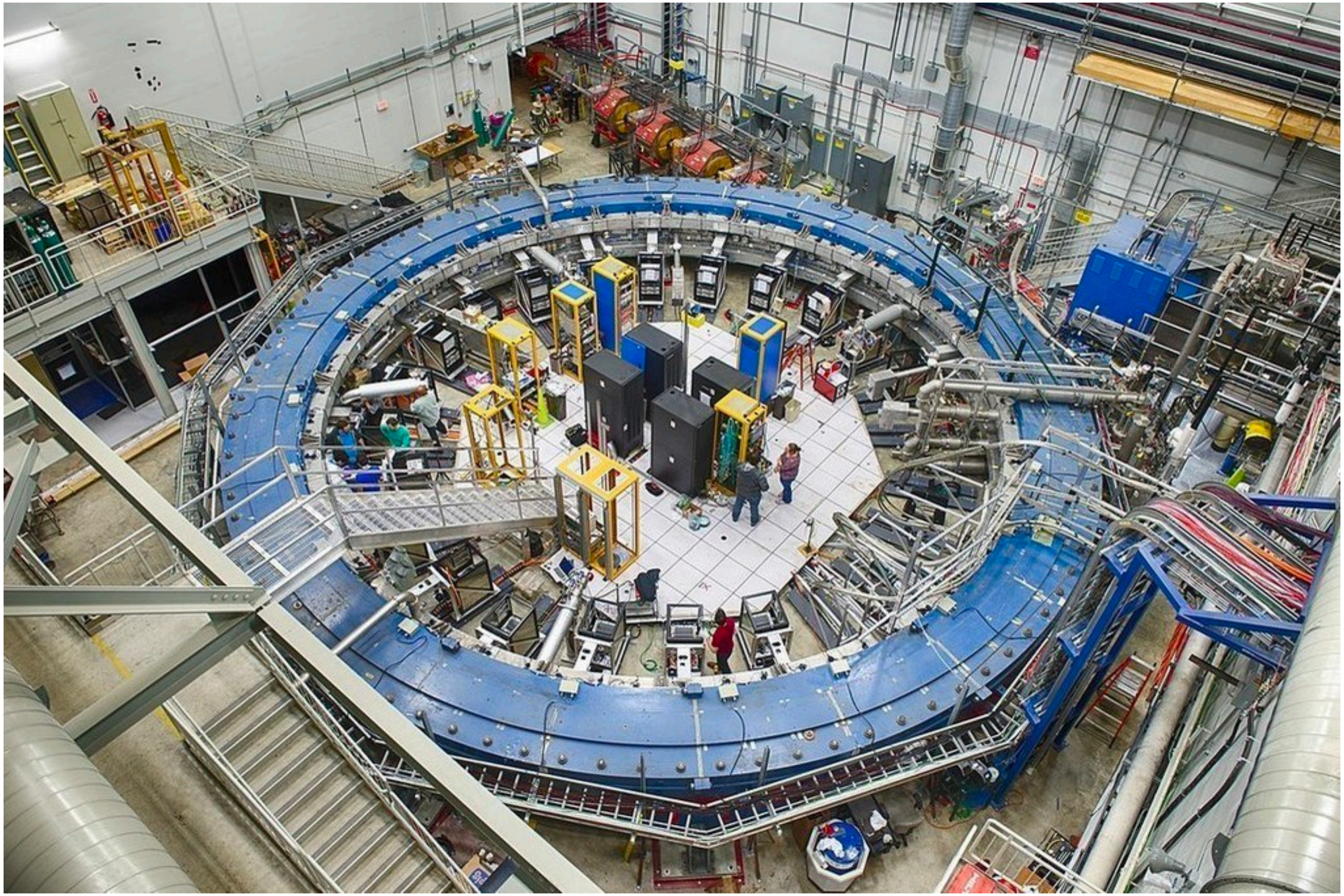
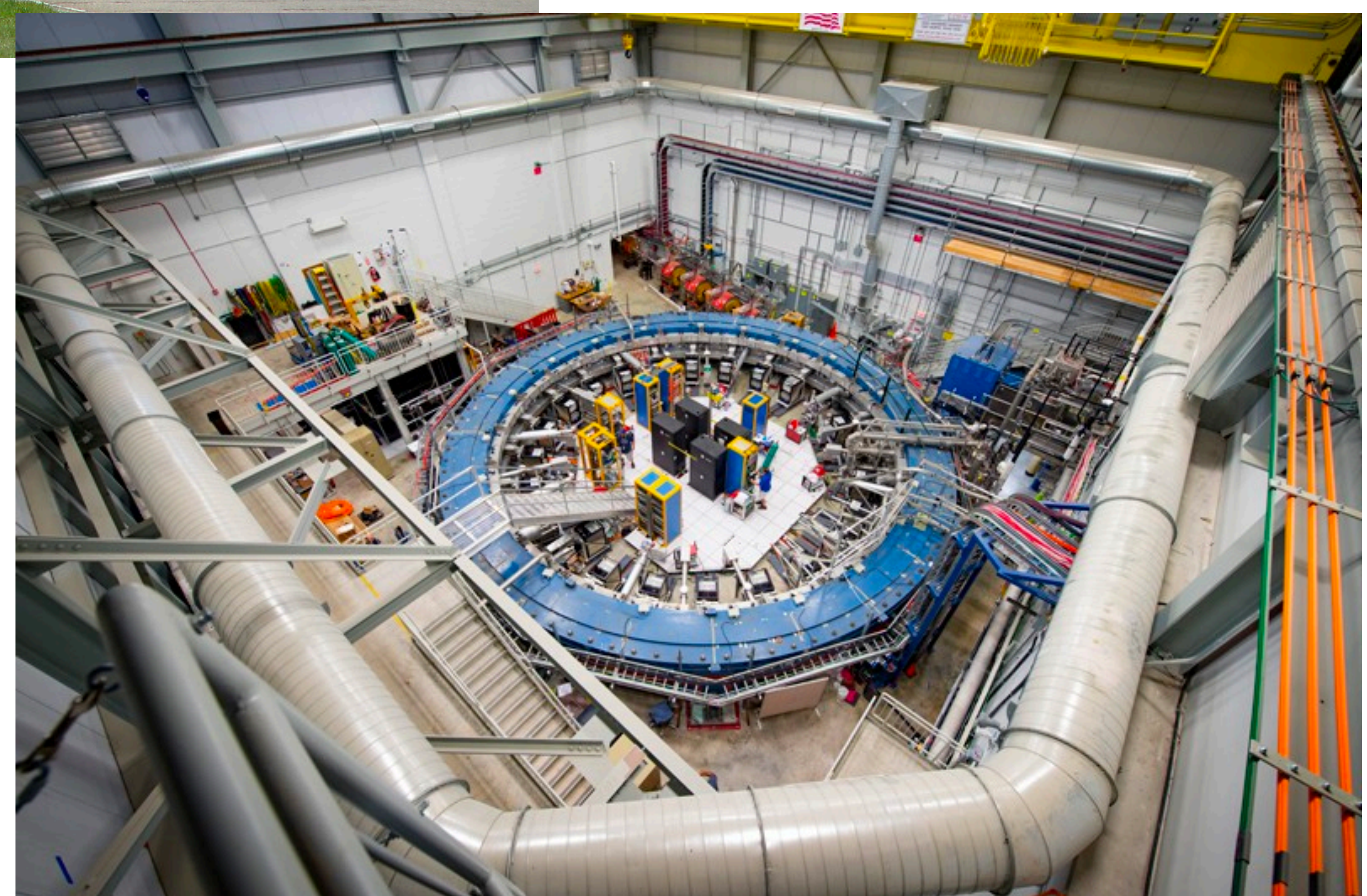
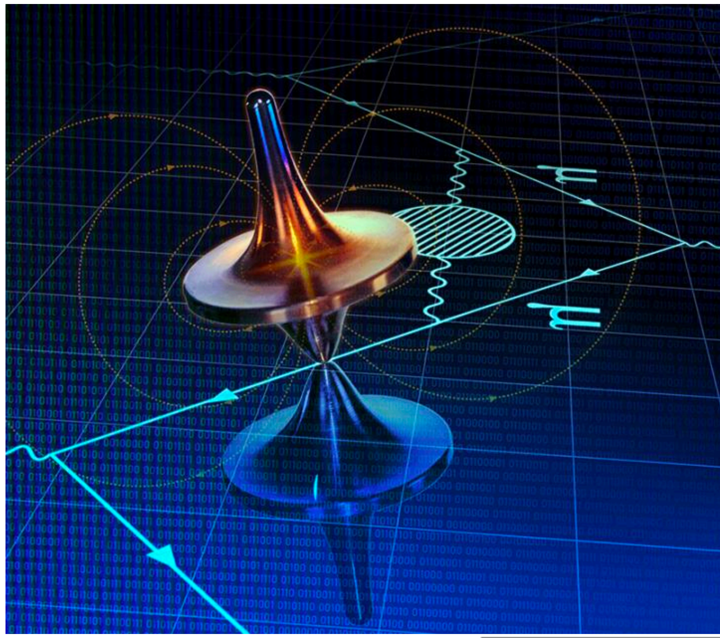


Новая физика, где она?


OVERSIZE LOAD





	Section	Equation	Value $\times 10^{11}$	References
E821)		Eq. (8.13)	116 592 089(63)	Ref. [1]
HVP LO (e^+e^-)	Sec. 2.3.7	Eq. (2.33)	6931(40)	Refs. [2–7]
HVP NLO (e^+e^-)	Sec. 2.3.8	Eq. (2.34)	−98.3(7)	Ref. [7]
HVP NNLO (e^+e^-)	Sec. 2.3.8	Eq. (2.35)	12.4(1)	Ref. [8]
HVP LO (lattice, *udsc*)	Sec. 3.5.1	Eq. (3.49)	7116(184)	Refs. [9–17]
HLbL (phenomenology)	Sec. 4.9.4	Eq. (4.92)	92(19)	Refs. [18–30]
HLbL NLO (phenomenology)	Sec. 4.8	Eq. (4.91)	2(1)	Ref. [31]
HLbL (lattice, *uds*)	Sec. 5.7	Eq. (5.49)	79(35)	Ref. [32]
HLbL (phenomenology + lattice)	Sec. 8	Eq. (8.10)	90(17)	Refs. [18–30, 32]
QED	Sec. 6.5	Eq. (6.30)	116 584 718.931(104)	Refs. [33, 34]
Electroweak				
HVP (e^+e^-, LO + NLO + NNL				
HLbL (phenomenology + lattic				
Total SM Value				
Difference: $\Delta a_\mu := a_\mu^{\text{exp}} - a_\mu^{\text{SM}}$				

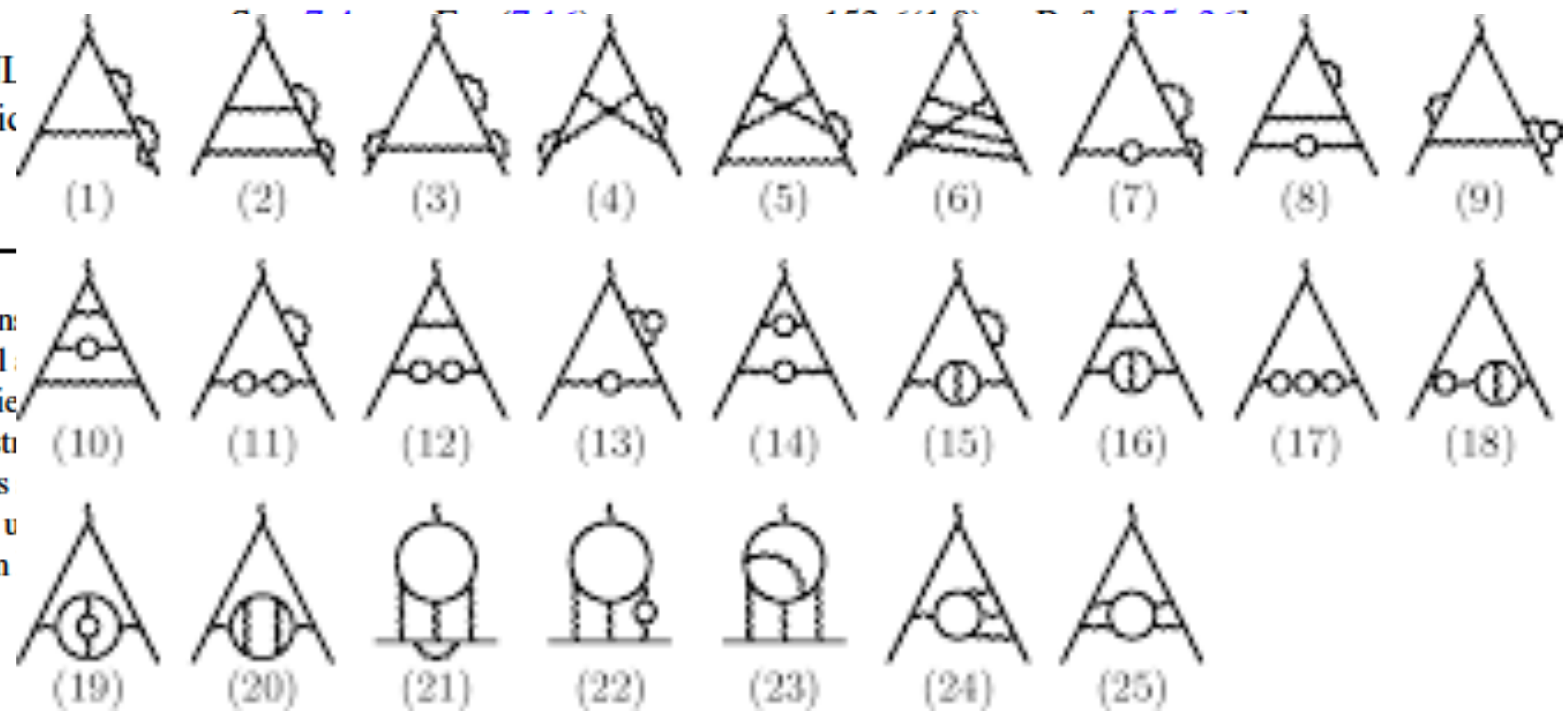
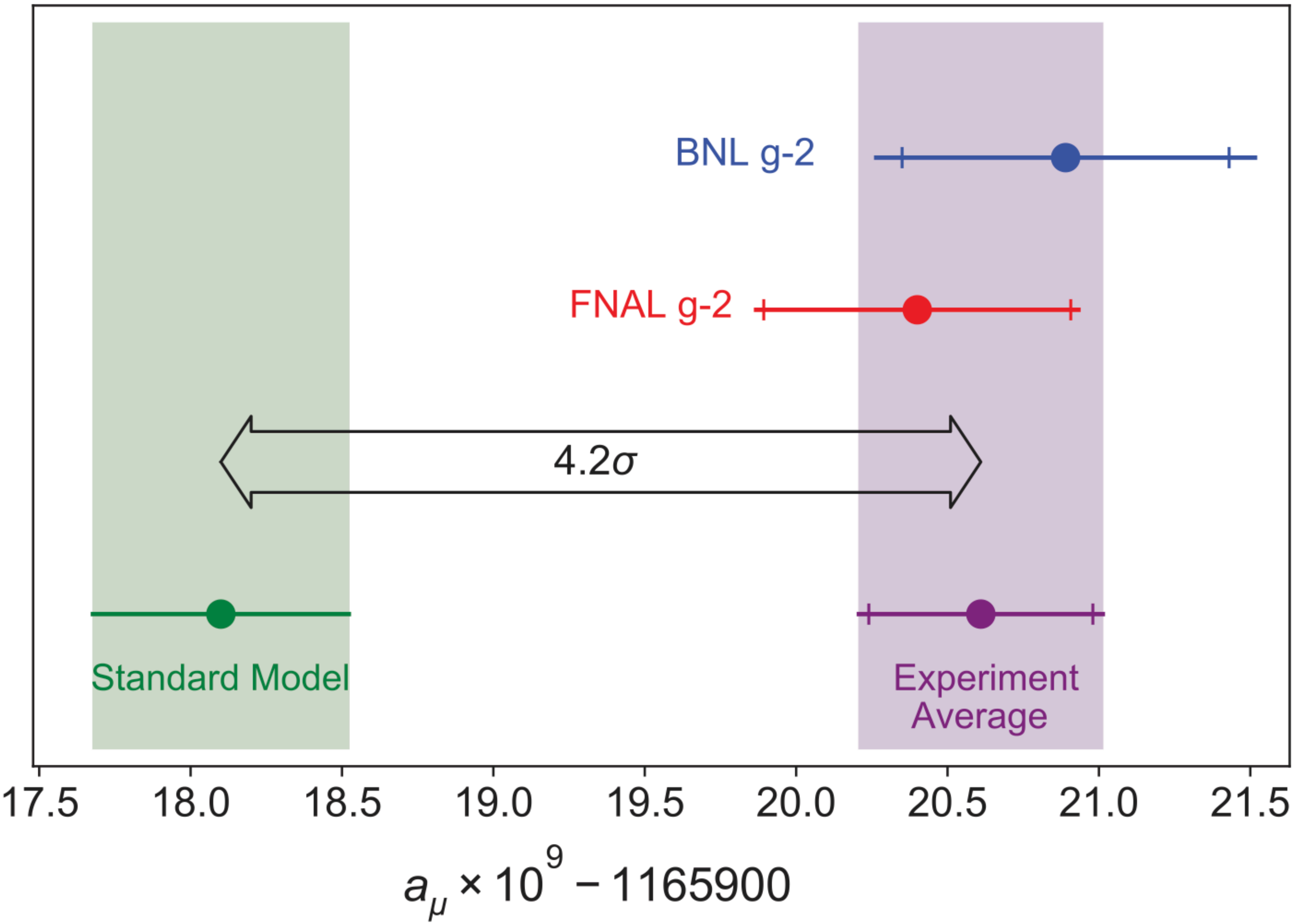
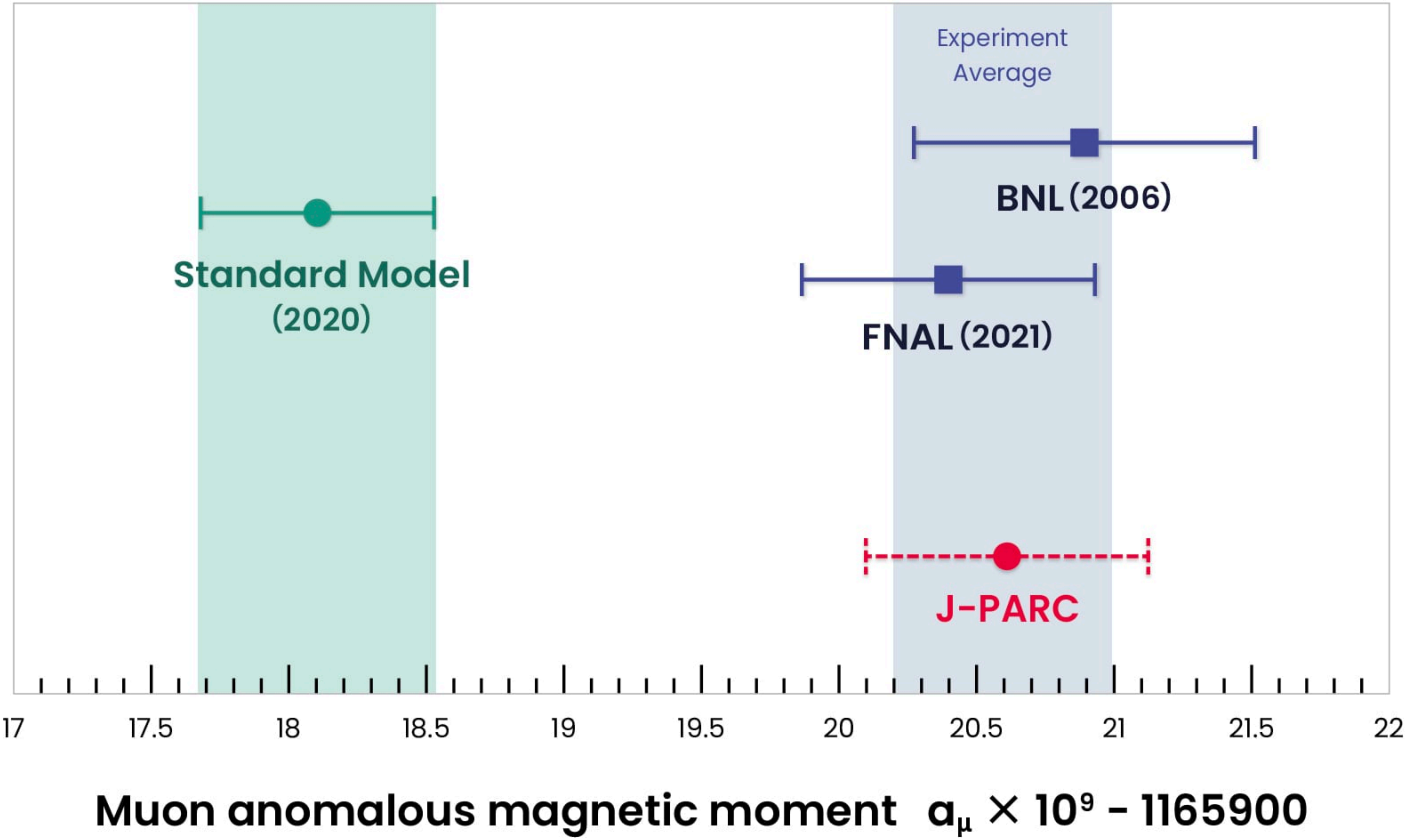


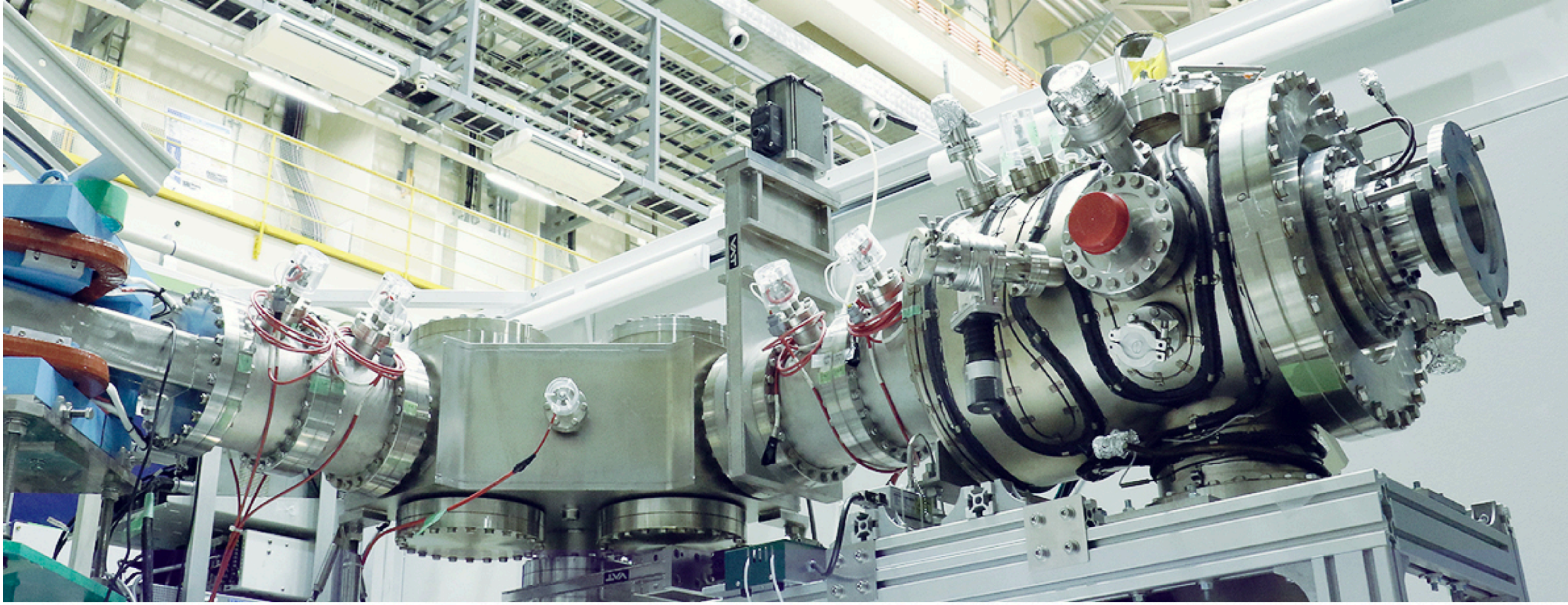
Table 1: Summary of the contribution
contributions from Secs. 2 to 5 as well
second block summarizes the quantitie
and the total HLbL number. The const
orders, and the final rounding includes
89]. In addition, the HLbL evaluation u
crucial methodological advances from
measurements of the Cs atom [117].

Contribution	Section	Equation	Value $\times 10^{11}$	References
Experiment (E821)		Eq. (8.13)	116 592 089(63)	Ref. [1]
HVP LO (e^+e^-)	Sec. 2.3.7	Eq. (2.33)	6931(40)	Refs. [2–7]
HVP NLO (e^+e^-)	Sec. 2.3.8	Eq. (2.34)	−98.3(7)	Ref. [7]
HVP NNLO (e^+e^-)	Sec. 2.3.8	Eq. (2.35)	12.4(1)	Ref. [8]
HVP LO (lattice, $udsc$)	Sec. 3.5.1	Eq. (3.49)	7116(184)	Refs. [9–17]
HLbL (phenomenology)	Sec. 4.9.4	Eq. (4.92)	92(19)	Refs. [18–30]
HLbL NLO (phenomenology)	Sec. 4.8	Eq. (4.91)	2(1)	Ref. [31]
HLbL (lattice, uds)	Sec. 5.7	Eq. (5.49)	79(35)	Ref. [32]
HLbL (phenomenology + lattice)	Sec. 8	Eq. (8.10)	90(17)	Refs. [18–30, 32]
QED	Sec. 6.5	Eq. (6.30)	116 584 718.931(104)	Refs. [33, 34]
Electroweak	Sec. 7.4	Eq. (7.16)	153.6(1.0)	Refs. [35, 36]
HVP (e^+e^-, LO + NLO + NNLO)	Sec. 8	Eq. (8.5)	6845(40)	Refs. [2–8]
HLbL (phenomenology + lattice + NLO)	Sec. 8	Eq. (8.11)	92(18)	Refs. [18–32]
Total SM Value	Sec. 8	Eq. (8.12)	116 591 810(43)	Refs. [2–8, 18–24, 31–36]
Difference: $\Delta a_\mu := a_\mu^{\text{exp}} - a_\mu^{\text{SM}}$	Sec. 8	Eq. (8.14)	279(76)	

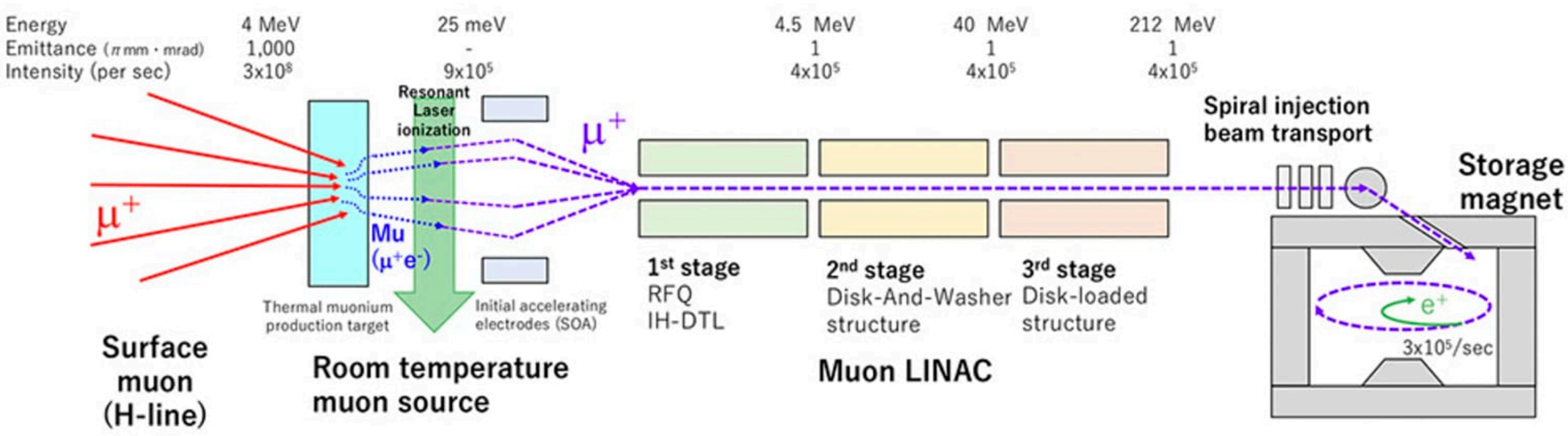
Table 1: Summary of the contributions to a_μ^{SM}. After the experimental number from E821, the first block gives the main results for the hadronic contributions from Secs. 2 to 5 as well as the combined result for HLbL scattering from phenomenology and lattice QCD constructed in Sec. 8. The second block summarizes the quantities entering our recommended SM value, in particular, the total HVP contribution, evaluated from e^+e^- data, and the total HLbL number. The construction of the total HVP and HLbL contributions takes into account correlations among the terms at different orders, and the final rounding includes subleading digits at intermediate stages. The HVP evaluation is mainly based on the experimental Refs. [37–89]. In addition, the HLbL evaluation uses experimental input from Refs. [90–109]. The lattice QCD calculation of the HLbL contribution builds on crucial methodological advances from Refs. [110–116]. Finally, the QED value uses the fine-structure constant obtained from atom-interferometry measurements of the Cs atom [117].


BNL g-2
FNAL g-2
4.2σ
Standard Model
Experiment
Average
17.5
18.0
18.5
19.0
19.5
20.0
20.5
21.0
21.5
$a_\mu \times 10^9 - 1165900$

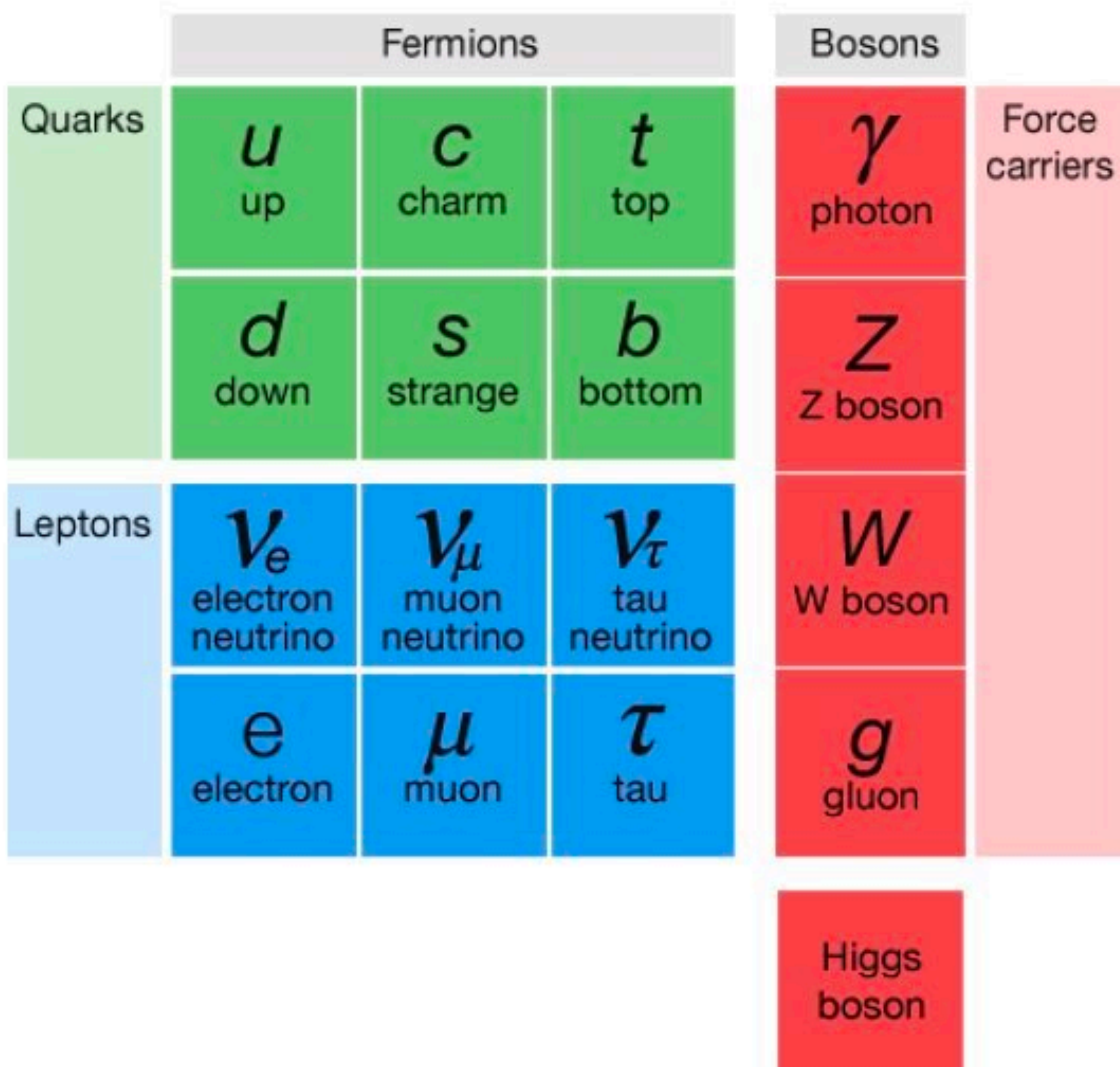

Experiment
Average
BNL (2006)
Standard Model
(2020)
FNAL (2021)
J-PARC
17
17.5
18
18.5
19
19.5
20
20.5
21
21.5
22
Muon anomalous magnetic moment $a_\mu \times 10^9 - 1165900$



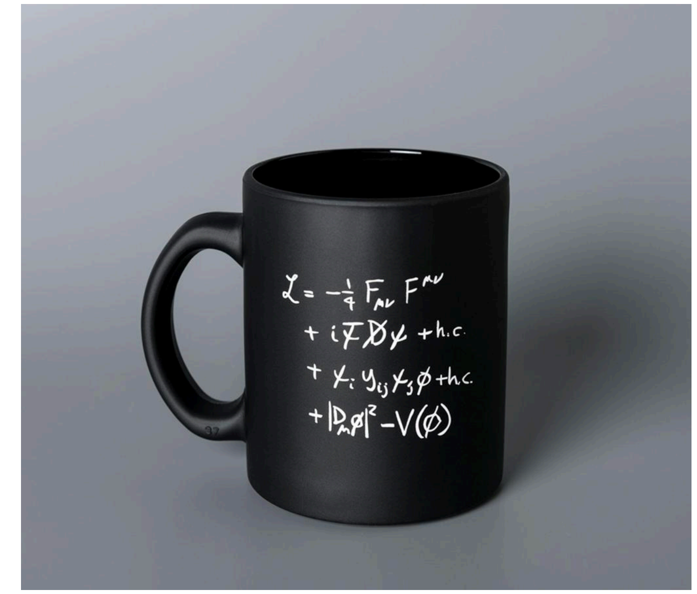
J-PARC muon
g-2/EDM experiment

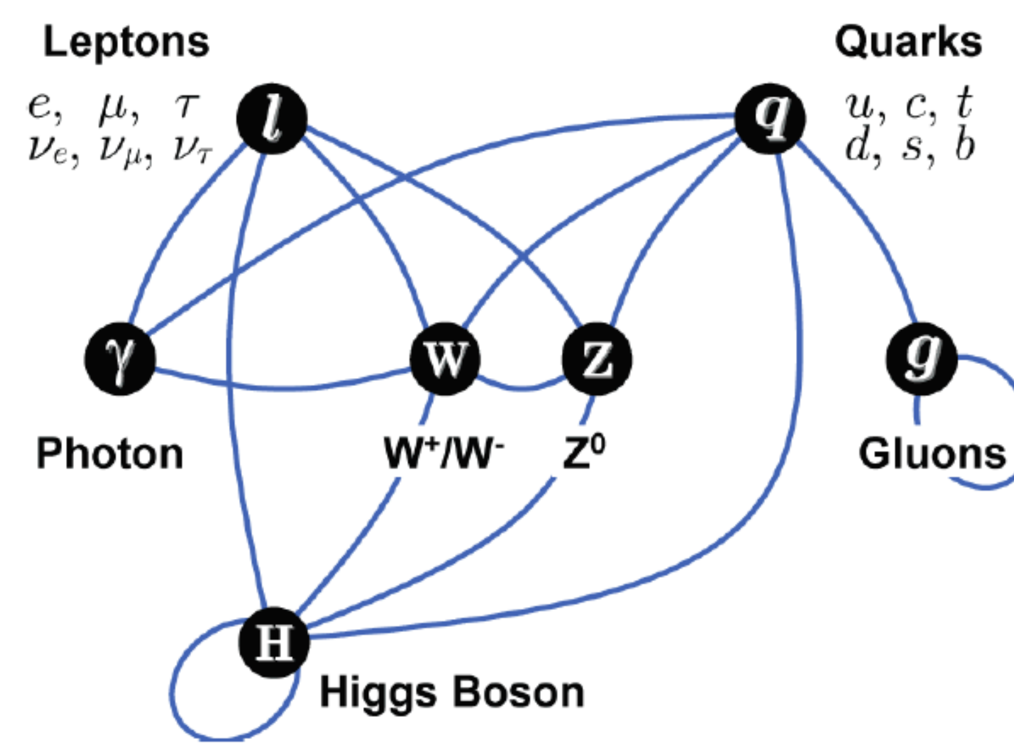


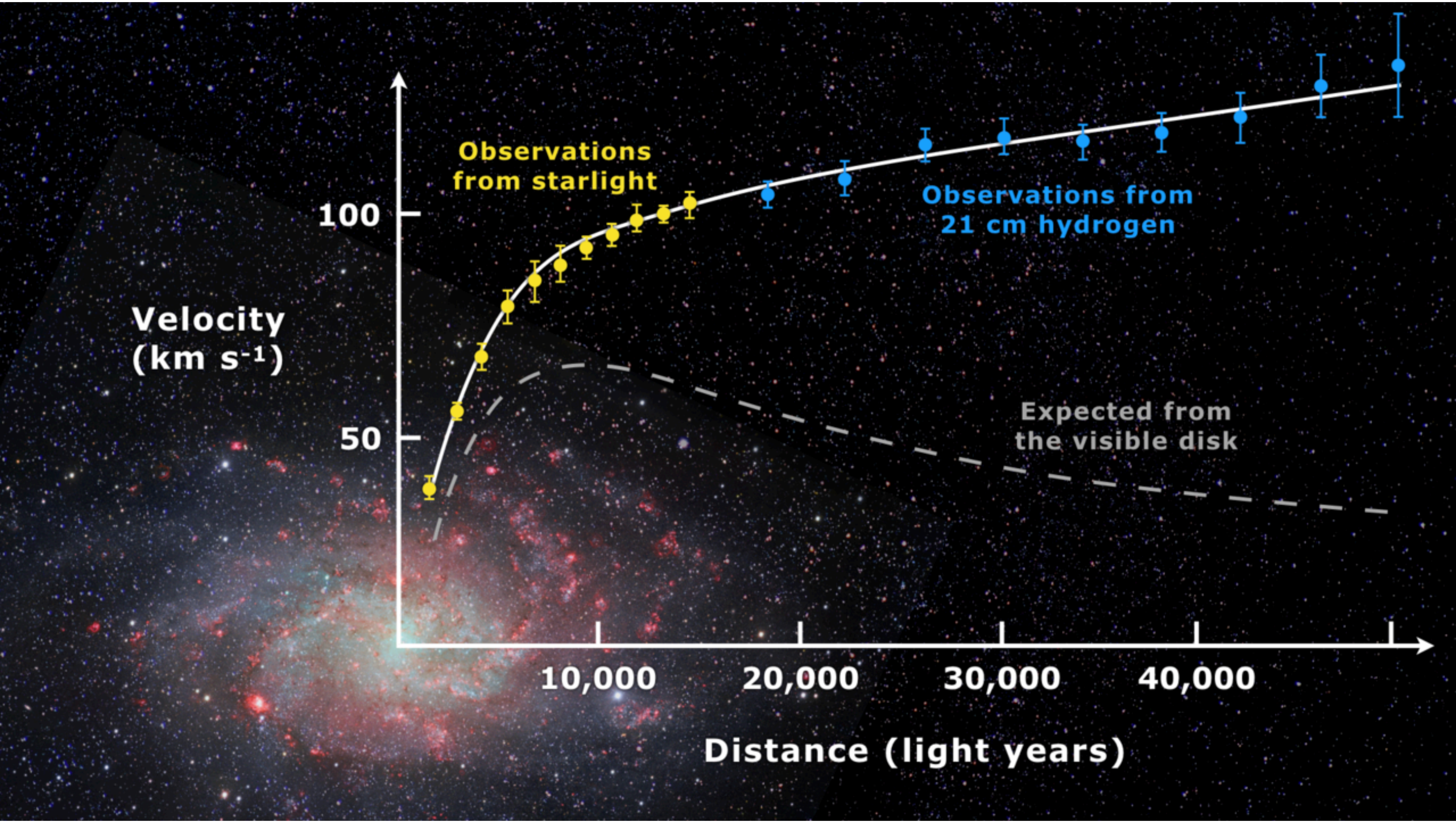
КАРТИНА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ:

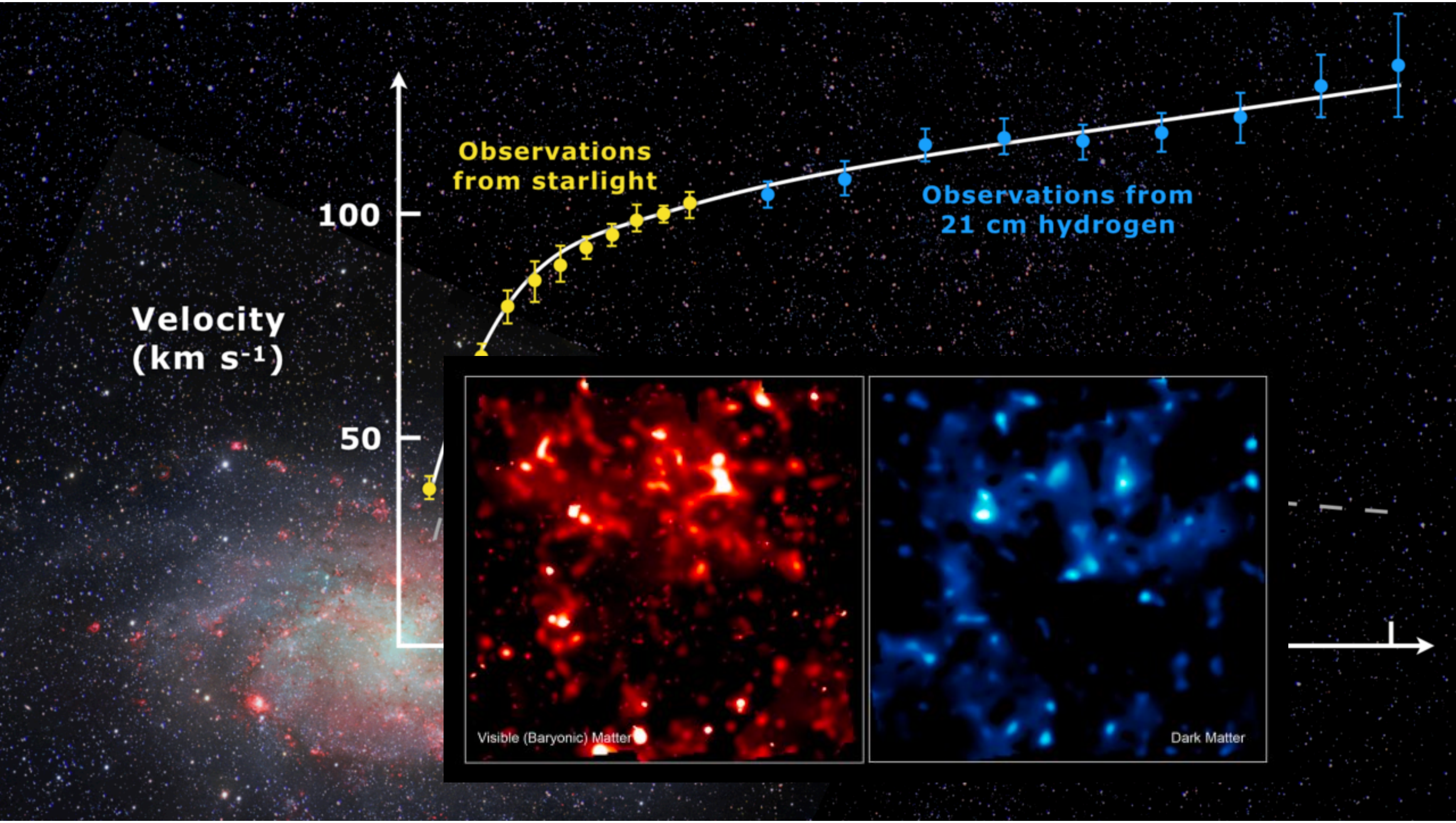


Source: AAAS



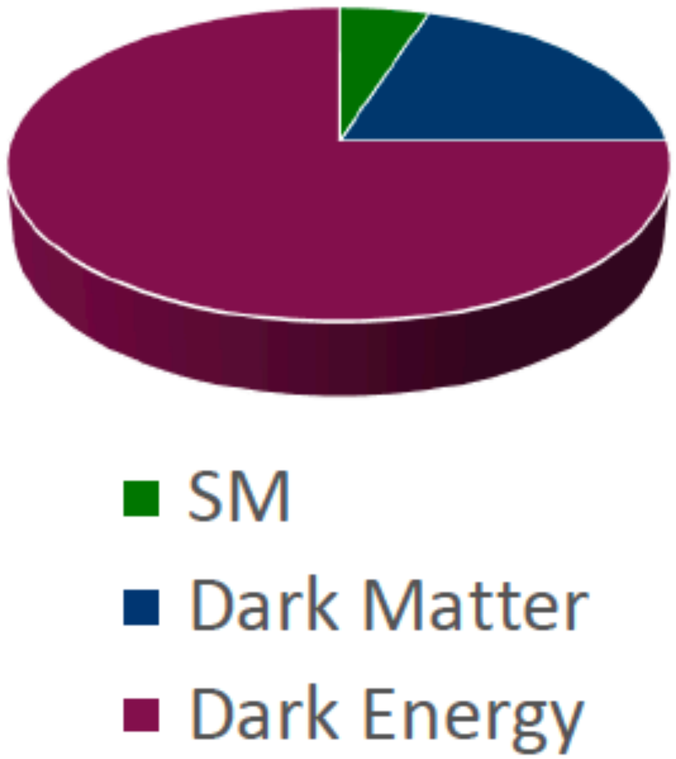



Observations
from starlight
Observations from
21 cm hydrogen
Velocity
(km s-1)
100
50
Expected from
the visible disk
10,000
20,000
30,000
40,000
Distance (light years)


Observations
from starlight
Observations from
21 cm hydrogen
100
50
Velocity
(km s-1)
Visible (Baryonic) Matter
Dark Matter

Physics Beyond the Standard Model

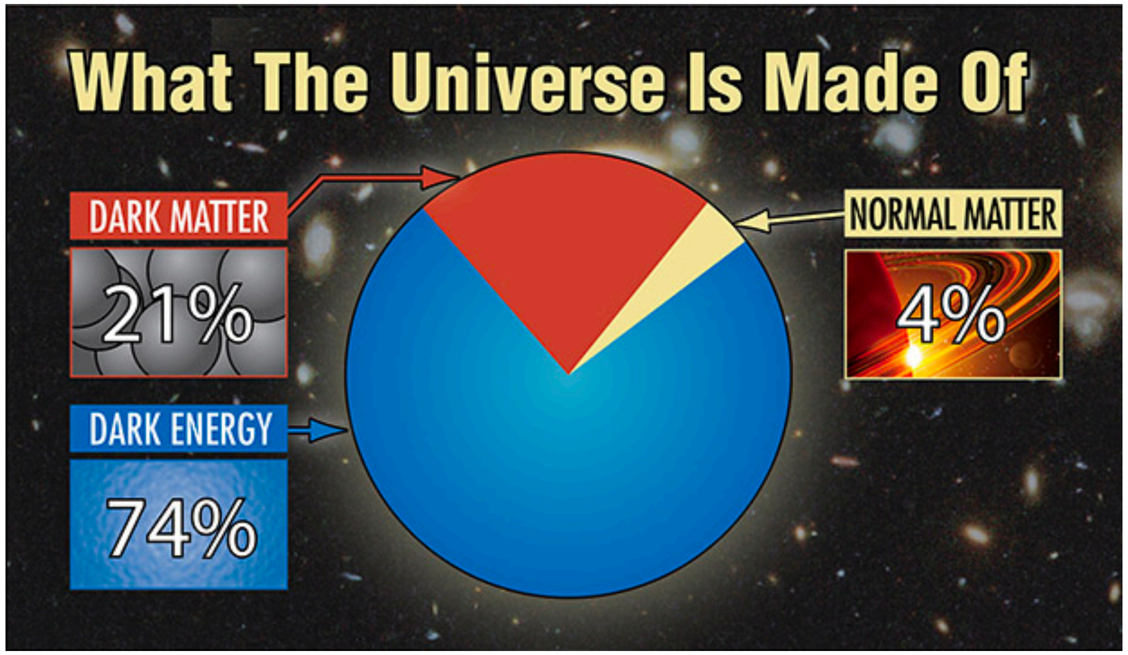
- Dark Matter existence established at cosmological scales
  - New weakly interacting particles
- Neutrinos not exactly massless
  - Right-handed (sterile) neutrinos
- Matter anti-matter asymmetry
  - Additional CP violating interactions



The SM must be extended!
What is the underlying fundamental theory?

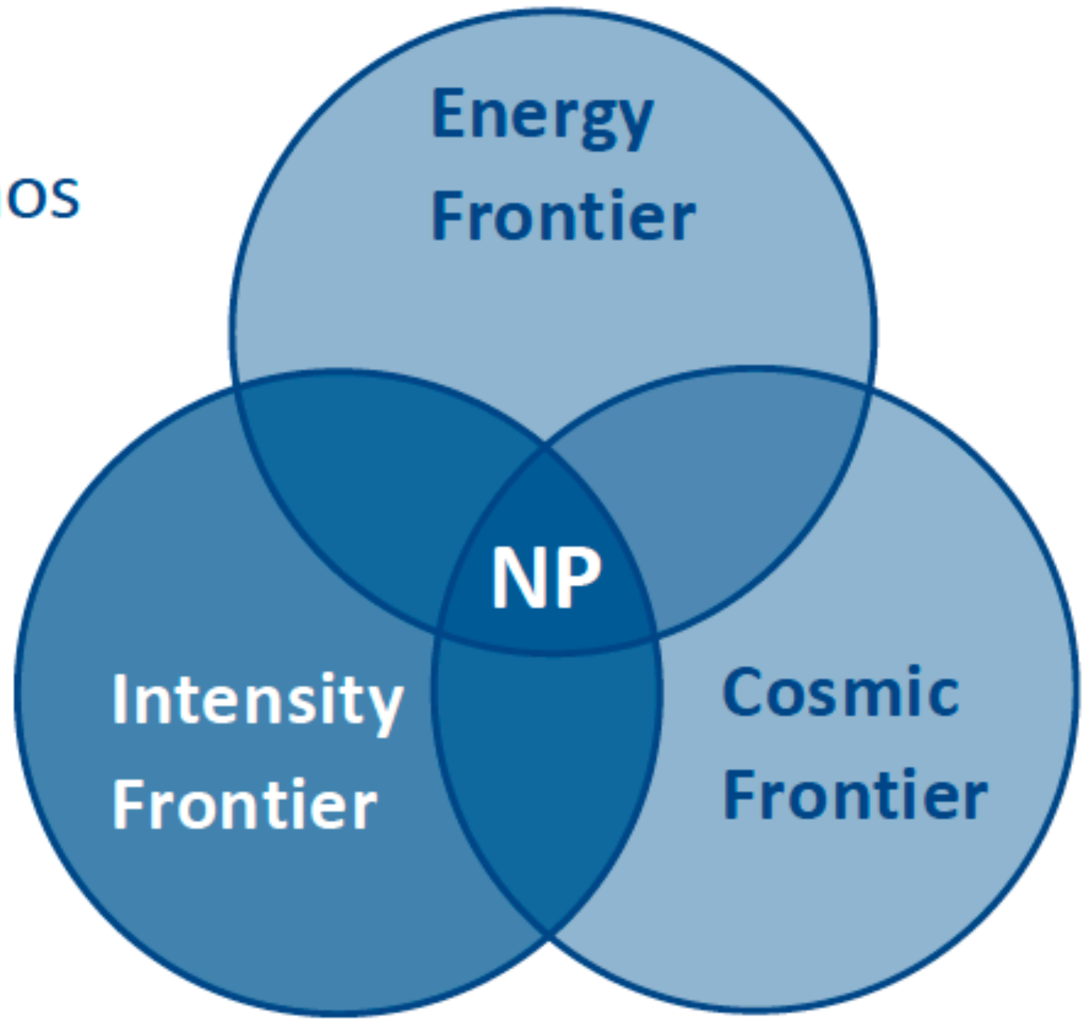
From talk of Andreas Crivellin

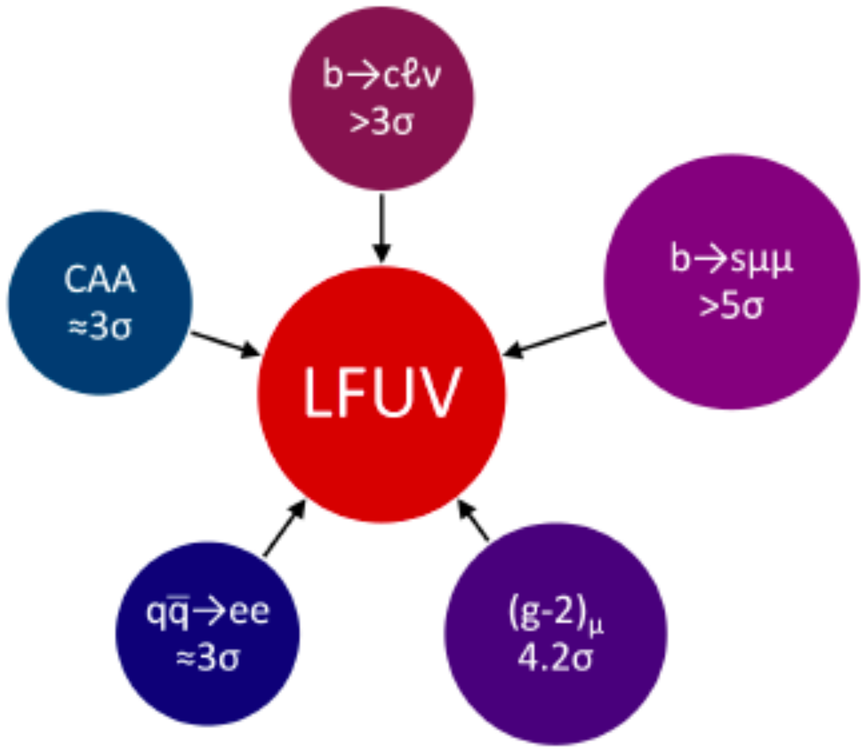

Dark matter
Light bosons
Axion-like particles
Fuzzy dark matter
QCD axions
Neutrinos
Standard-model neutrinos
Sterile neutrinos
Weak scale
Super-symmetry
Extra dimensions
Little Higgs
Simplified models
Effective field theory
Modified gravity
MOG
TeVeS
MOND
Emergent gravity
Macroscopic
Macros
Primordial black holes
MaCHOs
Other particles
WIMPzilla
Superfluid
Self-interacting


What The Universe Is Made Of
DARK MATTER
21%
NORMAL MATTER
4%
DARK ENERGY
74%

Discovering New Physics

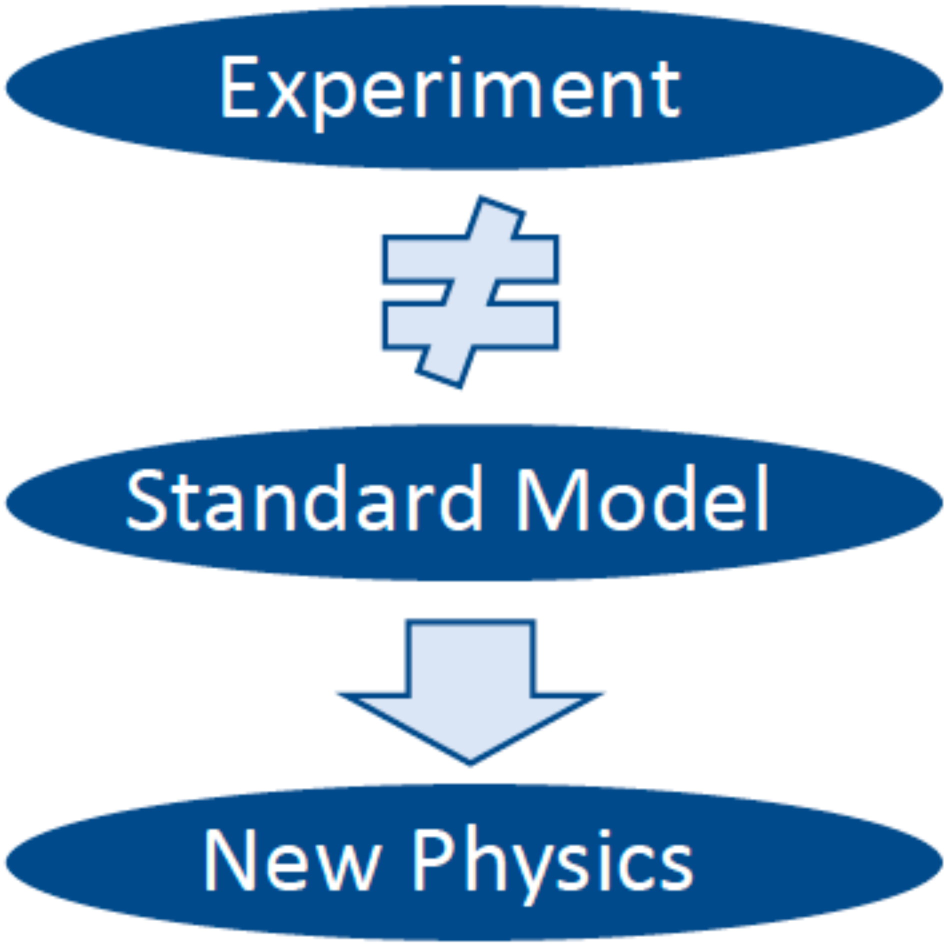
- Cosmic Frontier
  - Cosmic rays and neutrinos
  - Dark Matter
  - Dark Energy
- Energy Frontier
  - LHC
  - Future colliders
- Intensity Frontier
  - Flavour
  - Neutrino-less double-β decay
  - Test of fundamental symmetries
  - Proton decay





Different hints for the violation of LFU, with size of the spheres reflecting the significance of the respective tension.

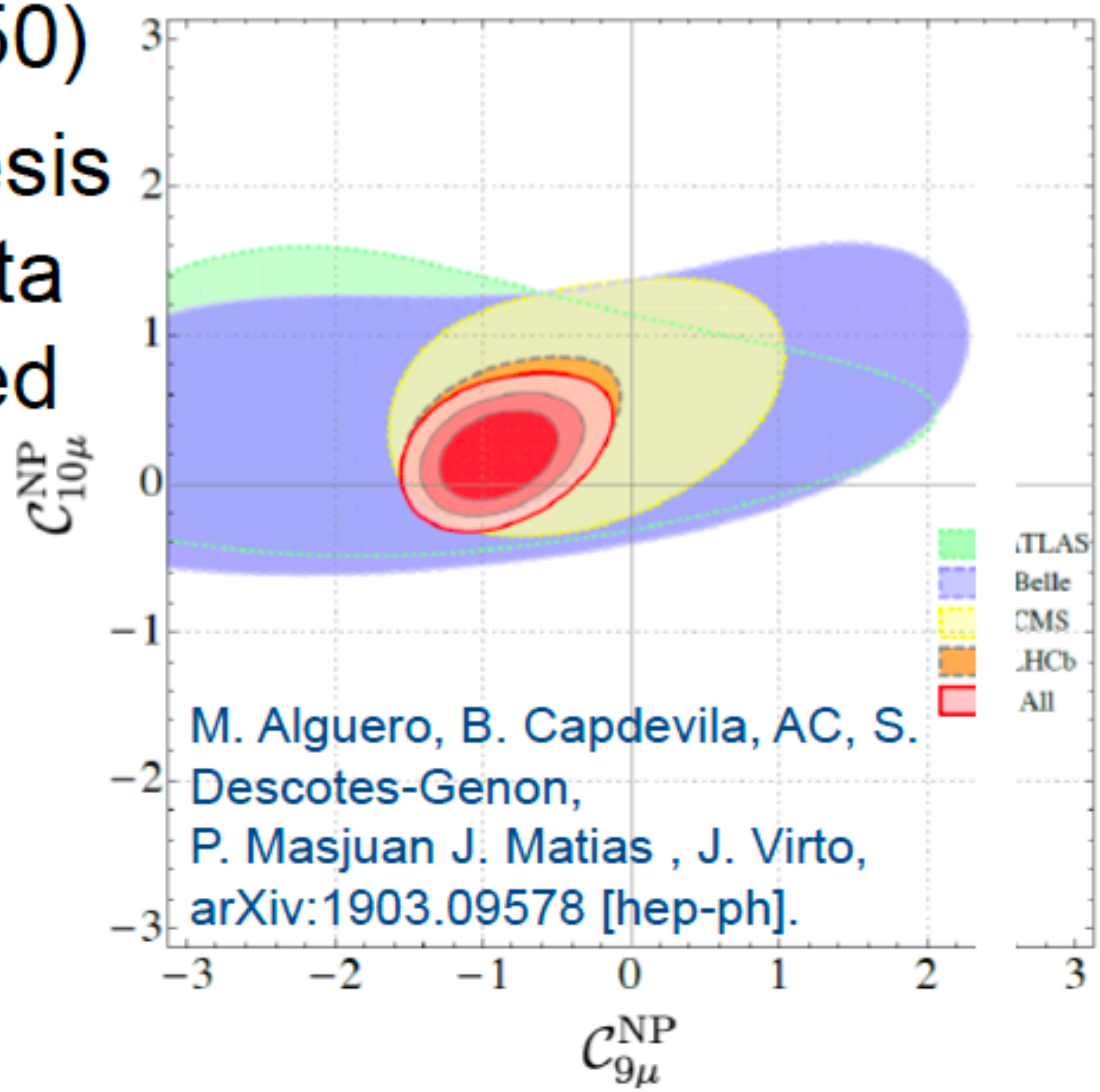
A. Crivellin and M. Hoferichter. Science 374(2021) no.6571, 1051



LFV Channel	Current limit	Projection
$\mu \to e\gamma$	4.2×10^{-13} [MEG Coll. (2016)]	6×10^{-14} [MEGII Coll. (2018)]
$\mu \to 3e$	1.0×10^{-12} [SINDRUM Coll. (1988)]	1×10^{-16} [Perrevoort, Mu3e (2018)]
$\mu \to ea, m_a < 13\,\mathrm{MeV}$	5.8×10^{-5} [Bayes *et al* (2014)]	1×10^{-8} [Perrevoort, Mu3e (2018)]
$\mu \to ea, m_a > 13\,\mathrm{MeV}$	9.0×10^{-6}	
$\mu \to ea\gamma$	1.1×10^{-9} [Bolton *et al* (1988)]	
$\mu \to e\gamma\gamma$	7.2×10^{-11} [LAMPF Coll (1986)]	
$\mu N \to eN$	7.0×10^{-13} [SINDRUM-II (2006)]	1×10^{-17} [Mu2e (2014)] [COMET (2020)]

Global Fit to b→sμ⁺μ⁻ Data

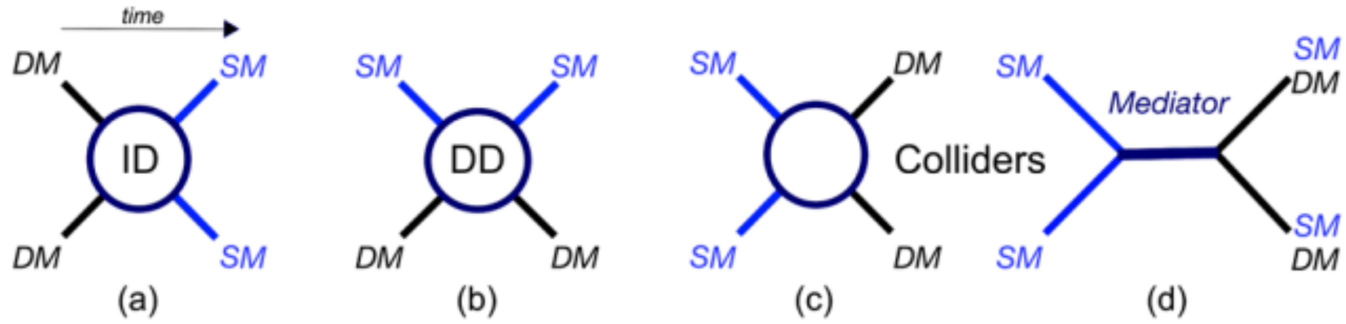
- Perform global model independent fit to include all observables (≈150)
- Several NP hypothesis give a good fit to data significantly preferred over the SM hypothesis

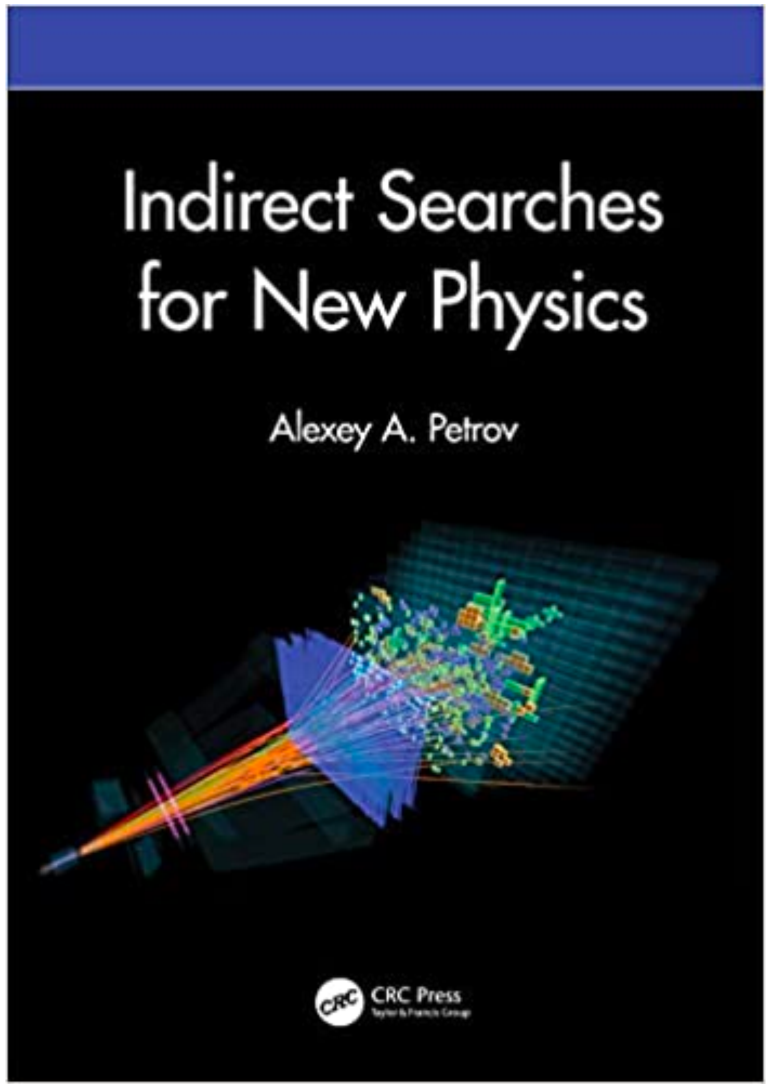


$$O_9 = \bar{s}\gamma^\mu P_L b\, \bar{\ell}\gamma_\mu \ell$$

$$O_{10} = \bar{s}\gamma^\mu P_L b\, \bar{\ell}\gamma_\mu \gamma^5 \ell$$

Fit is 5-6 σ better than the SM



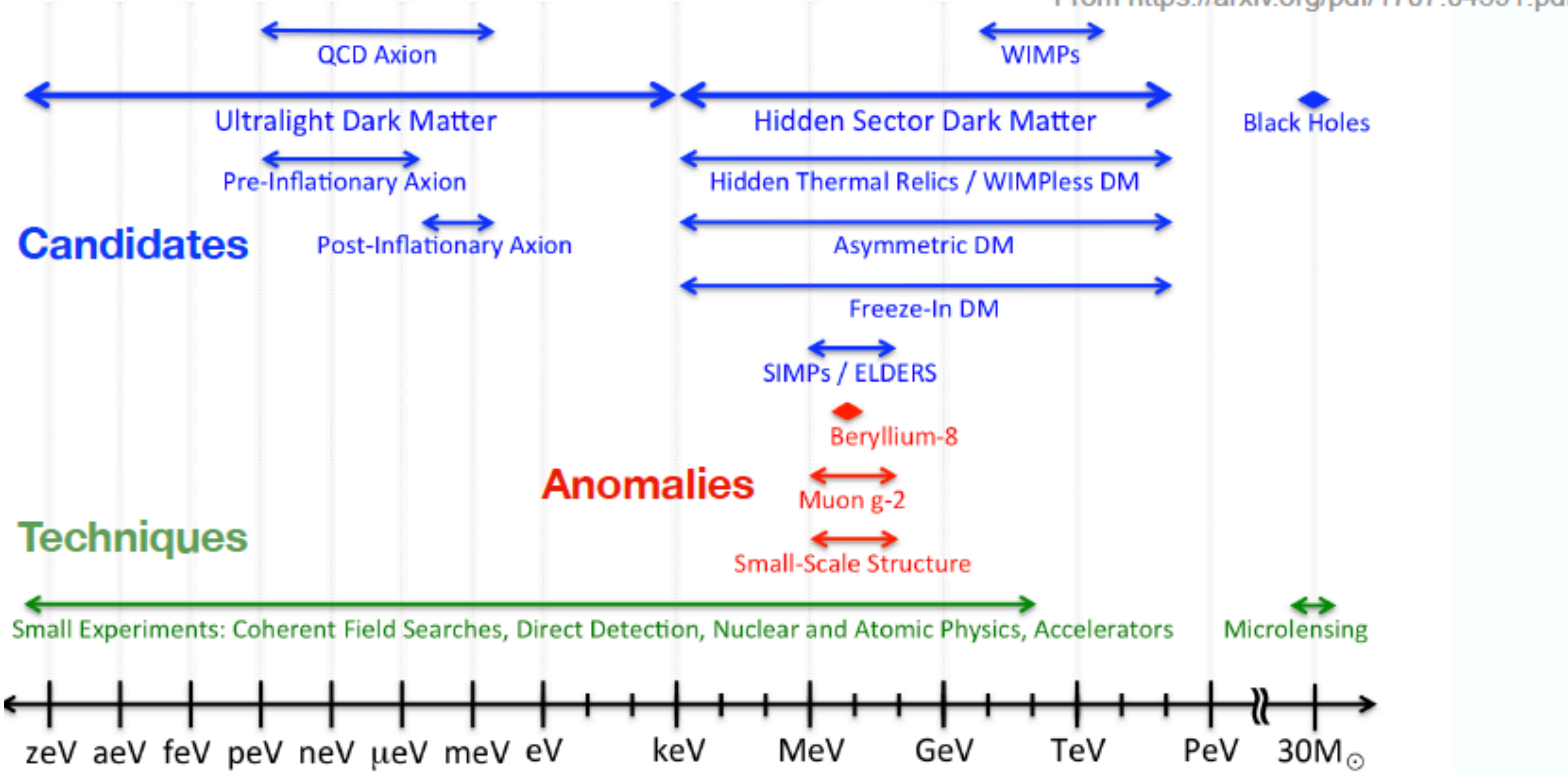


There have been four popular portals:

(1) Vector portal
(2) Axion portal:
(3) Higgs portal:
(4) Neutrino portal

Dark sectors landscape

From https://arxiv.org/pdf/1707.04591.pdf



Broad mass range ➡ **can not be covered by a single experiment**

Complementary searches involving different techniques

Search of DM

Precision experiments:

1) g-2 of leptons
2) EDM of leptons, neutrons and etc
3) Atomic clock
4) Resonator experiments

Search at LHC and other collider experiments :

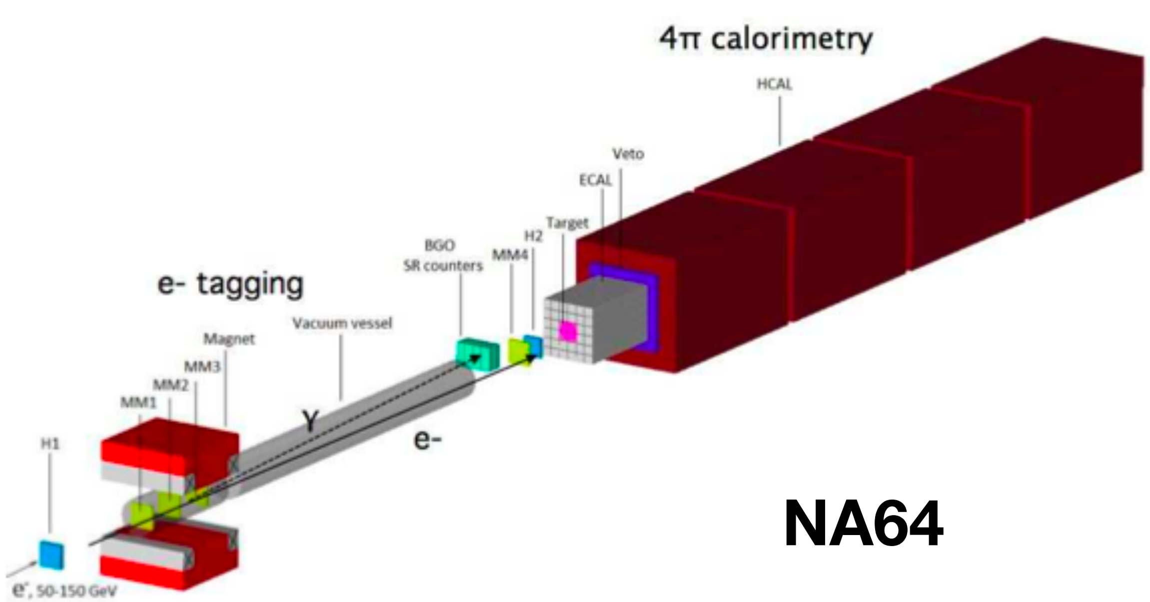
1) CMS, Atlas
2) LHCb
3) NA62
4) GlueX

Missing Energy and Missing momenta experiments

1)NA64 at SPS CERN
2) LDMX

In superconductors

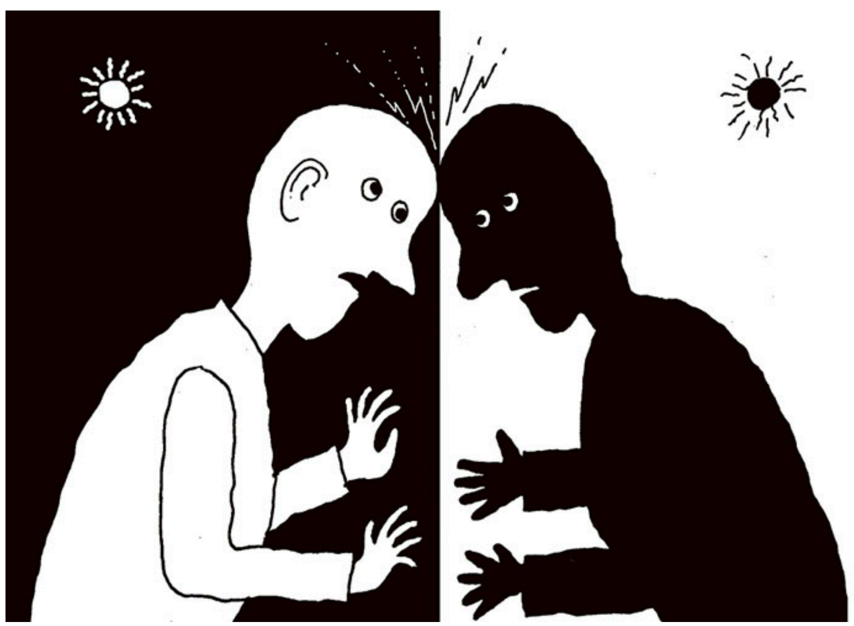
LFV process



NA64

Search of DM

$$\mathscr{L} \supset -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{m^2_{A'}}{2}A'_\mu A'^\mu - A'_\mu(\epsilon e J^\mu_{\rm EM} + g_D J^\mu_D),$$



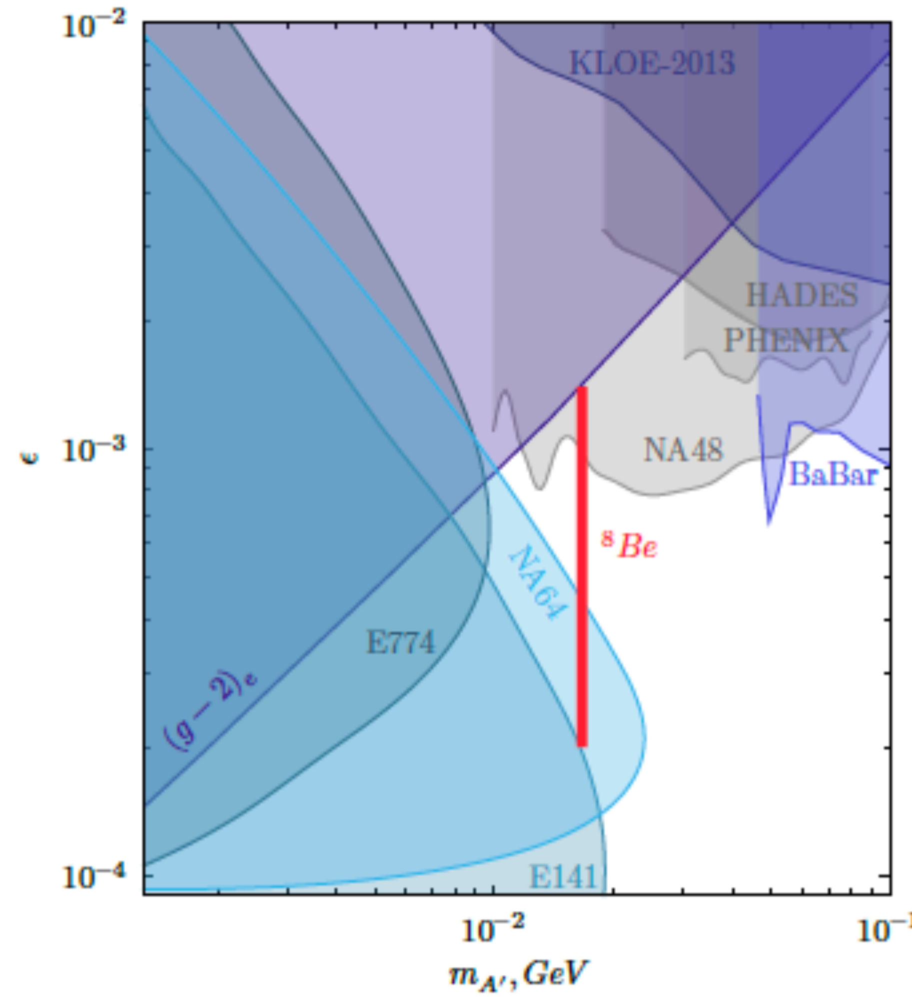
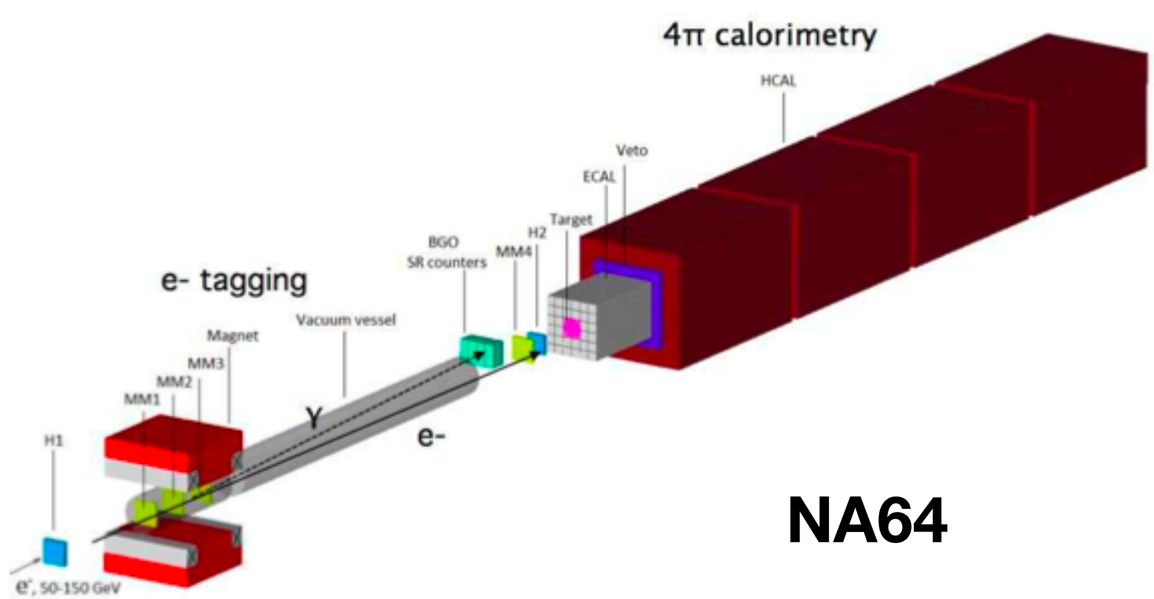


FIG. 3. The 90% C.L. exclusion areas in the $(m_X; \epsilon)$ plane from the NA64 experiment (blue area). For the mass of 16.7 MeV, the $X - e^-$ coupling region excluded by NA64 is $1.3 \times 10^{-4} < \epsilon_e < 4.2 \times 10^{-4}$. The allowed range of ϵ_e explaining the ^{8}Be* anomaly (red area) [2, 3], constraints on the mixing ϵ from the experiments E141 [22], E774 [25], BaBar [40], KLOE [45], HADES [48], PHENIX [49], NA48 [51], and bounds from the electron anomalous magnetic moment $(g-2)_e$ [71] are also shown.



NA64

LDMX

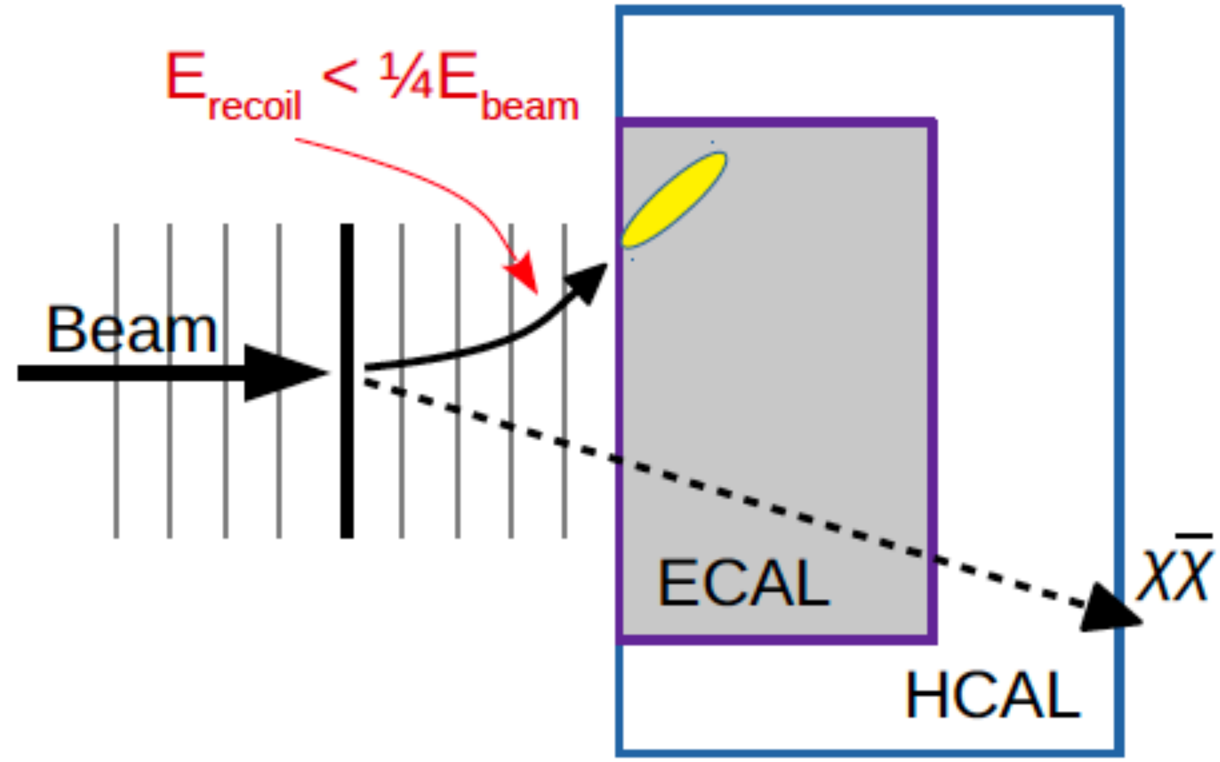
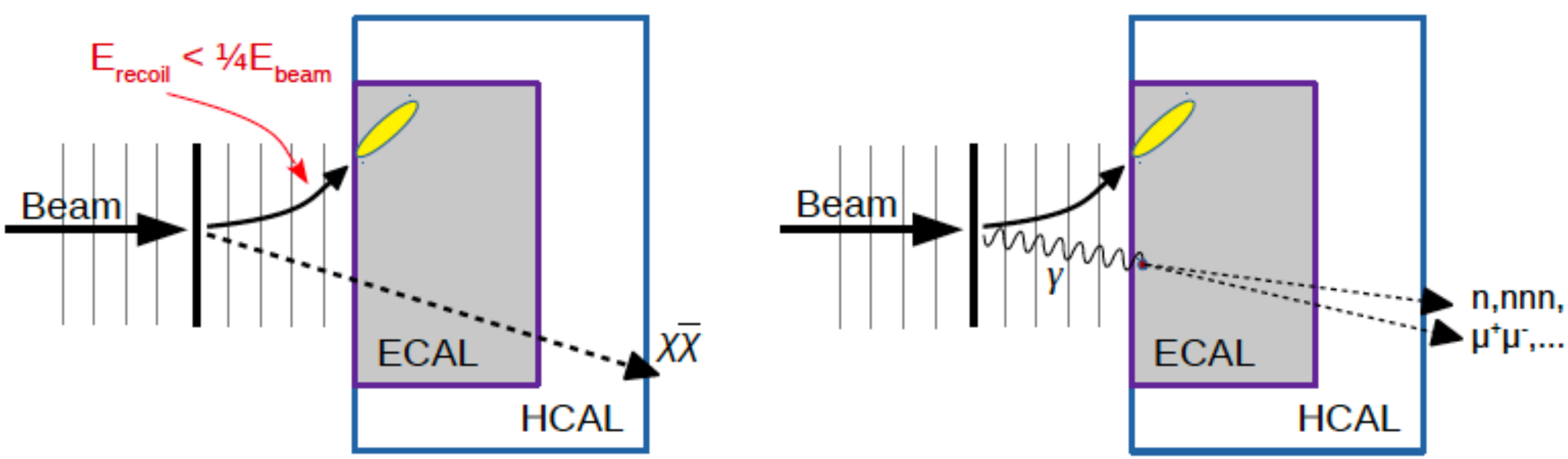


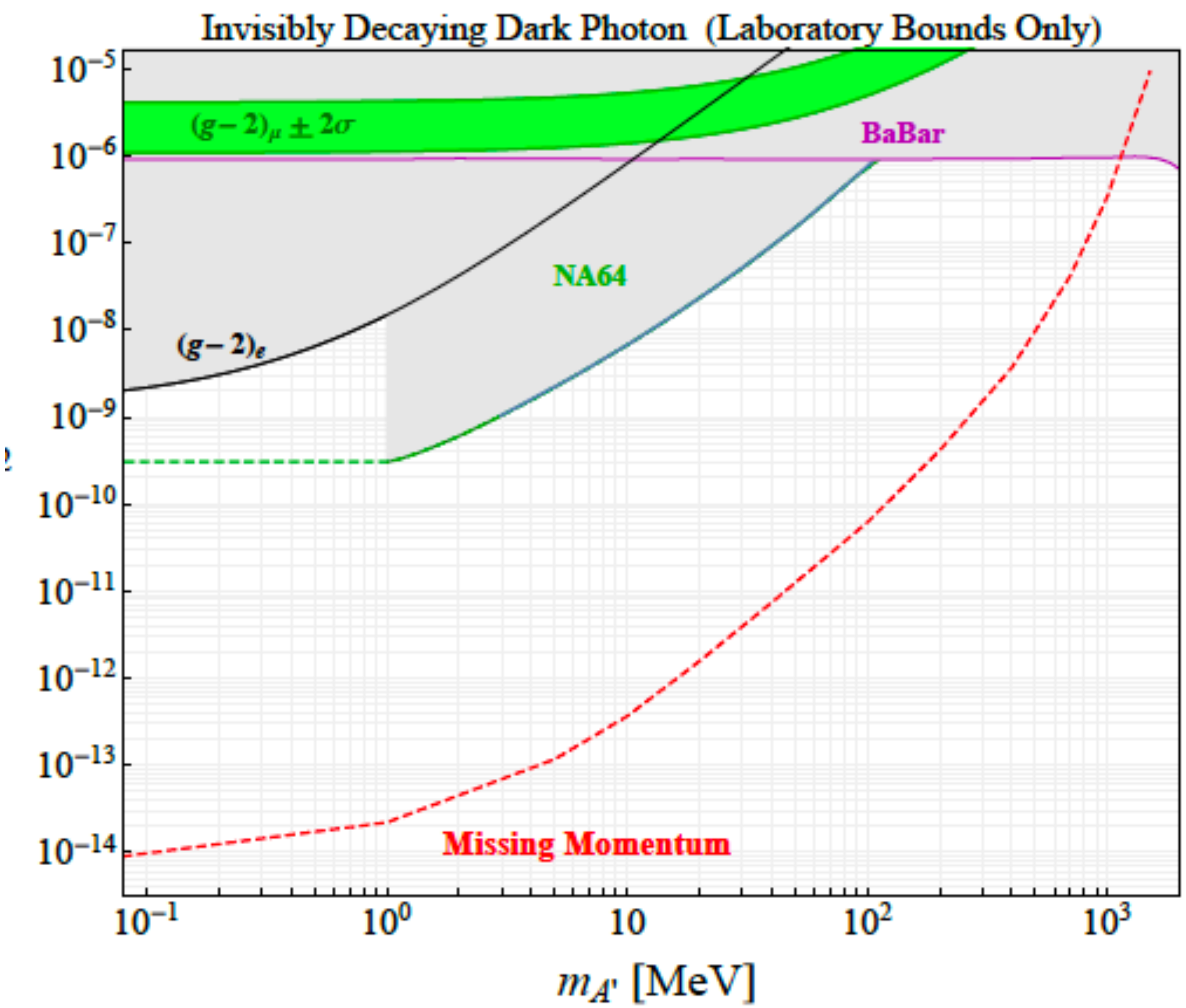
FIG. 8: Conceptual drawing of the LDMX experiment, showing the electron beam passing through a tagging tracker, impacting on a thin tungsten target, the recoil tracker, the electromagnetic calorimeter, and hadron calorimeter.



(a) (b)

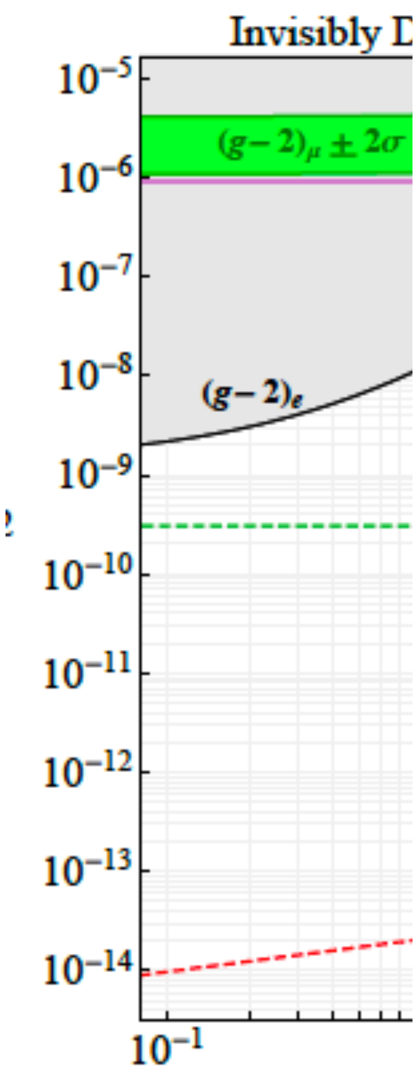
The general Lagrangian for this family of models contains

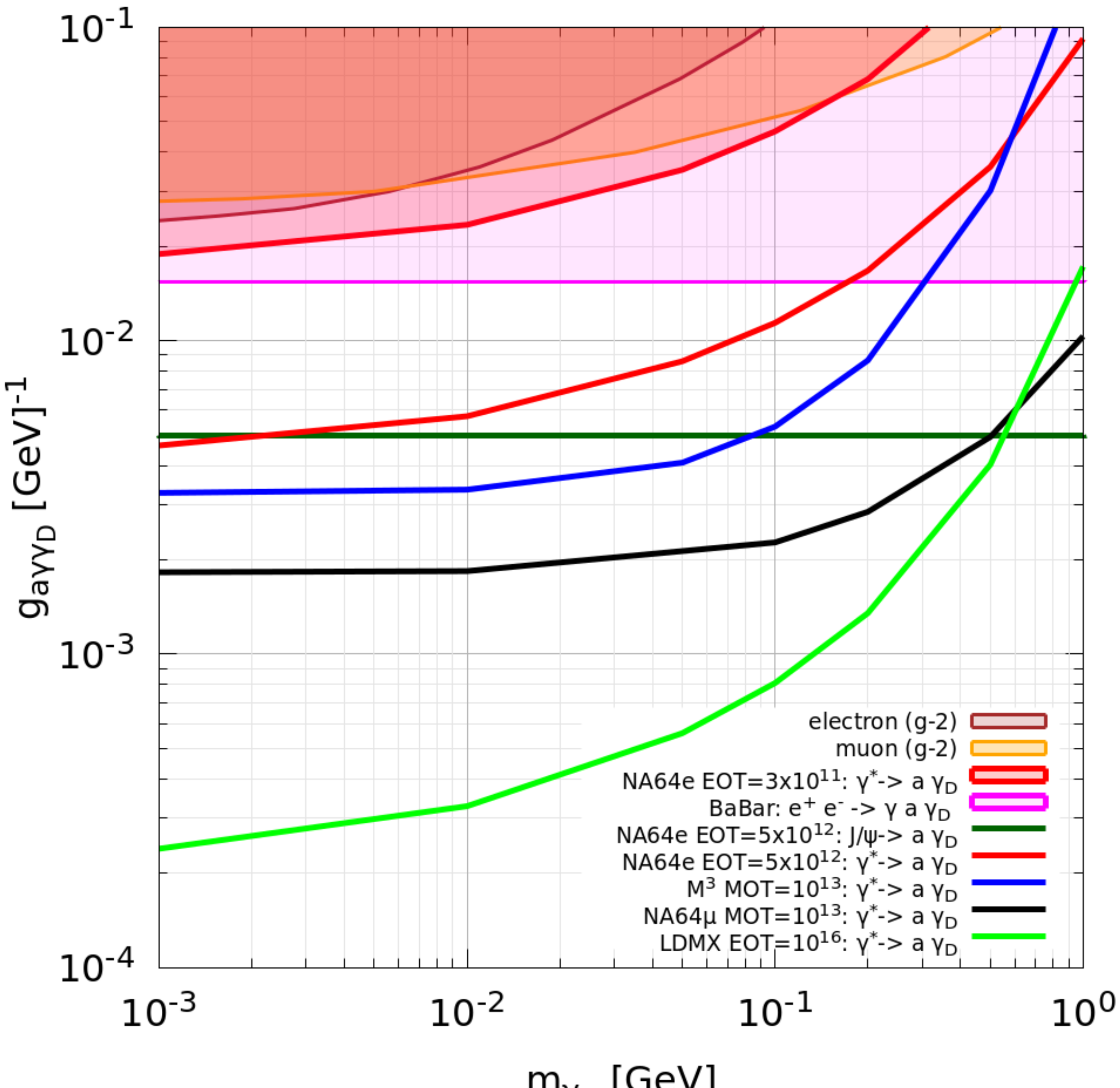
$$\mathscr{L} \supset -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{m_{A'}^2}{2}A'_\mu A'^\mu - A'_\mu(\epsilon e J^\mu_{\rm EM} + g_D J^\mu_D),$$



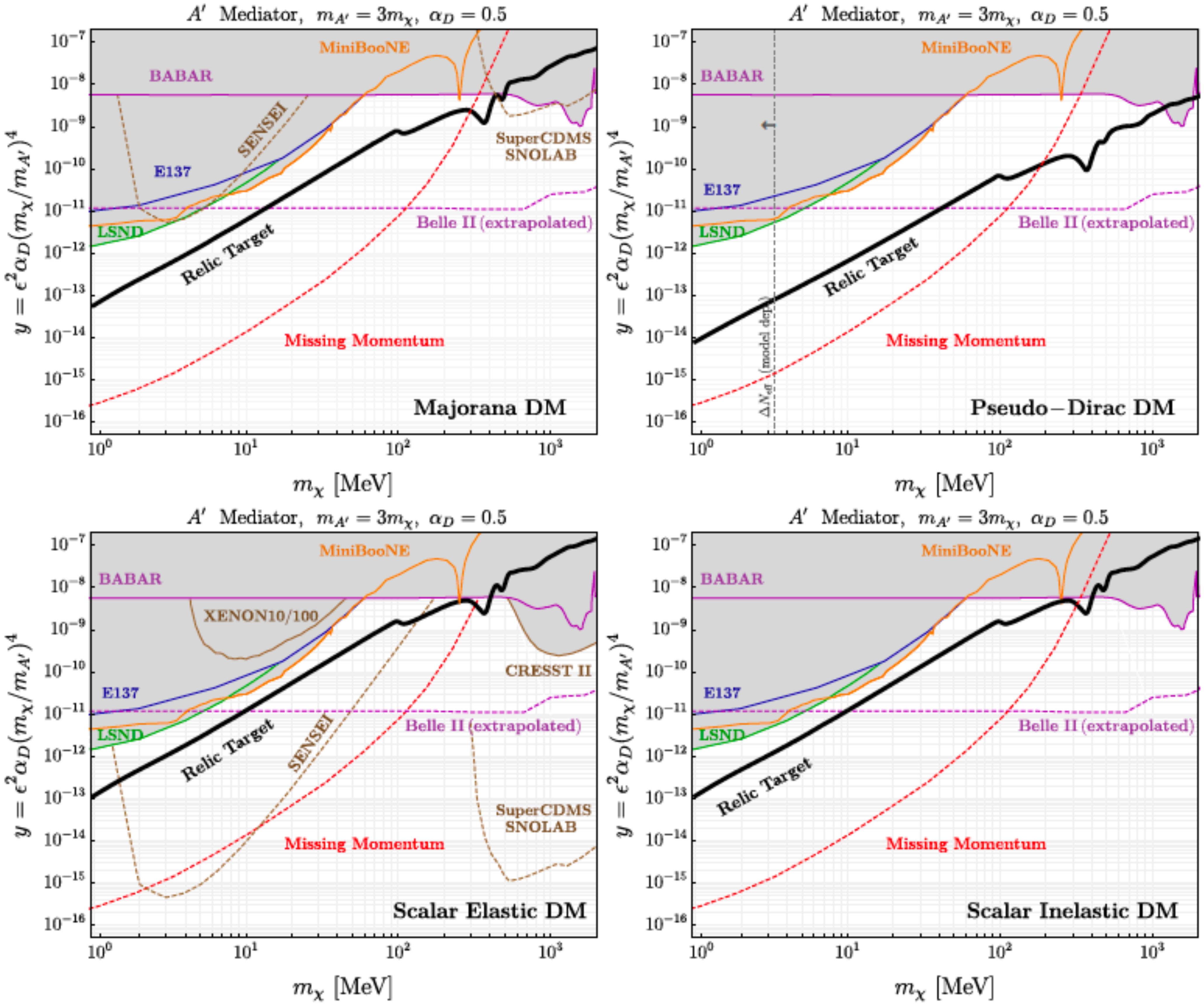
The general Lagrangian for this family of models contains

$$\mathcal{L}_{\textbf{dark axion portal}} = \frac{g_{a\gamma_D\gamma_D}}{4} a F'_{\mu\nu}\widetilde{F}'^{\mu\nu} + \frac{g_{a\gamma\gamma_D}}{2} a F_{\mu\nu}\widetilde{F}'^{\mu\nu}$$





LDMX



A′ Mediator, $m_{A'} = 3m_\chi$, $\alpha_D = 0.5$
MiniBooNE
BABAR
SENSEI
SuperCDMS SNOLAB
E137
LSND
Relic Target
Belle II (extrapolated)
Missing Momentum
Majorana DM
Pseudo−Dirac DM
$\Delta N_{\rm eff}$ (model dep.)
XENON10/100
CRESST II
Scalar Elastic DM
Scalar Inelastic DM
$y = \epsilon^2 \alpha_D (m_\chi/m_{A'})^4$
m_χ [MeV]

Neutron EDM – Situation & Perspective

- **First Ramsey measurement**

  Smith, Purcell & Ramsey, Phys. Rev. 108, 120 (1957)

- **Current limit:**

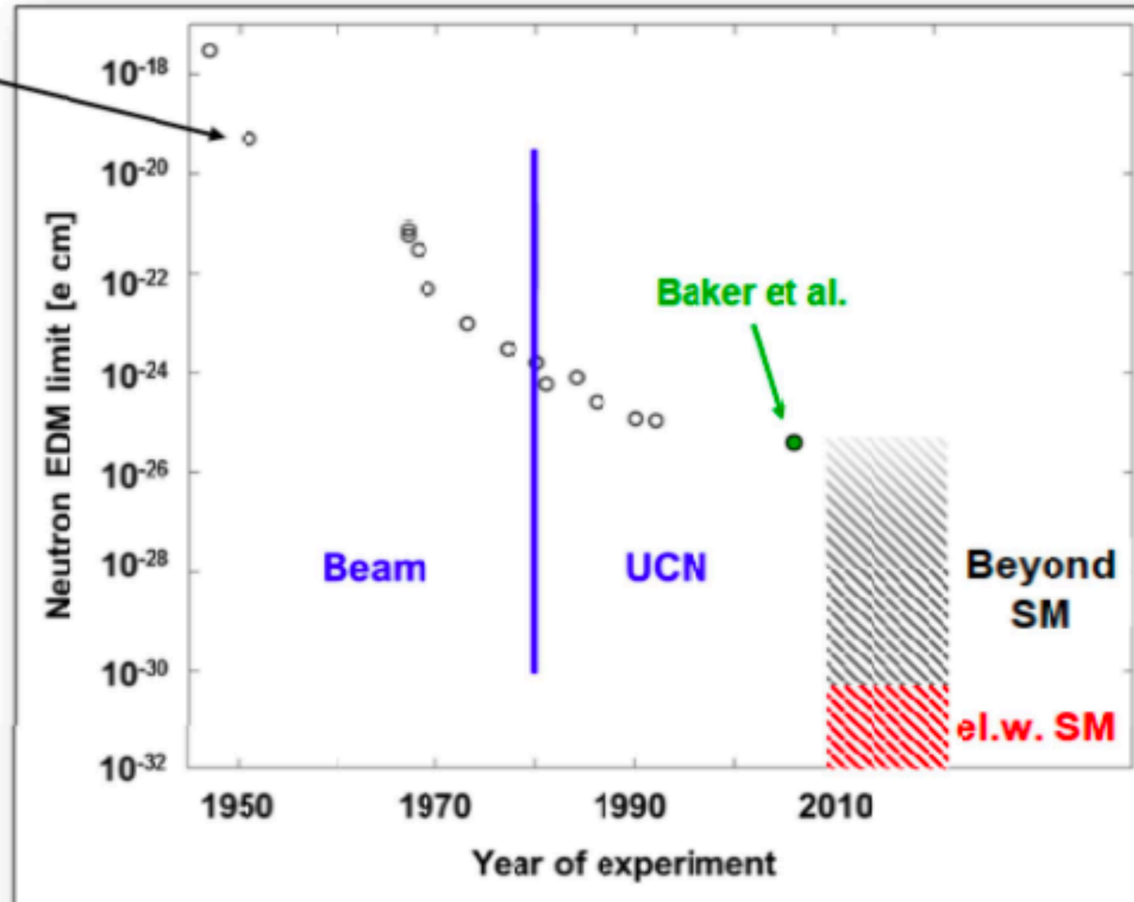
  $$|d_n| < 2.9 \times 10^{-26} \text{ e cm}$$

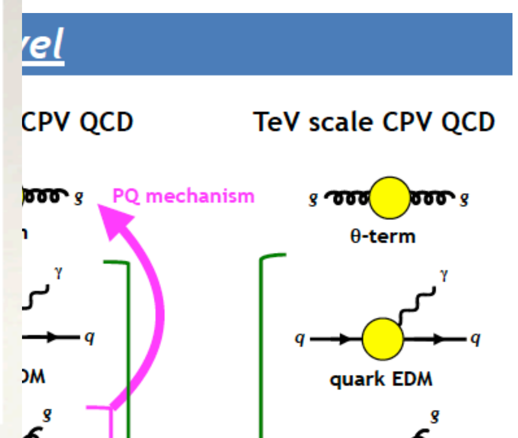
  (90% CL)

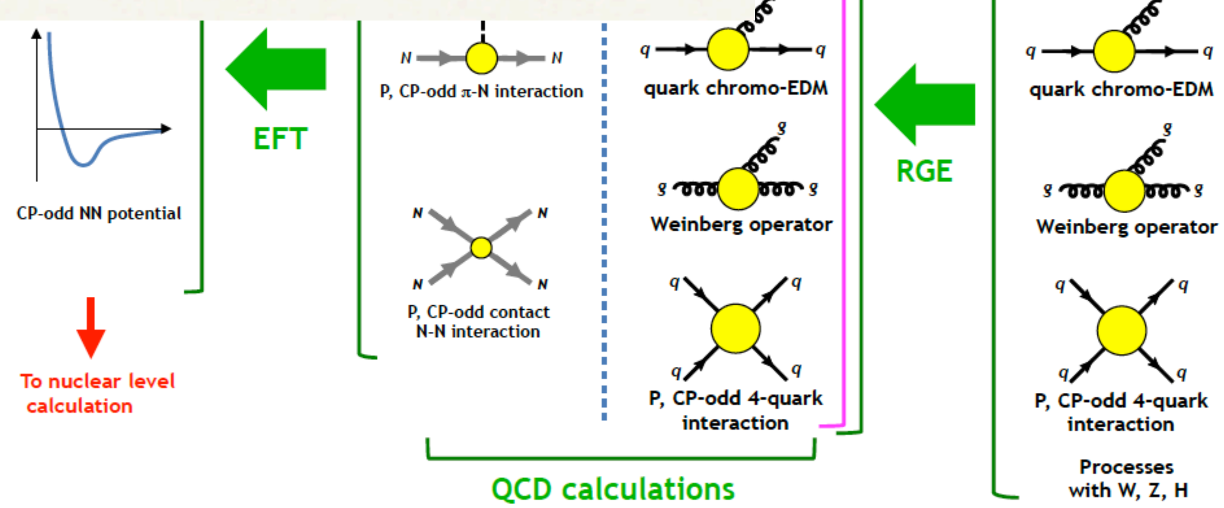
  Baker et al., PRL 97, 131801 (2006)

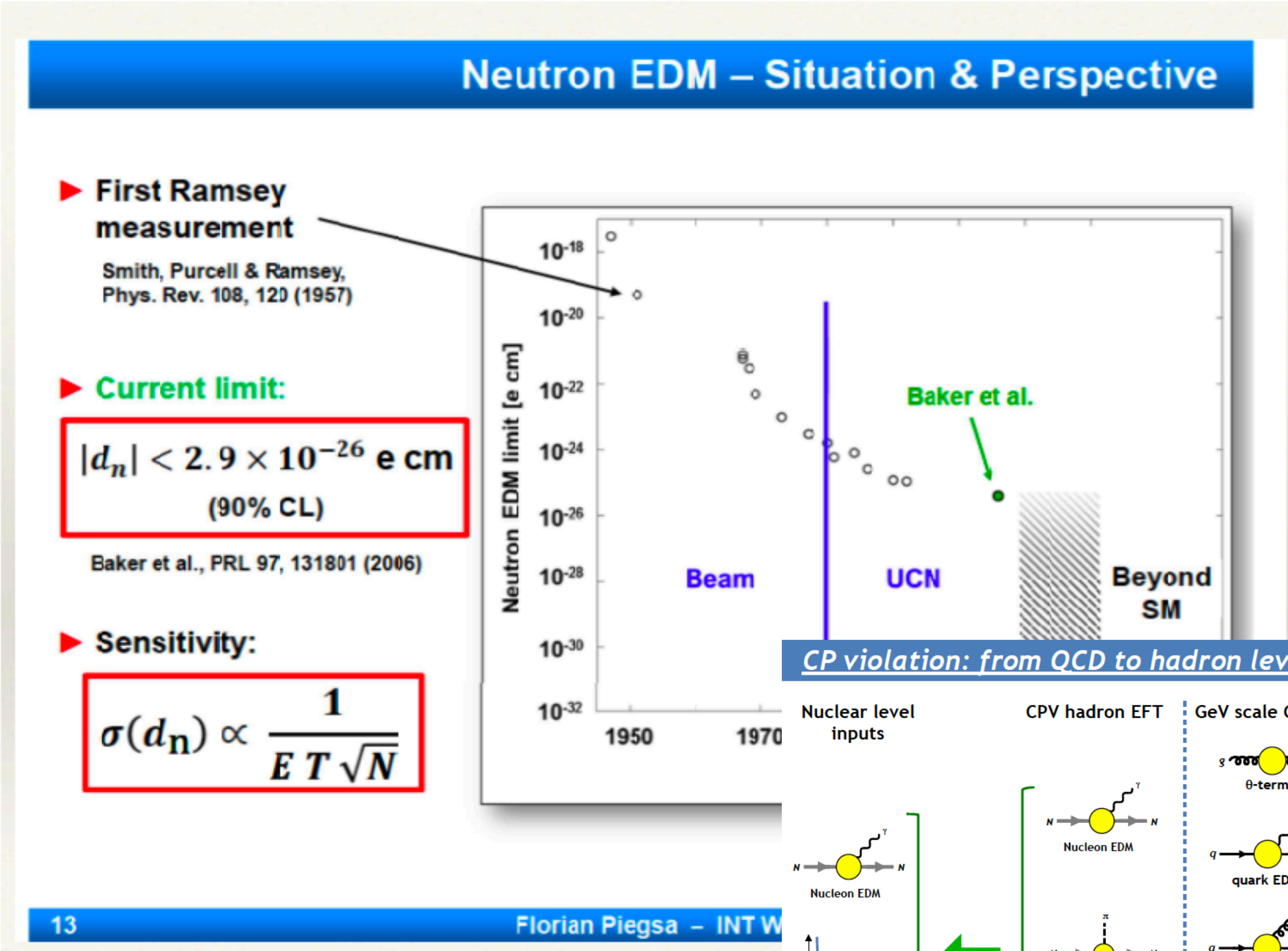
- **Sensitivity:**

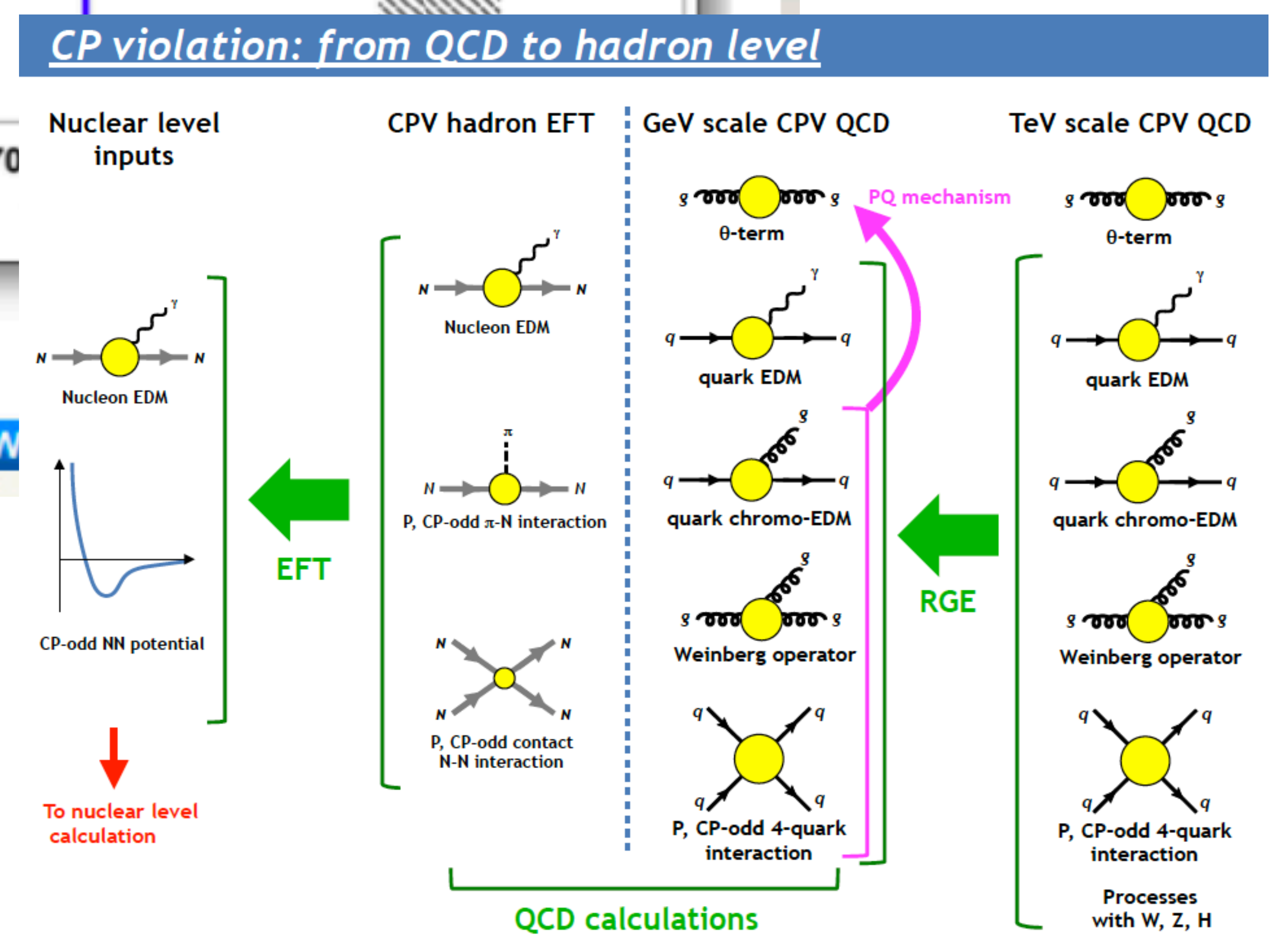
  $$\sigma(d_n) \propto \frac{1}{E\,T\sqrt{N}}$$



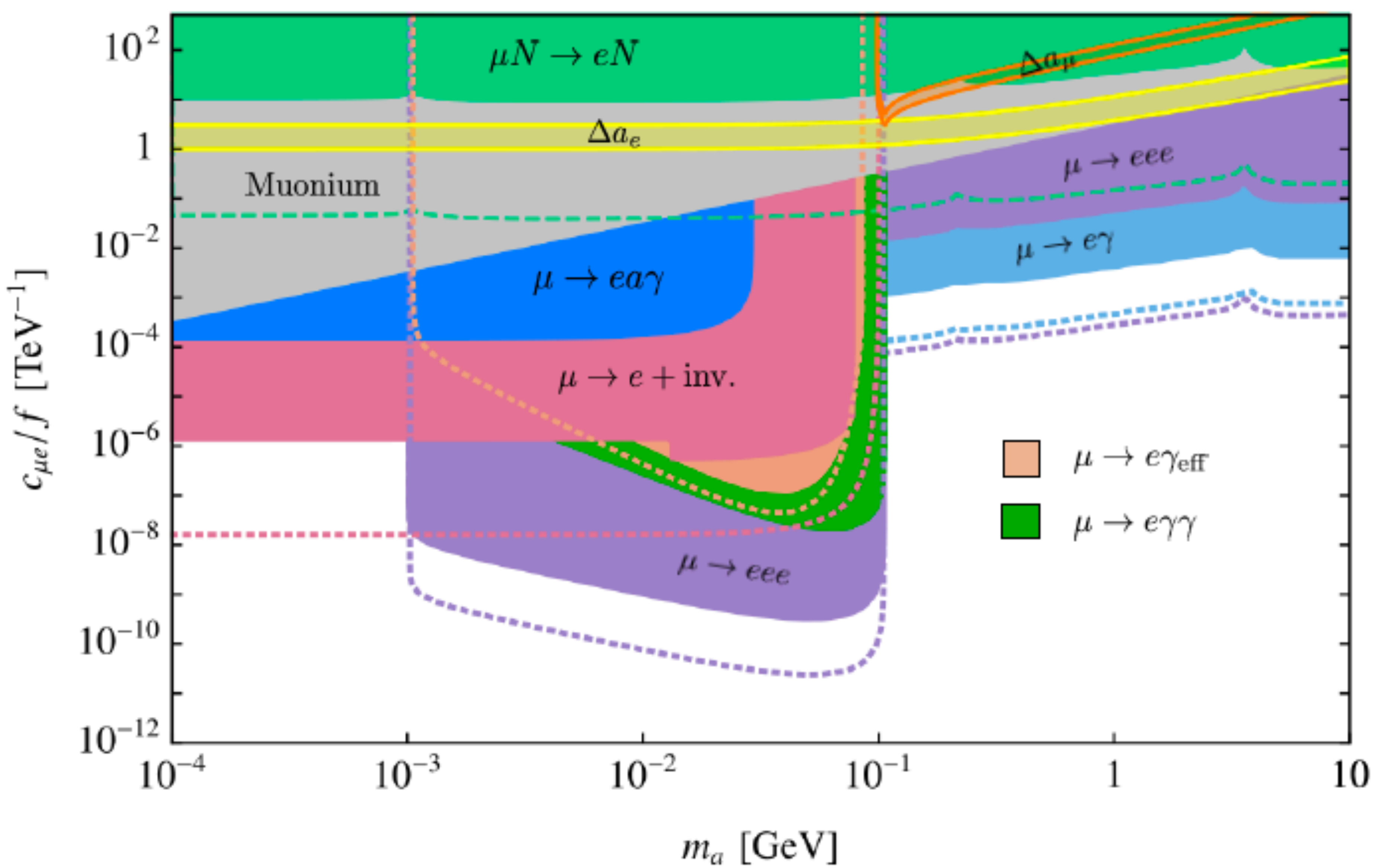


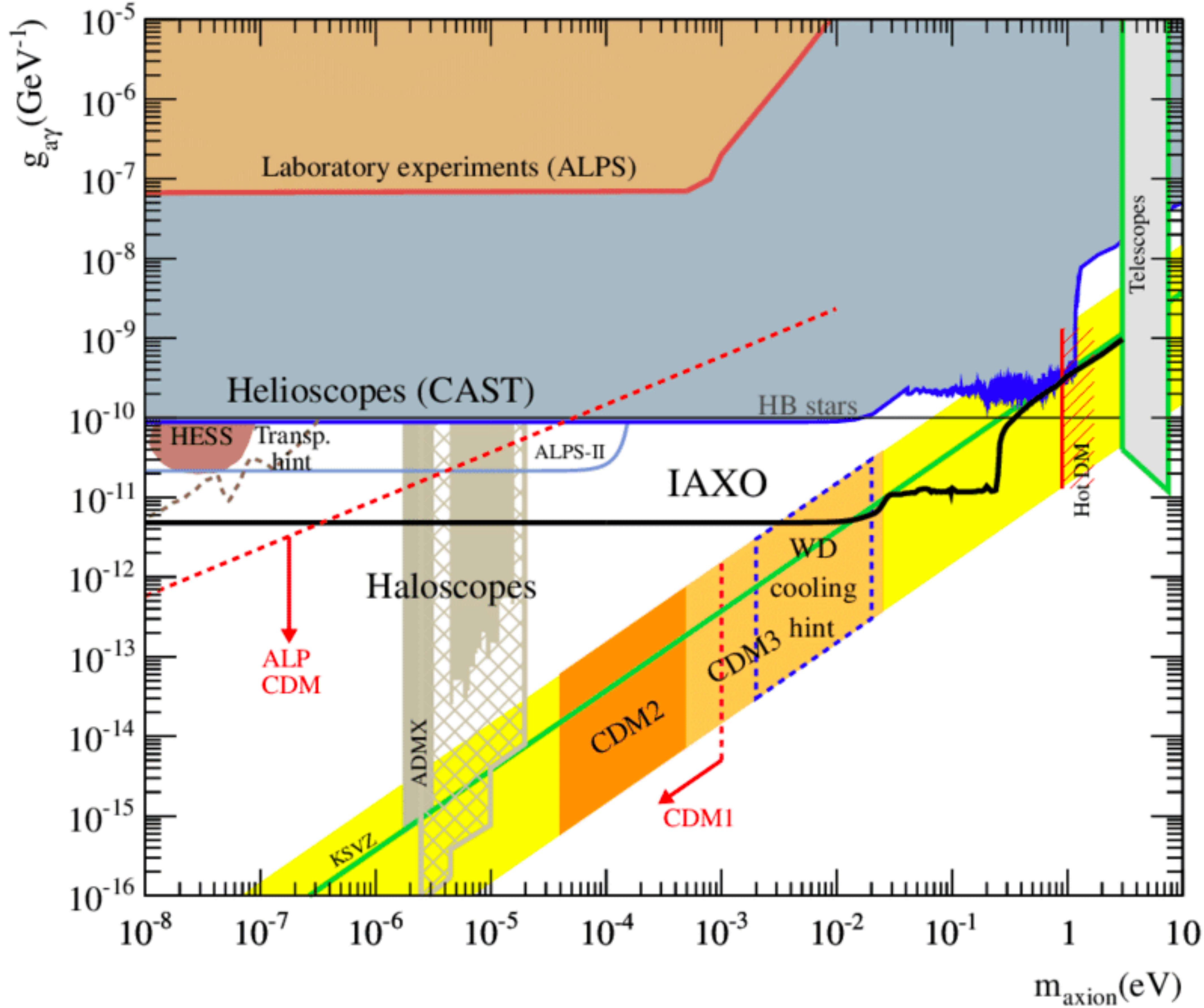



Neutron EDM – Situation & Perspective
First Ramsey measurement
Smith, Purcell & Ramsey, Phys. Rev. 108, 120 (1957)
Current limit:
$|d_n| < 2.9 \times 10^{-26}$ e cm
(90% CL)
Baker et al., PRL 97, 131801 (2006)
Sensitivity:
$\sigma(d_n) \propto \frac{1}{E\,T\sqrt{N}}$
Neutron EDM limit [e cm]
10^{-18}
10^{-20}
10^{-22}
10^{-24}
10^{-26}
10^{-28}
10^{-30}
10^{-32}
1950
1970
Baker et al.
Beam
UCN
Beyond SM
13
Florian Piegsa – INT W

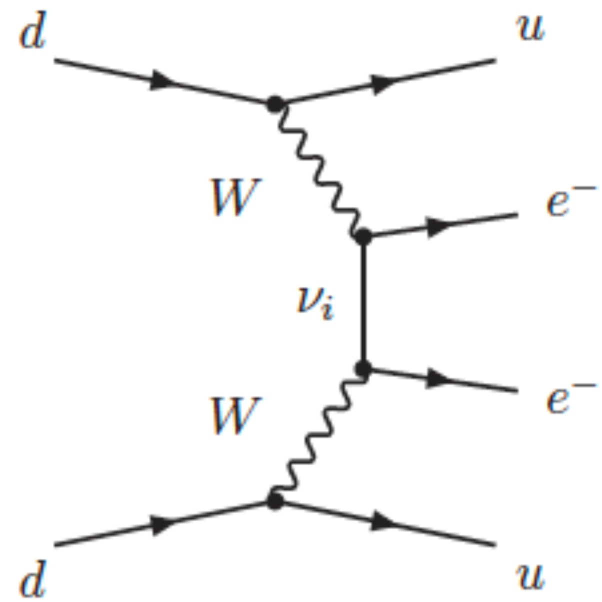

CP violation: from QCD to hadron level
Nuclear level inputs
CPV hadron EFT
GeV scale CPV QCD
TeV scale CPV QCD
θ-term
PQ mechanism
Nucleon EDM
quark EDM
P, CP-odd π-N interaction
quark chromo-EDM
CP-odd NN potential
EFT
RGE
Weinberg operator
P, CP-odd contact N-N interaction
P, CP-odd 4-quark interaction
To nuclear level calculation
Processes with W, Z, H
QCD calculations

$$\mathscr{L}_{eff}^{D\leq 5} = \frac{1}{2}(\partial_\mu a)(\partial^\mu a) - \frac{m_{a,0}^2}{2}a^2 + \frac{\partial_\mu a}{\Lambda}\gamma_\mu \bar{\ell}\,(K_E P_L + K_e P_R)\,\ell + e^2 c_{\gamma\gamma}^{\rm eff}\frac{a}{\Lambda}F_{\mu\nu}\tilde{F}^{\mu\nu}$$





$g_{a\gamma}$ (GeV^{-1})
Laboratory experiments (ALPS)
Helioscopes (CAST)
HB stars
Telescopes
HESS
Transp. hint
ALPS-II
IAXO
Haloscopes
ALP CDM
WD cooling hint
CDM3
CDM2
CDM1
ADMX
KSVZ
Hot DM
m_{axion} (eV)



Quark-level transition that induces neutrinoless double beta decay.

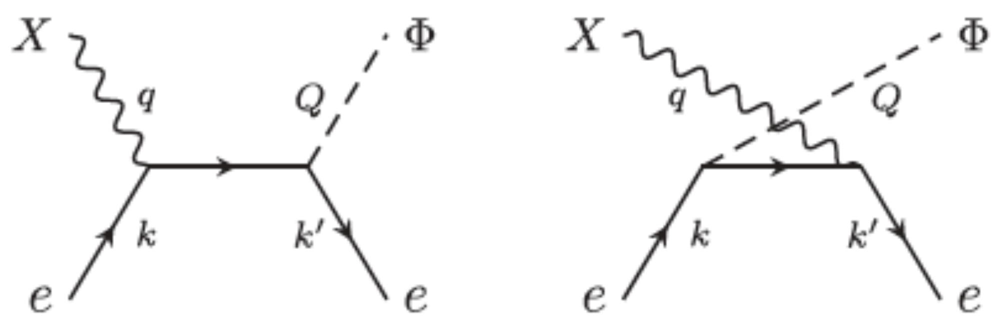
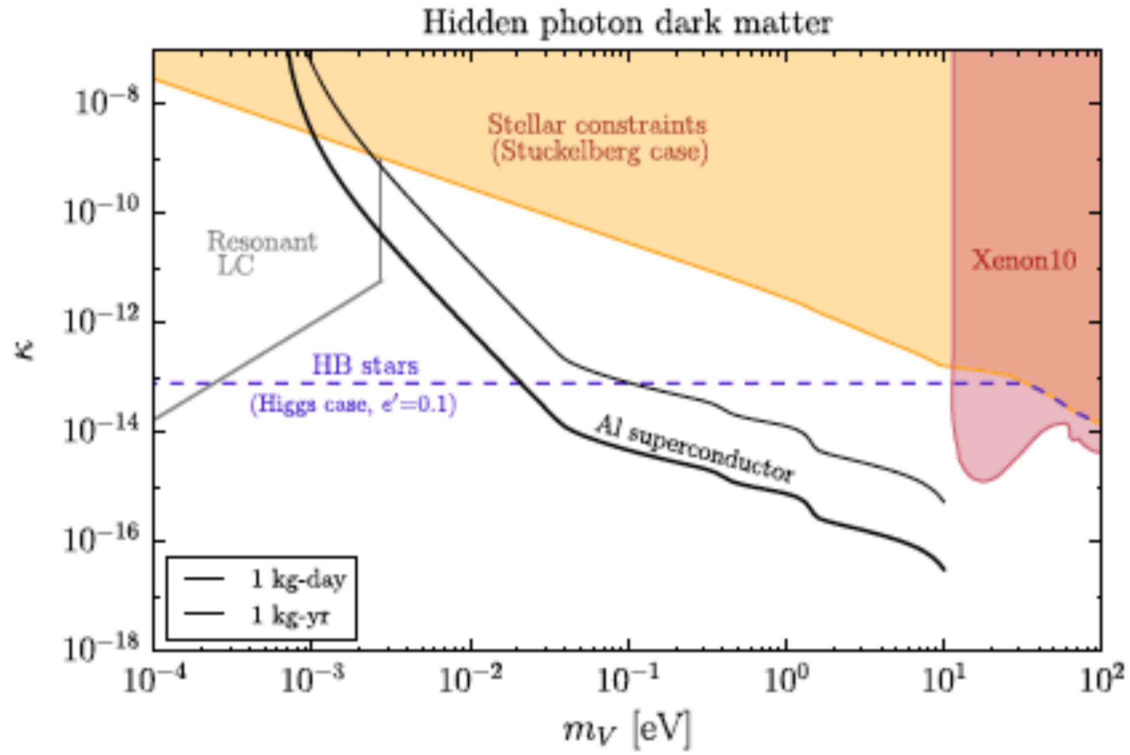
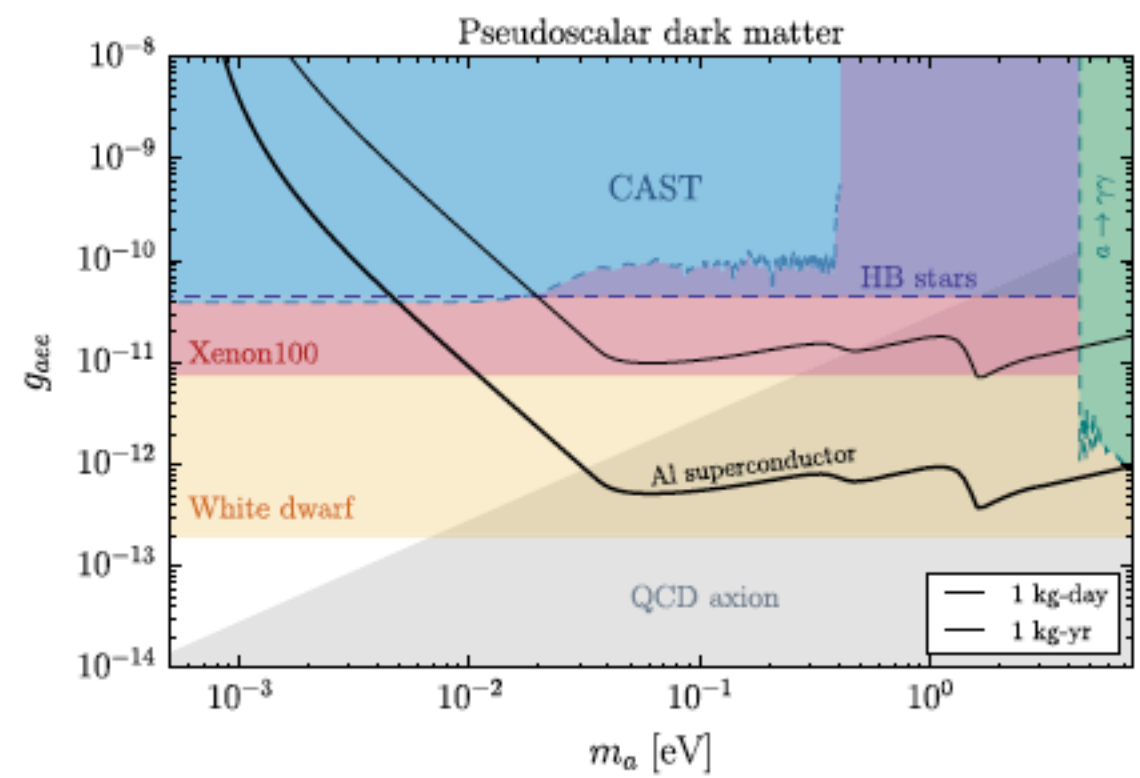


FIG. 1. Absorption process on electrons for an incoming relic particle X, where a phonon Φ is emitted in the final state: $X(q) + e(k) \to e(k') + \Phi(Q)$.





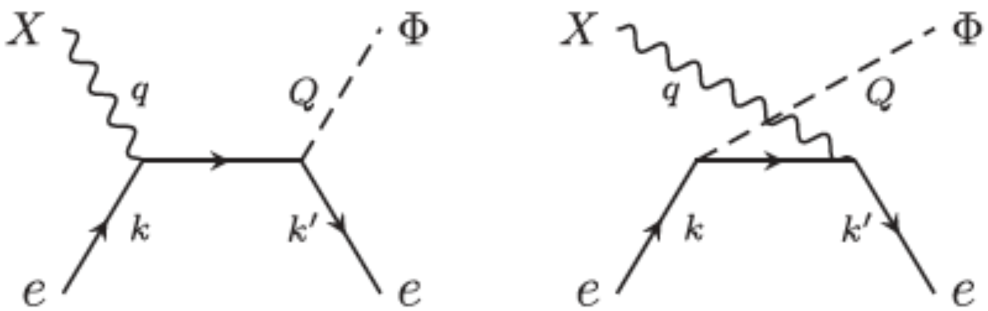
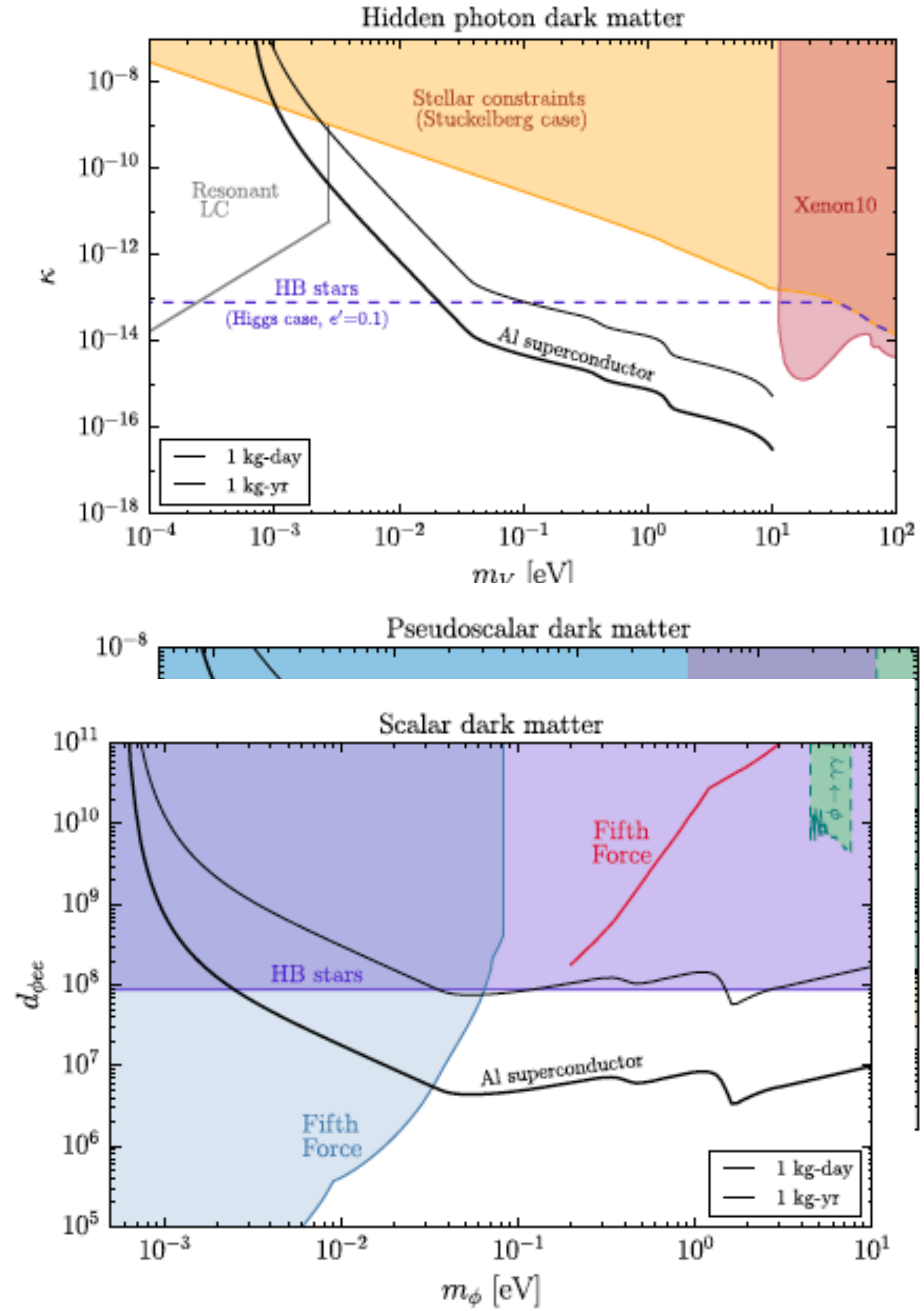
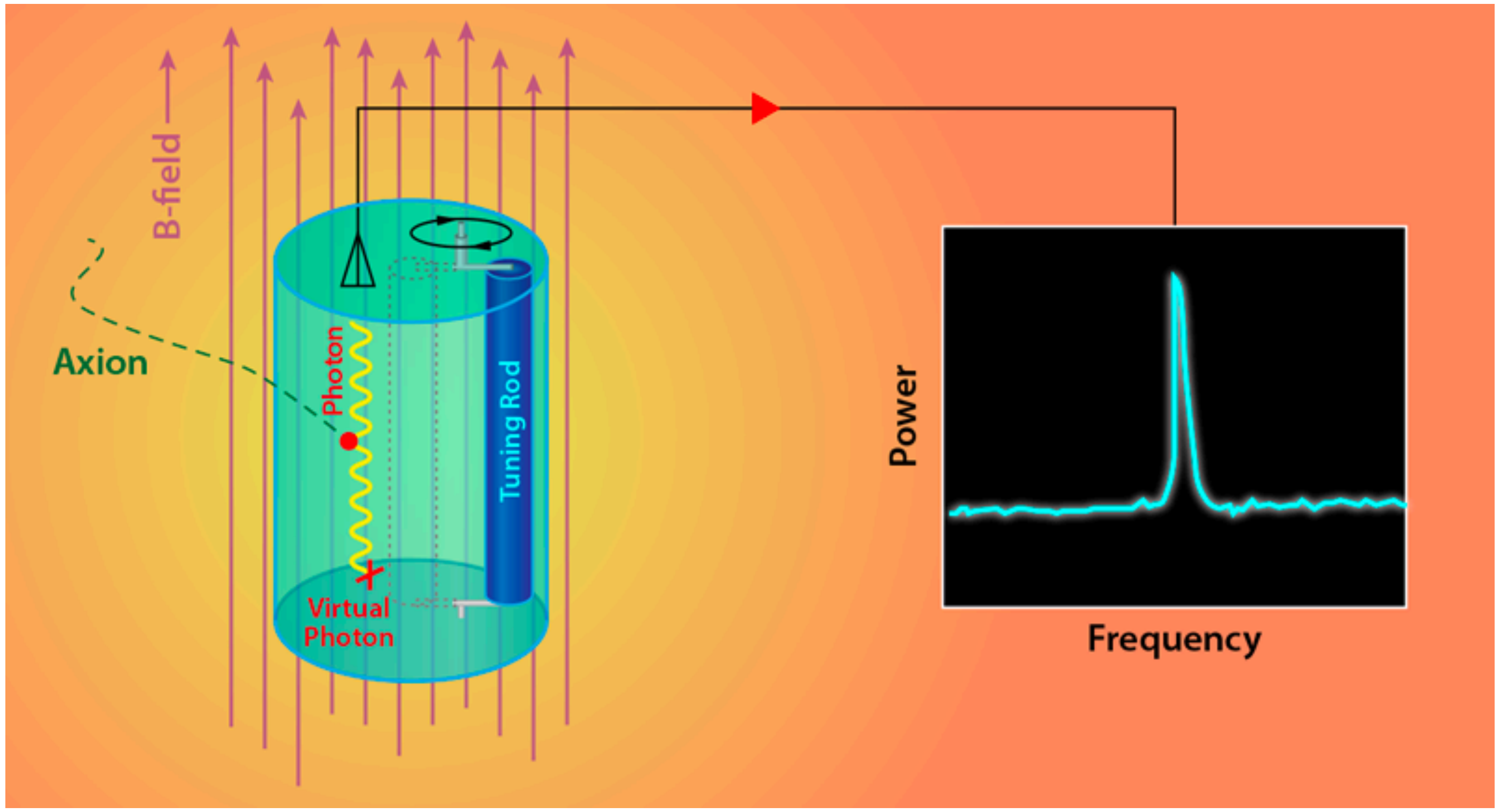
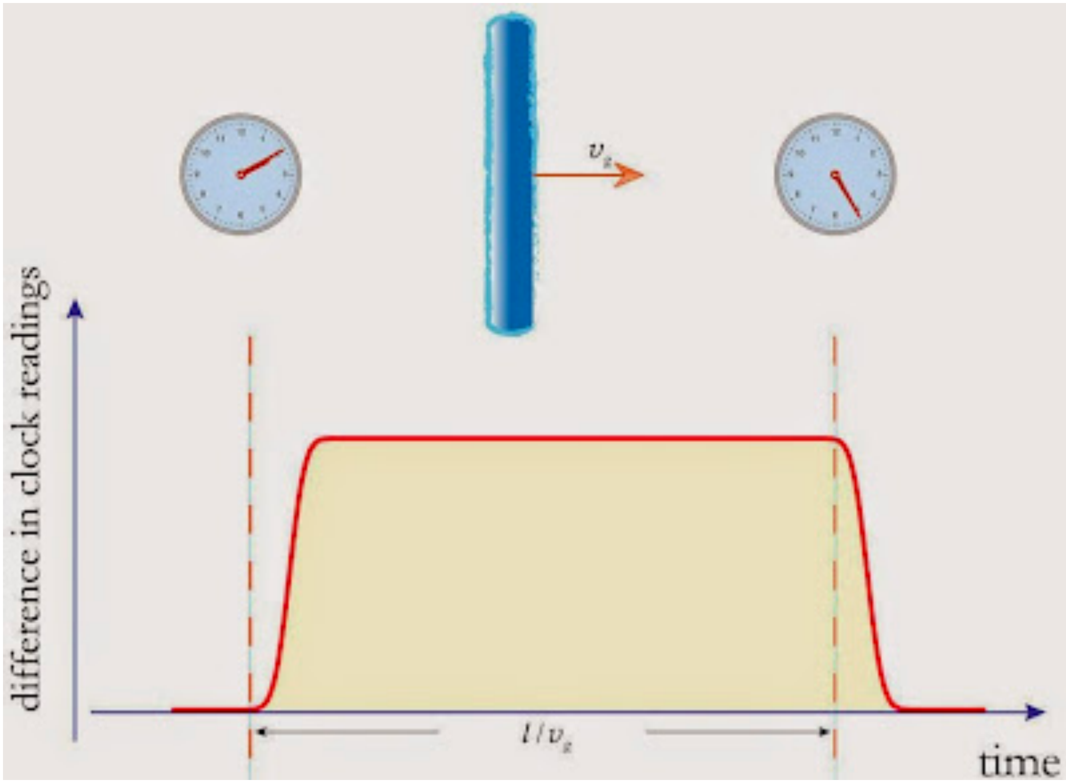
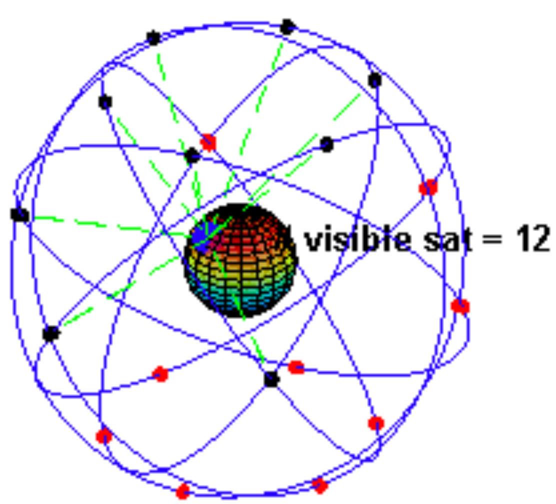


FIG. 1. Absorption process on electrons for an incoming relic particle X, where a phonon Φ is emitted in the final state: $X(q) + e(k) \to e(k') + \Phi(Q)$.



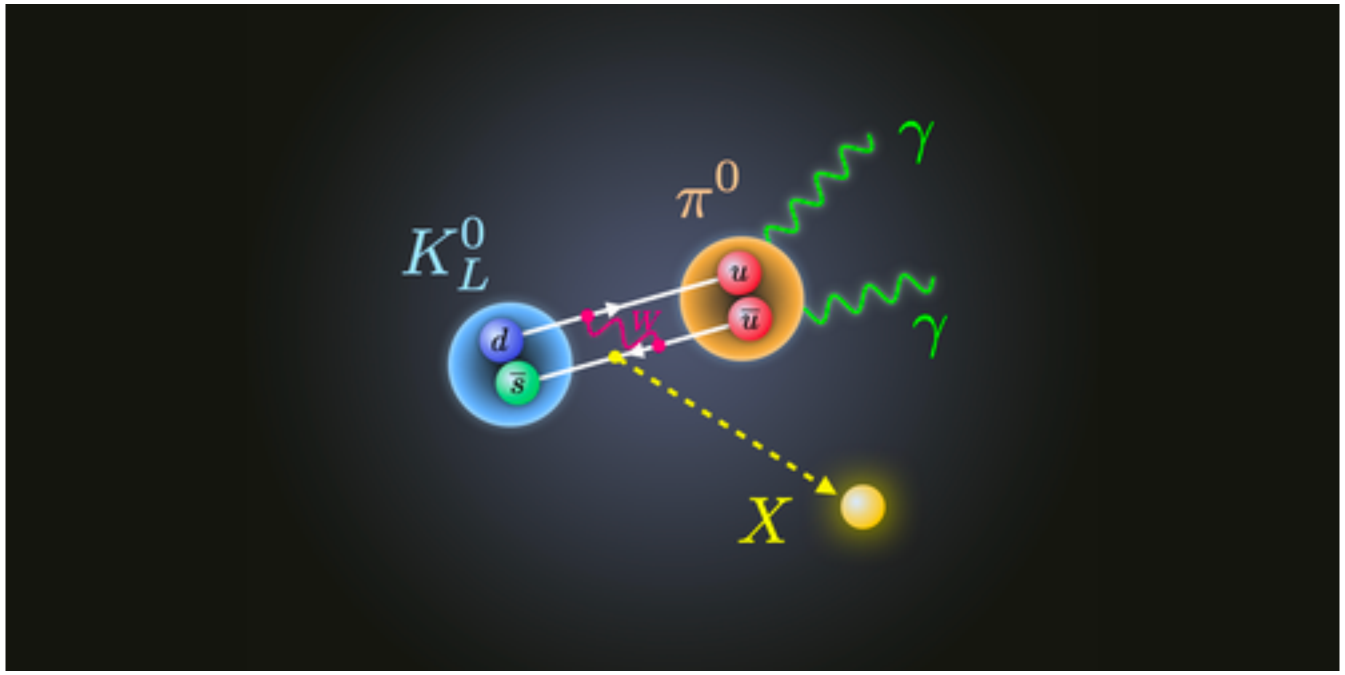

B-field
Axion
Photon
Tuning Rod
Virtual
Photon
Power
Frequency





Derevianko and Pospelov calculated how long topological dark matter might de-synchronize a series of atomic clocks on GPS satellites -- essentially the window of time scientists would have to detect such a measurement.

They explain in a paper they published last November on the scientific paper repository arXiv (1311.1244) that the clocks would be desynchronized for about 180 seconds. Since atomic clocks are precise to within one nanosecond, they will need to be desynchronized by at least that amount in order for scientists to detect topological dark matter.



Спасибо за внимание!