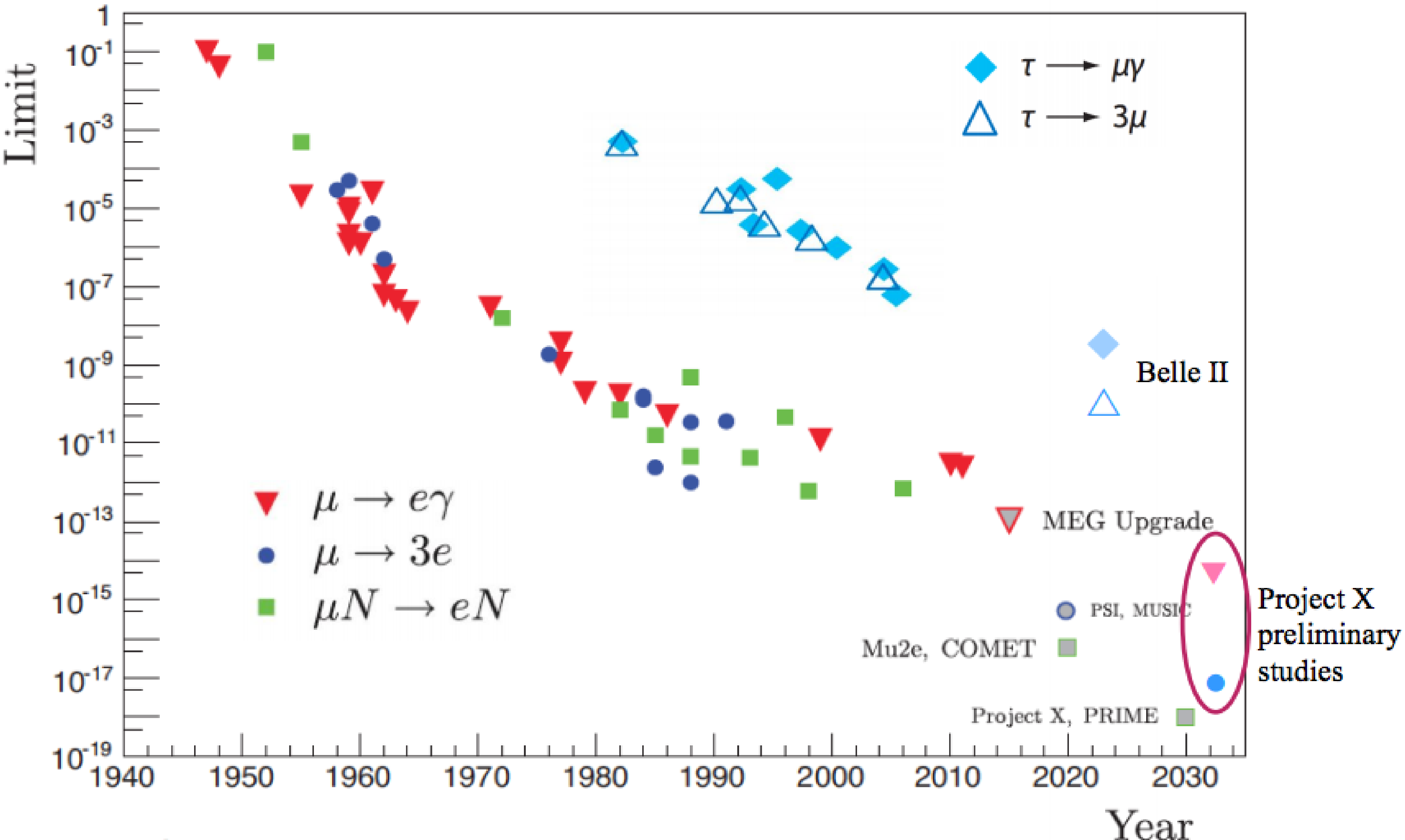
$$B(K^0 \to \pi^0 \nu\bar{\nu}) = (2.43 \pm 0.39 \pm 0.06) \times 10^{-11}$$

Theoretically clean decays

Charged mode:
NA62: near-term (10% precision)
ORKA: Proposed,
1000 events w/ Main Injector

Neutral mode:
KOTO: near term (few events)
Projected: 5% precision @ Project X

CLFV Timeline



Bernstein, Cooper + Marciano, Mori, Roney + DH

Hitlin

Flavor in the LHC Era

New Physics found at LHC

⇒ New particles with unknown flavor- and CP-violating couplings

New Physics NOT found at LHC

Precision flavor-physics expts will be needed sort out the flavor- and CP-violating couplings of the NP.

Precision flavor-physics expts will be needed since they are sensitive to NP at mass scales beyond the LHC.

Precision quark-flavor experiments (and lepton-flavor too) are essential.

A healthy U.S. HEP program will include a vigorous flavor-physics component (like Europe and Asia).

Ritchie

edm's and the Higgs

Two Loop EDM

- Electron or neutron EDM at 2-loops (Barr-Zee):

$$\phi_e, \phi_q \lesssim 0.1$$

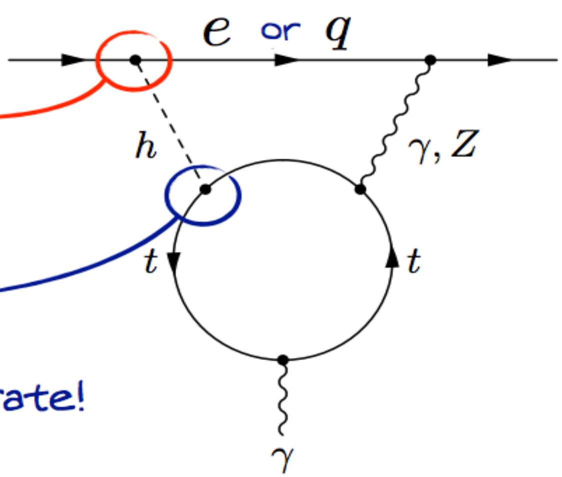
from e and n EDM's

$$\phi_t \lesssim 0.05$$

from e and n EDM's

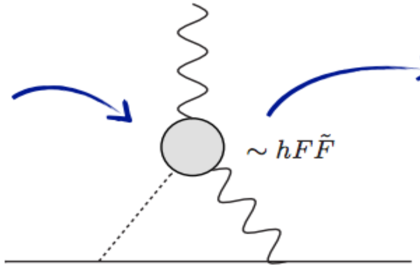
Interplay with LHC Higgs production rate!

Brod, Haisch, Zupan (in prep.)



- Also sensitive to CPV in $h\gamma\gamma$ from NP:

$$c_\gamma \frac{\alpha}{\pi v} h F_{\mu\nu} F^{\mu\nu} + \tilde{c}_\gamma \frac{\alpha}{2\pi v} h F_{\mu\nu} \tilde{F}^{\mu\nu}$$



$$\phi_\gamma \lesssim 0.01 - 0.1$$

McKeen, Pospelov, Ritz (1208.4597)

edm's and SUSY

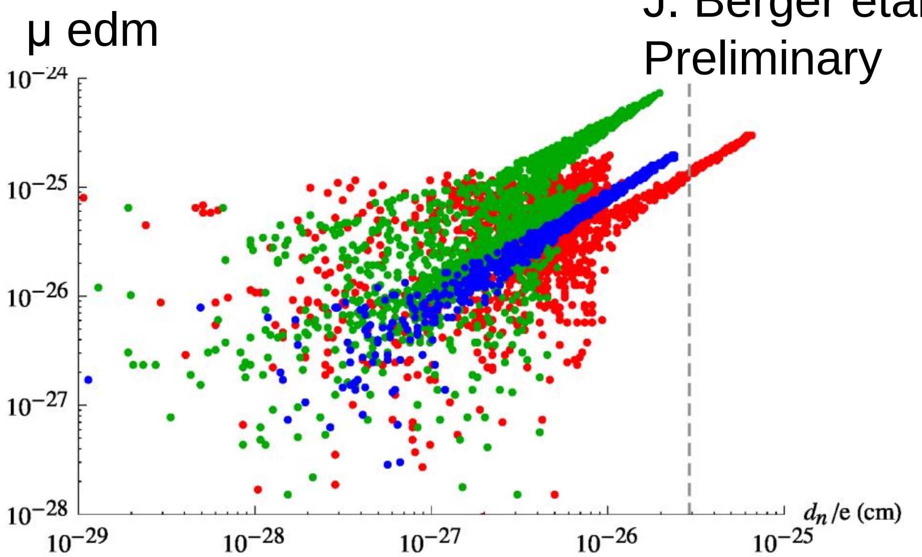
pMSSM benchmark points

- 19 weak-scale parameters
- No high-scale assumptions
- All sparticle masses < 4 TeV
- All points consistent with global data set
- Assume MFV ➔ perform expansion in MFV
- Scan over phases

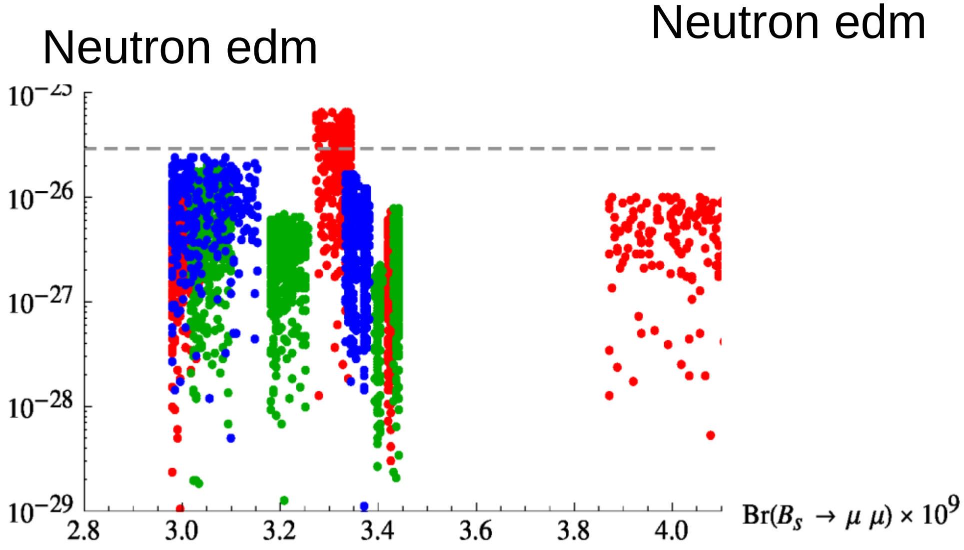
Same points studied across all 3 frontiers!!

Low fine-tuning models
Survive 300 fb^{-1} @ 14 TeV LHC
Survive 3 ab^{-1} @ 14 TeV LHC

J. Berger etal
Preliminary



Neutron edm



Far Future Precision