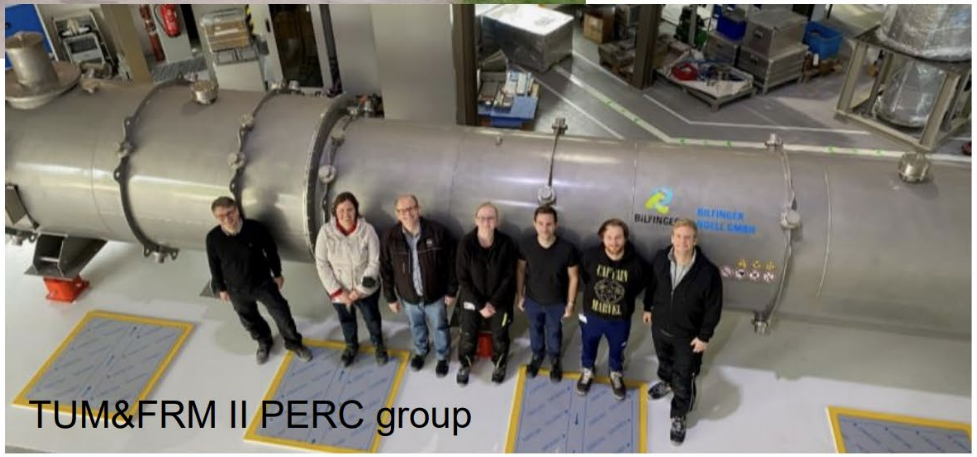
Particle Physics @ with Neutrons

- CREScent@PERC
- qBOUNCE@PF2
- Interferometry@ATI/S18
- CANNEX@ Conrad Observatory
- NUCLEUS@Chooz
- Theory Group@ATI

Hartmut Abele

E. Jericha, I. Pradler: Beta decay & PERC @ FRM2 / Munich

Delivery of the Magnet System PERC



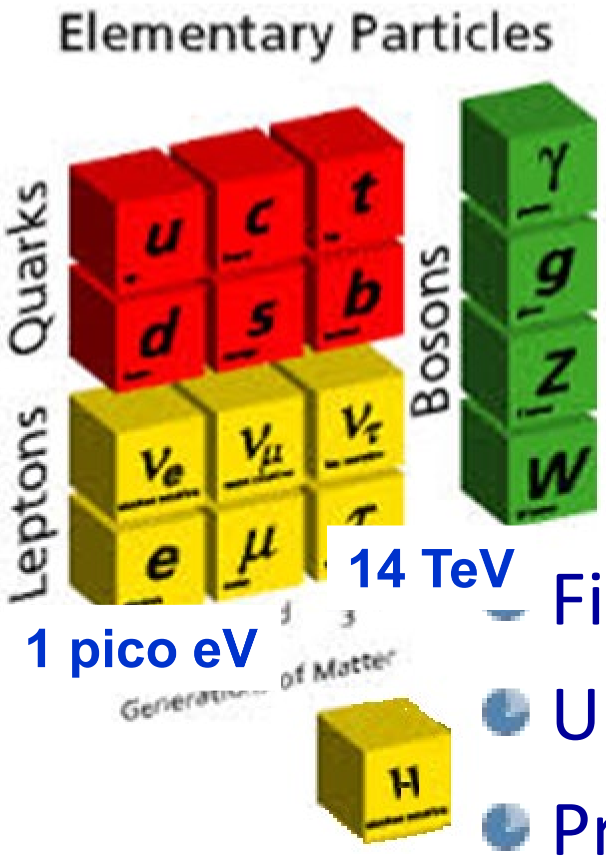
September 2021

Delivery on 3 trucks
Unloading with 3 mobile cranes

https://youtu.be/1LCj3SLxSvI

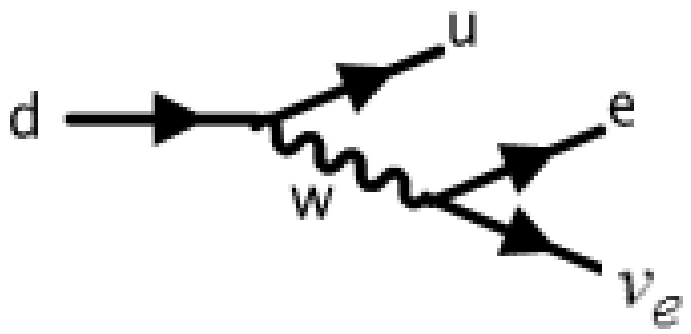
Particle Physics @ Atominstitut

Precision Experiments with Atoms, Thermal, Cold and Ultracold Neutrons



14 TeV

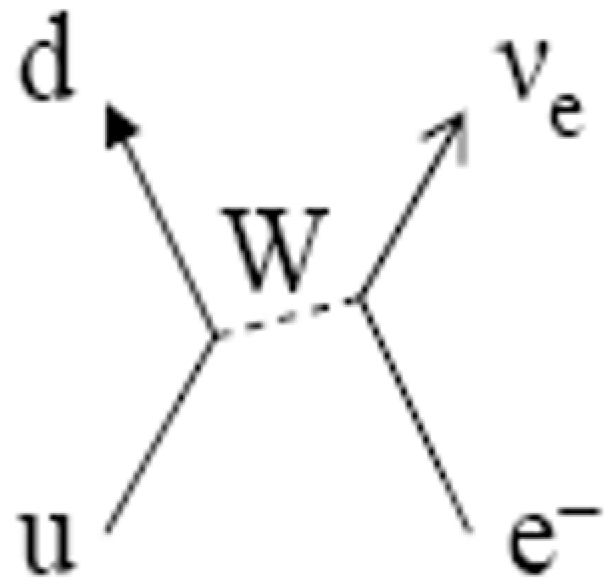
1 pico eV



- First particle family
- Ultra cold: 1 pico eV
- Precision through Quantum Interference
- Basic Laws of Physics

1. Neutron Beta - Deacy

- Determine the weak coupling constants
  - gA, gV
- Neutrino physics
  - Neutrino induced reactions
  - Neutrino detectors
- Cosmology
  - Big bang primordial element abundances
  - Solar cycle gA
- Beyond SM:
  - Unitarity of CKM Matrix
  - Search for Decay in Dark Matter Particles



Editors' Suggestion

Measurement of the Weak Axial-Vector Coupling Constant in the Decay of Free Neutrons Using a Pulsed Cold Neutron Beam

B. Märkisch,[1,2,*] H. Mest,[2] H. Saul,[1,3,4] X. Wang,[1,3] H. Abele,[1,2,3,†] D. Dubbers,[2] M. Klopf,[3] A. Petoukhov,[5] C. Roick,[1,2] T. Soldner,[5] and D. Werder[2]

[1]*Physik-Department, Technische Universität München, James-Franck-Straße 1, 85748 Garching, Germany*
[2]*Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany*
[3]*Technische Universität Wien, Atominstitut, Stadionallee 2, 1020 Wien, Austria*
[4]*Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II), Technische Universität München, Lichtenbergstraße 1, 85748 Garching, Germany*
[5]*Institut Laue-Langevin, 71 avenue des Martyrs, CS 20156, 38042 Grenoble Cedex 9, France*

(Received 31 January 2019; published 21 June 2019)

We present a precision measurement of the axial-vector coupling constant g_A in the decay of polarized free neutrons. For the first time, a pulsed cold neutron beam was used for this purpose. By this method, leading sources of systematic uncertainty are suppressed. From the electron spectra we obtain $\lambda = g_A/g_V = -1.27641(45)_{\mathrm{stat}}(33)_{\mathrm{sys}}$, which confirms recent measurements with improved precision. This corresponds to a value of the parity violating beta asymmetry parameter of $A_0 = -0.11985(17)_{\mathrm{stat}}(12)_{\mathrm{sys}}$. We discuss implications on the Cabibbo-Kobayashi-Maskawa matrix element V_{ud} and derive a limit on left-handed tensor interaction.

PHYSICAL REVIEW LETTERS **122,** 242501 (2019)

Editors' Suggestion

Measurement of the Weak Axial-Vector Coupling Constant in the Decay of Free Neutrons Using a Pulsed Cold Neutron Beam

B. Märkisch,[1,2,*] H. Mest,[2] H. Saul,[1]
A. Petoukhov,[5] C.
[1]Physik-Department, Technische Universitä
[2]Physikalisches Institut, Universität Heide
[3]Technische Universität Wier
[4]Forschungs-Neutronenquelle Heinz I
Lichtenbergst
[5]Institut Laue-Langevin, 71 avenue c

(Received 31

We present a precision measurement of t
neutrons. For the first time, a pulsed co
leading sources of systematic uncertai
$\lambda = g_A/g_V = -1.27641(45)_{\rm stat}(33)_{\rm sys}$, wh
corresponds to a value of the parity violatin
discuss implications on the Cabibbo-Kob
handed tensor interaction.

PHYSICAL REVIEW LETTERS **125,** 112501 (2020)

Limit on the Fierz Interference Term *b* from a Measurement of the Beta Asymmetry in Neutron Decay

H. Saul,[1] C. Roick,[1] H. Abele,[1,2,3] H. Mest,[3] M. Klopf,[2] A. K. Petukhov,[4] T. Soldner,[4] X. Wang,[1,2] D. Werder,[3] and B. Märkisch[1,3,*]
[1]Physik-Department ENE, Technische Universität München, James-Franck-Straße 1, 85748 Garching, Germany
[2]Technische Universität Wien, Atominstitut, Stadionallee 2, 1020 Wien, Austria
[3]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany
[4]Institut Laue-Langevin, 71 avenue des Martyrs, CS 20156, 38042 Grenoble Cedex 9, France

(Received 6 November 2019; accepted 22 July 2020; published 9 September 2020)

In the standard model of particle physics, the weak interaction is described by vector and axial-vector couplings only. Nonzero scalar or tensor interactions would imply an additional contribution to the differential decay rate of the neutron, the Fierz interference term. We derive a limit on this hypothetical term from a measurement using spin-polarized neutrons. This method is statistically less sensitive than the determination from the spectral shape but features much cleaner systematics. We obtain a limit of $b = 0.017(21)$ at 68.27% C.L., improving the previous best limit from neutron decay by a factor of four.

Neutron Alphabet deciphers the Standard Model

Decay rate J.D. Jackson et al., PR 106, 517 (1957)

$$\frac{d^3\Gamma}{dE_e d\Omega_e d\Omega_\nu} = \frac{1}{2(2\pi)^5} G_F^2 |V_{ud}|^2 \left(1+3|\lambda|^2\right) p_e E_e (E_0 - E_e)^2$$

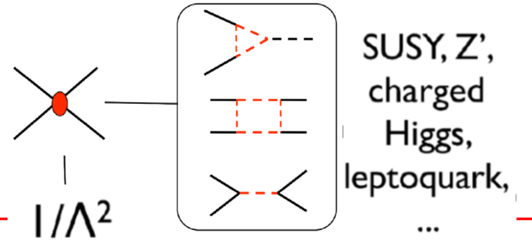
$$\times\left[1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \frac{\langle\vec{\sigma}_n\rangle}{\vec{\sigma}_n}\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_e E_\nu}\right)\right]$$

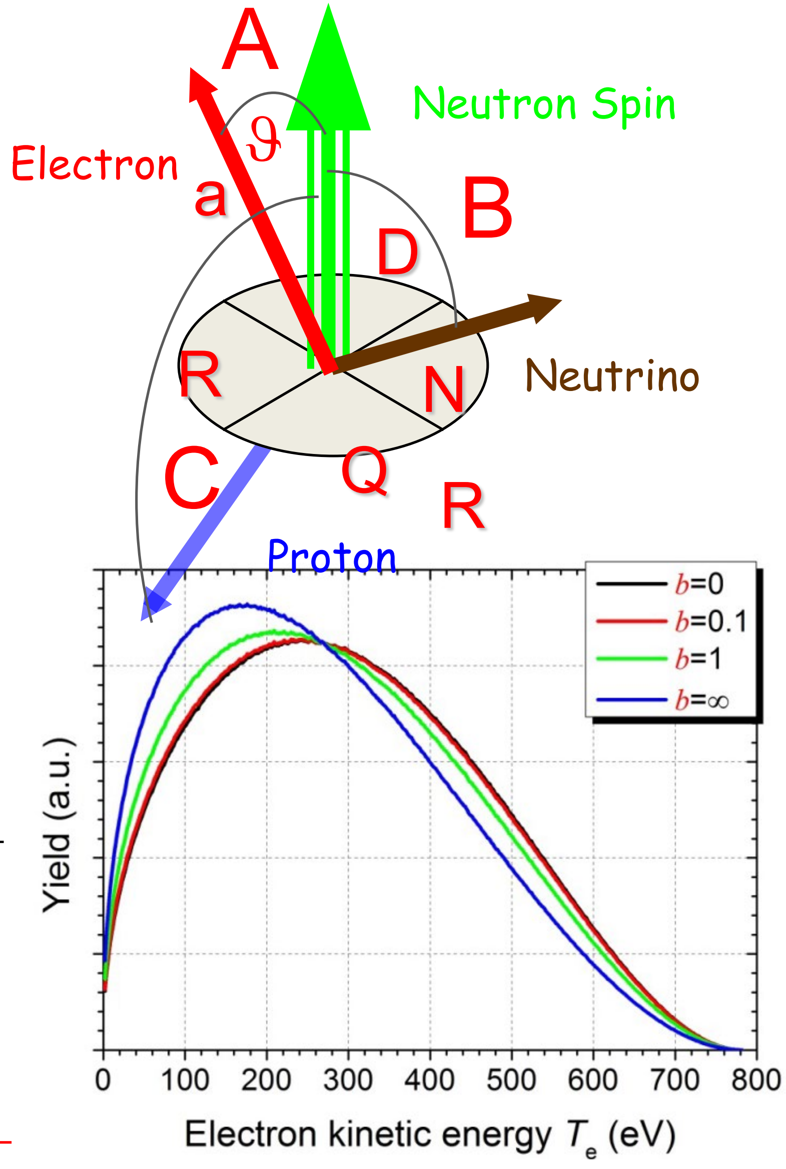
2 unknown parameters V_{ud}, $\lambda = g_A / g_V$

20 or more observables $\tau_n, a, b, A, B, C, D, \ldots$

$$\tau_n = \frac{4908.7(1.9)\,\mathrm{s}}{|V_{ud}|^2\left(1+3|\lambda|^2\right)}, \quad a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}, \quad A = -2\frac{|\lambda|^2 + \mathrm{Re}(\lambda)}{1+3|\lambda|^2}$$

$$b = 2\frac{\mathrm{Re}(g_S + 3\lambda g_T)}{1+3|\lambda|^2}$$





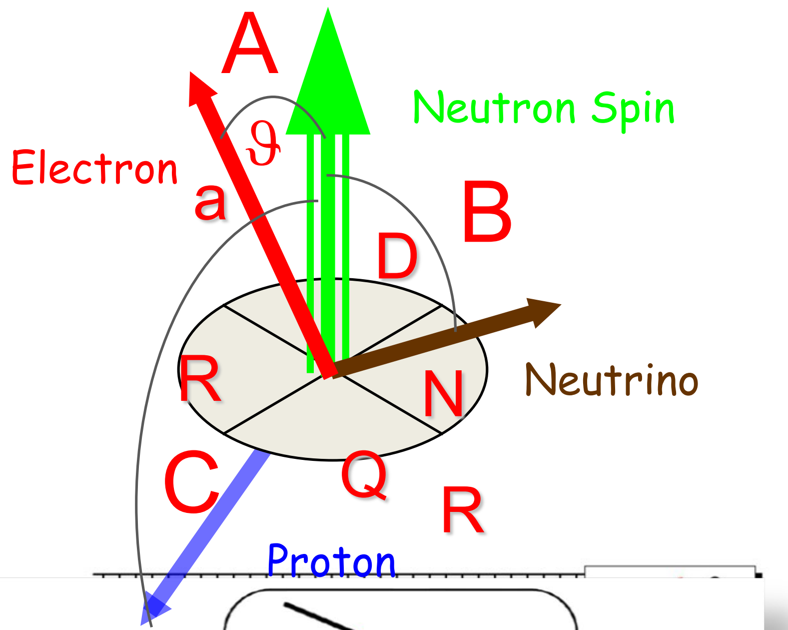
Neutron Alphabet deciphers the Standard Model

Decay rate J.D. Jackson et al., PR 106, 517 (1957)

$$\frac{d^3\Gamma}{dE_e\, d\Omega_e\, d\Omega_\nu} = \frac{1}{2(2\pi)^5} G_F^2 |V_{ud}|^2 \left(1+3|\lambda|^2\right) p_e E_e \left(E_0 - E_e\right)^2$$

$$\times\left[1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{\ \ \nu} + b\frac{m_e}{E_e} + \frac{\langle\vec{\sigma}_n\rangle}{\vec{\sigma}_n}\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_e E_\nu}\right)\right]$$

$1/\Lambda^2$

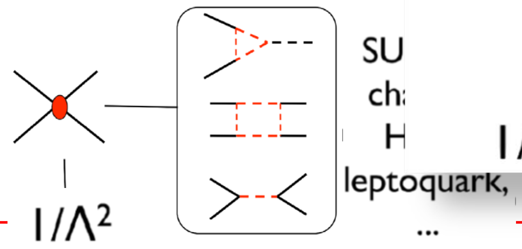


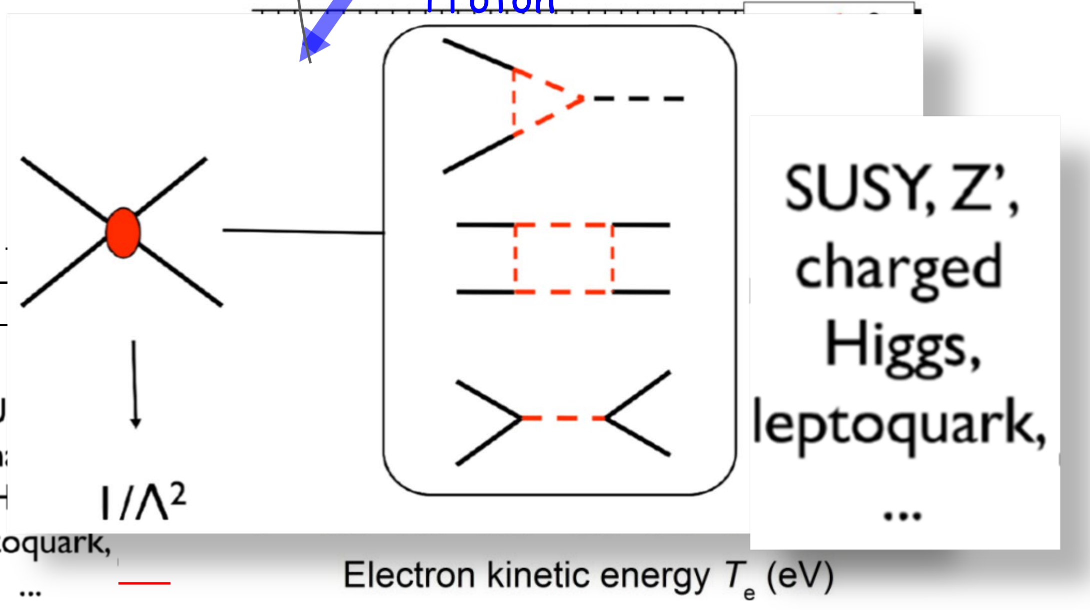
2 unknown parameters V_{ud}, $\lambda = g_A / g_V$

20 or more observables $\tau_n, a, b, A, B, C, D, \ldots$

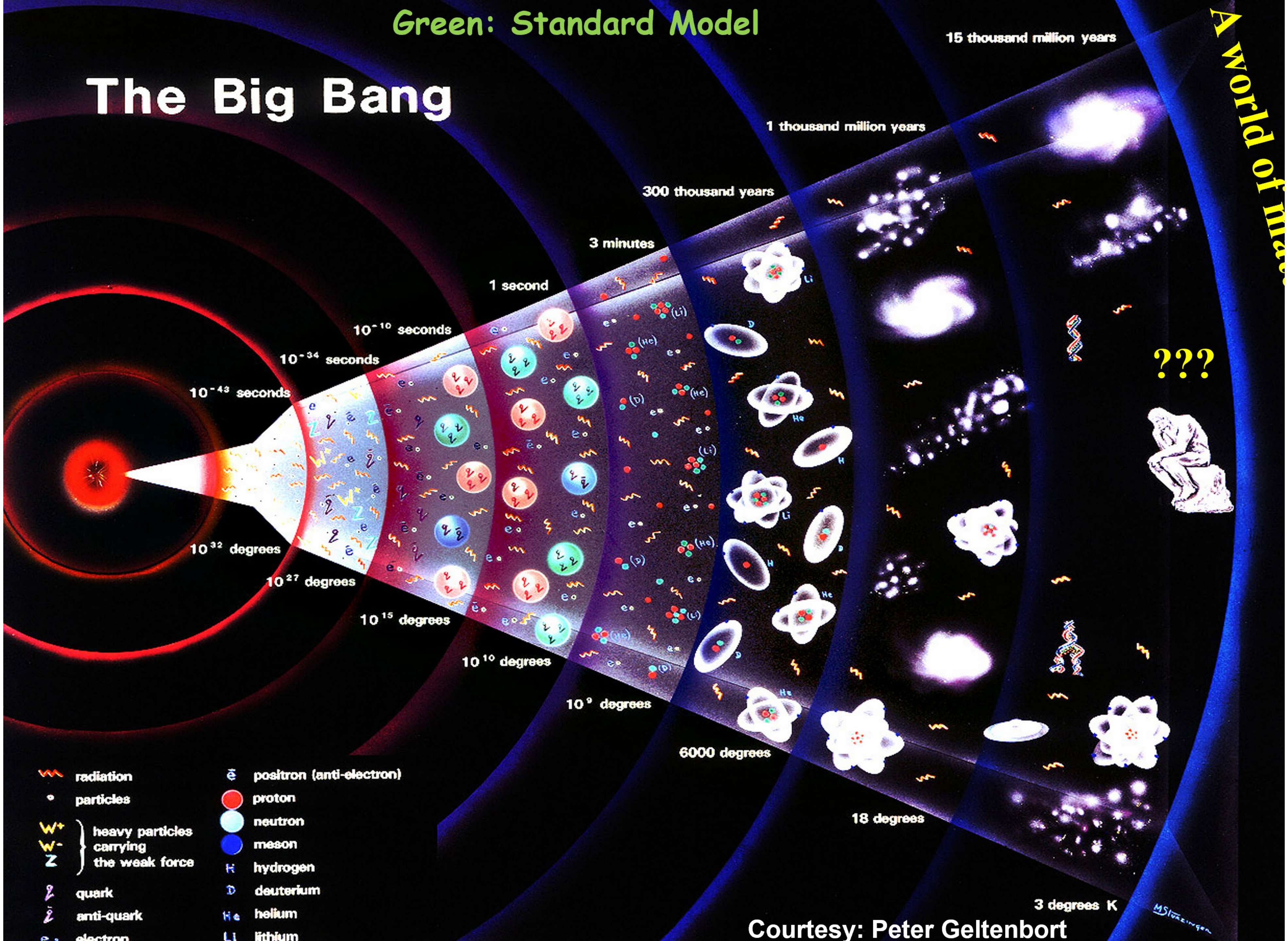
$$\tau_n = \frac{4908.7(1.9)\,\mathrm{s}}{|V_{ud}|^2\left(1+3|\lambda|^2\right)}, \quad a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}, \quad A = -2\frac{|\lambda|^2 \ldots}{1 \ldots}$$

$$b = 2\frac{\mathrm{Re}\left(g_S + 3\lambda g_T\right)}{1+3|\lambda|^2}$$

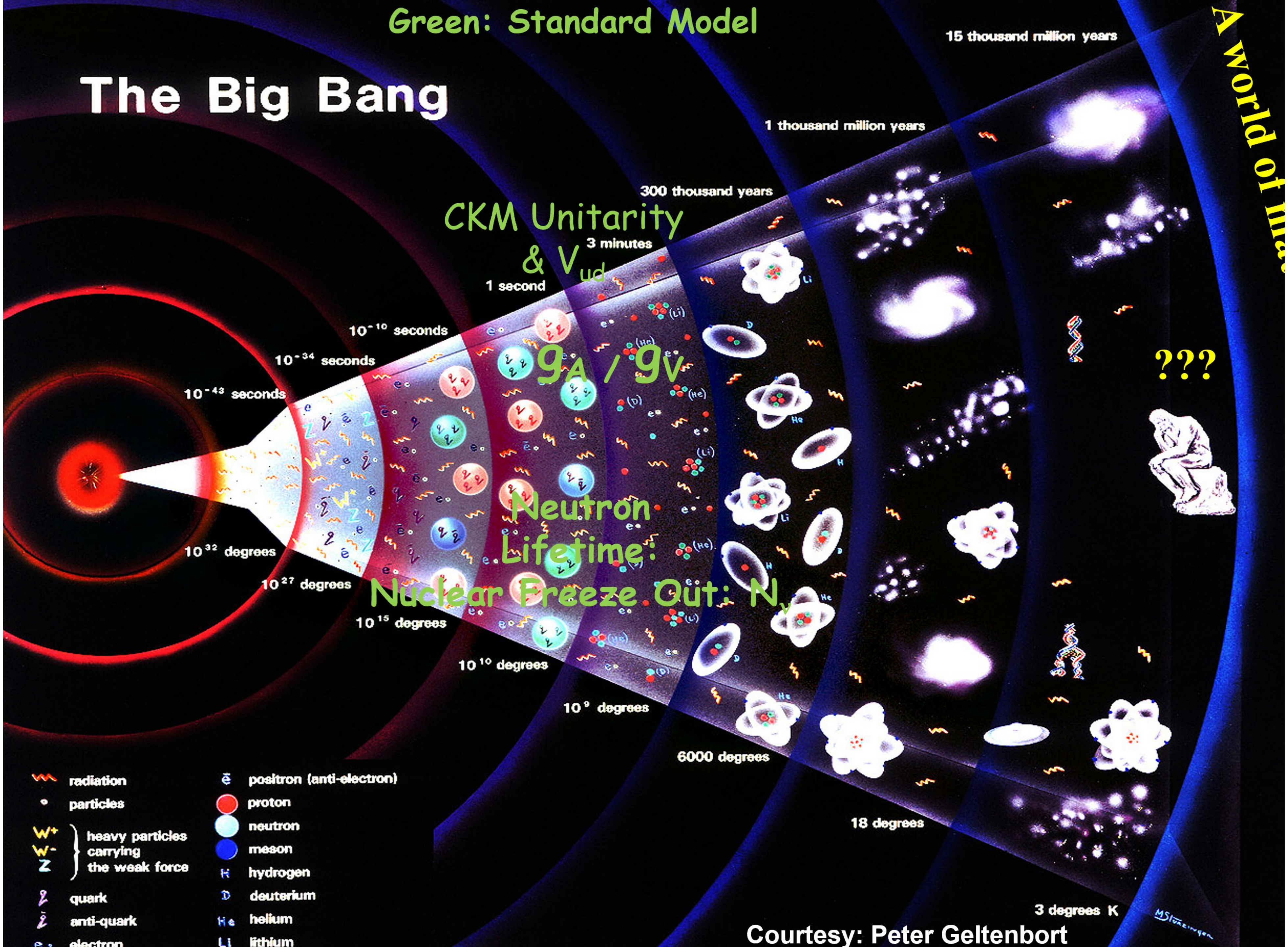




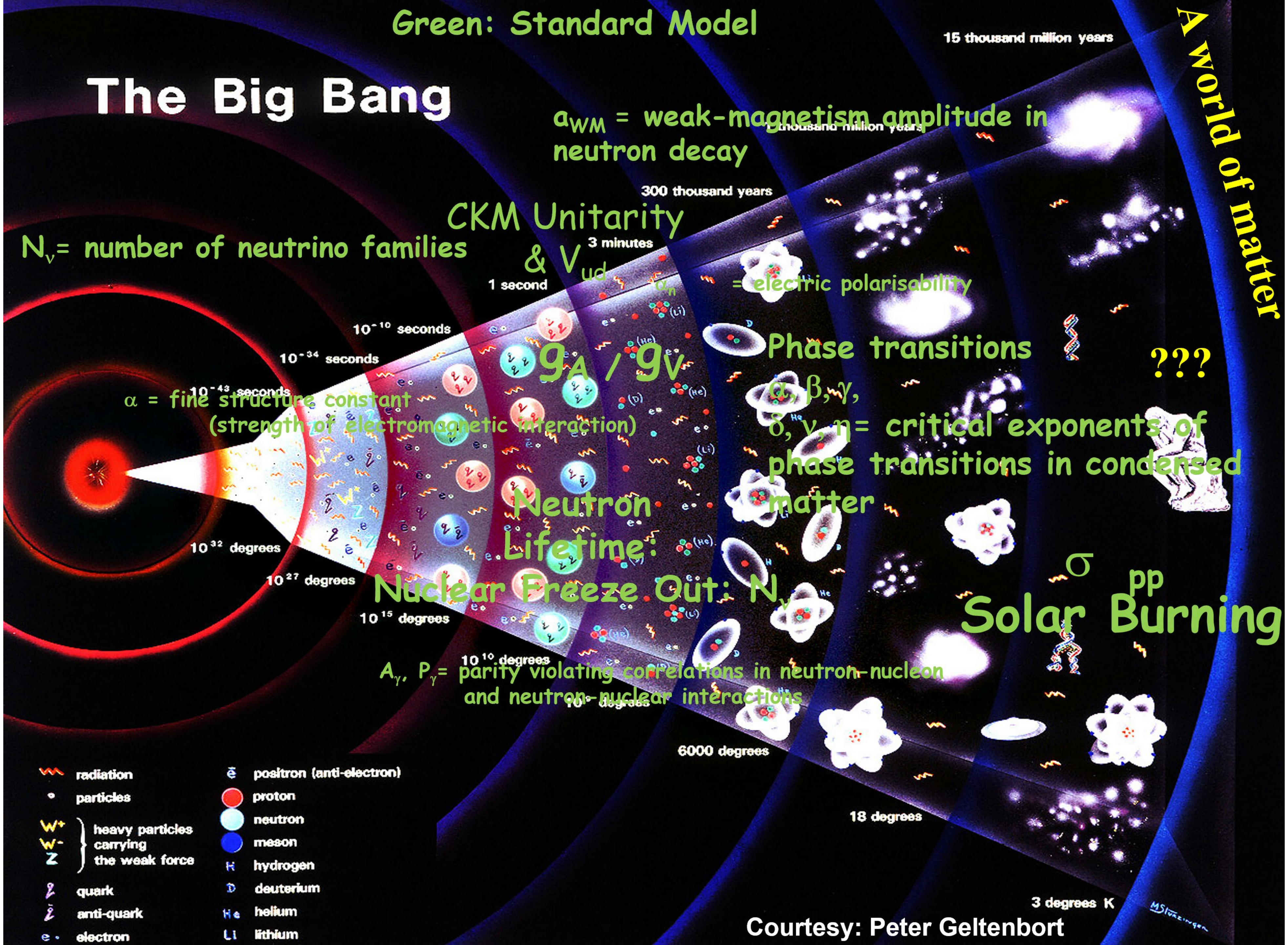
Green: Standard Model



Courtesy: Peter Geltenbort

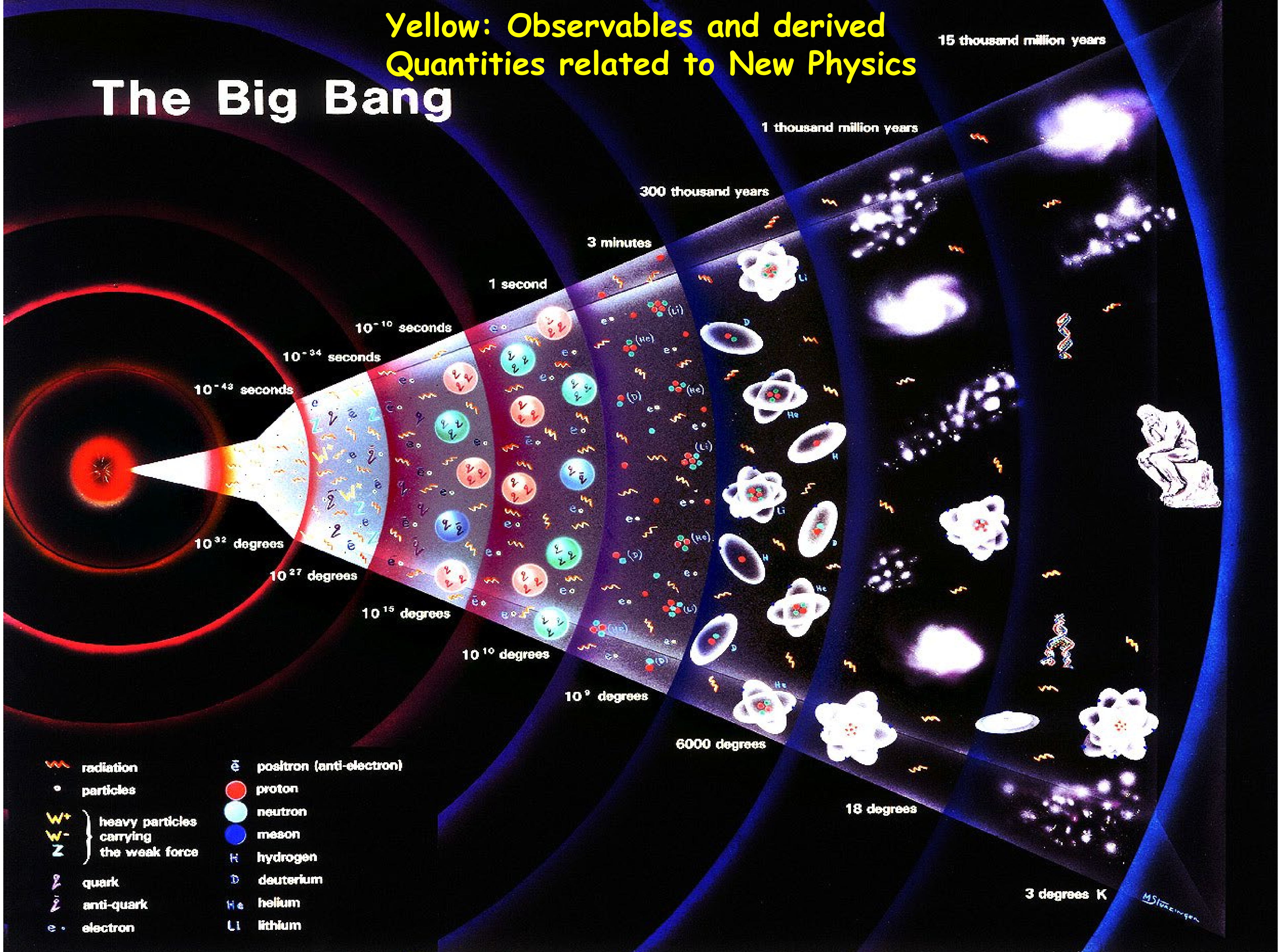


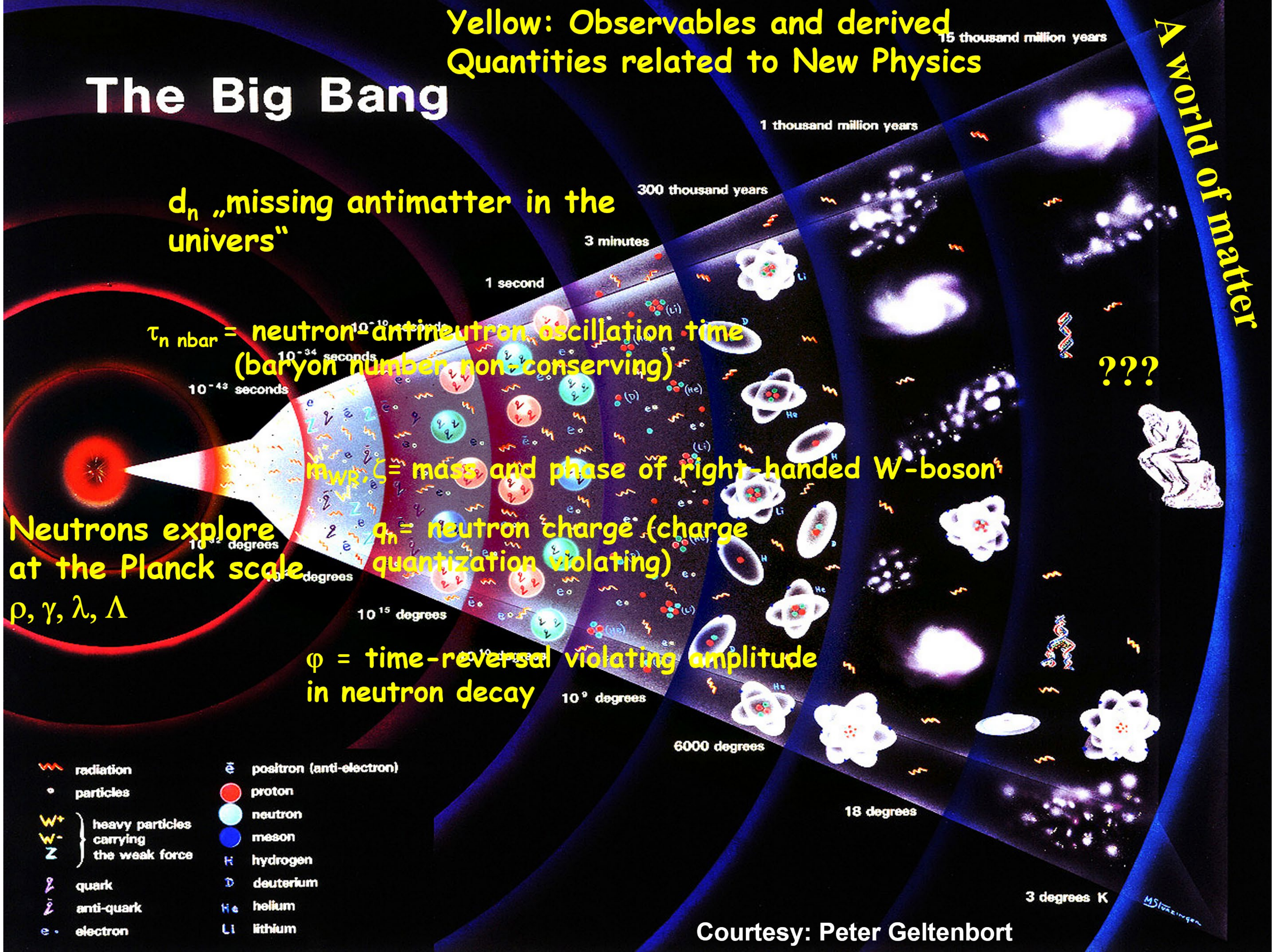
Green: Standard Model
The Big Bang
15 thousand million years
1 thousand million years
300 thousand years
CKM Unitarity
& V_{ud}
3 minutes
1 second
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
g_A / g_V
Neutron
Lifetime:
Nuclear Freeze Out: N_ν
10^{32} degrees
10^{27} degrees
10^{15} degrees
10^{10} degrees
10^{9} degrees
6000 degrees
18 degrees
3 degrees K
A world of
???
radiation
particles
W+
W-
Z
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium
Courtesy: Peter Geltenbort



Green: Standard Model
The Big Bang
A world of matter
15 thousand million years
a_{WM} = weak-magnetism amplitude in neutron decay
300 thousand years
CKM Unitarity & V_{ud}
3 minutes
1 second
N_ν= number of neutrino families
α_n = electric polarisability
10^{-10} seconds
10^{-34} seconds
10^{-43} seconds
g_A / g_V
Phase transitions
???
α = fine structure constant (strength of electromagnetic interaction)
$\alpha, \beta, \gamma,$
δ, ν, η= critical exponents of phase transitions in condensed matter
Neutron Lifetime:
10^{32} degrees
10^{27} degrees
10^{15} degrees
Nuclear Freeze Out: N_ν
σ_{pp}
Solar Burning
10^{10} degrees
A_γ, P_γ= parity violating correlations in neutron-nucleon and neutron-nuclear interactions
6000 degrees
18 degrees
3 degrees K
radiation
particles
W+ W- Z heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium
Courtesy: Peter Geltenbort

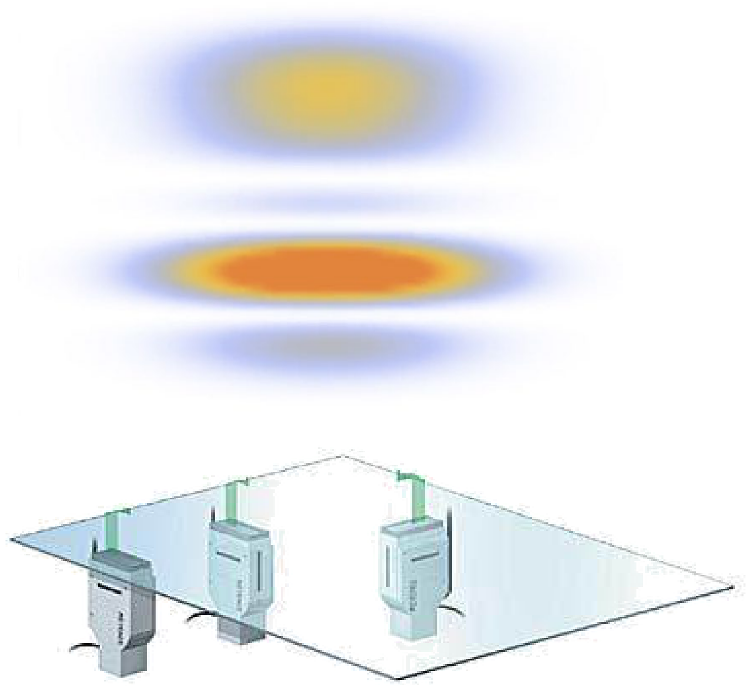
Yellow: Observables and derived Quantities related to New Physics




Yellow: Observables and derived
Quantities related to New Physics
The Big Bang
A world of matter
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
10⁻³⁴ seconds
10⁻⁴³ seconds
dn „missing antimatter in the univers"
τn nbar = neutron-antineutron oscillation time (baryon number non-conserving)
???
mWR, ζ = mass and phase of right-handed W-boson
qn = neutron charge (charge quantization violating)
Neutrons explore at the Planck scale
ρ, γ, λ, Λ
10¹⁵ degrees
φ = time-reversal violating amplitude in neutron decay
10⁹ degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
W+ W- Z heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium
Courtesy: Peter Geltenbort

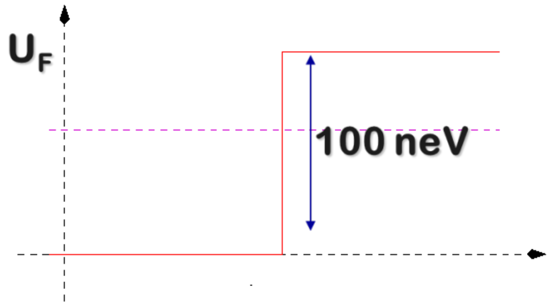
J. Bosina: qBOUNCE - FREE FALL AT SHORT DISTANCES

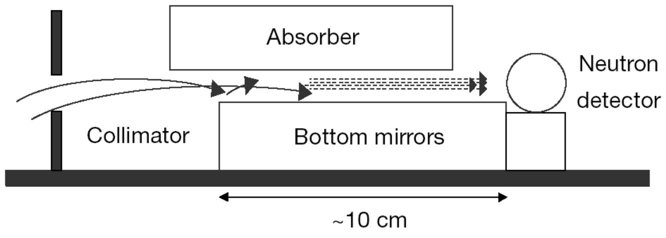
- A simple gravitationally interacting quantum system
  - A neutron with mass and spin
    - falling in the Earth‘s gravity potential
  - and a neutron reflector
    - made out of glass



Abele, Jenke, Lemmel, Nature 2019

- Reactor neutrons at ILL
  - 25 meV
- Ultra-cold Neutrons
  - @PF2 – ILL: T. Jenke
  - v = (7±1)m/s
  - U_F ~ 100 neV, 1…6 peV

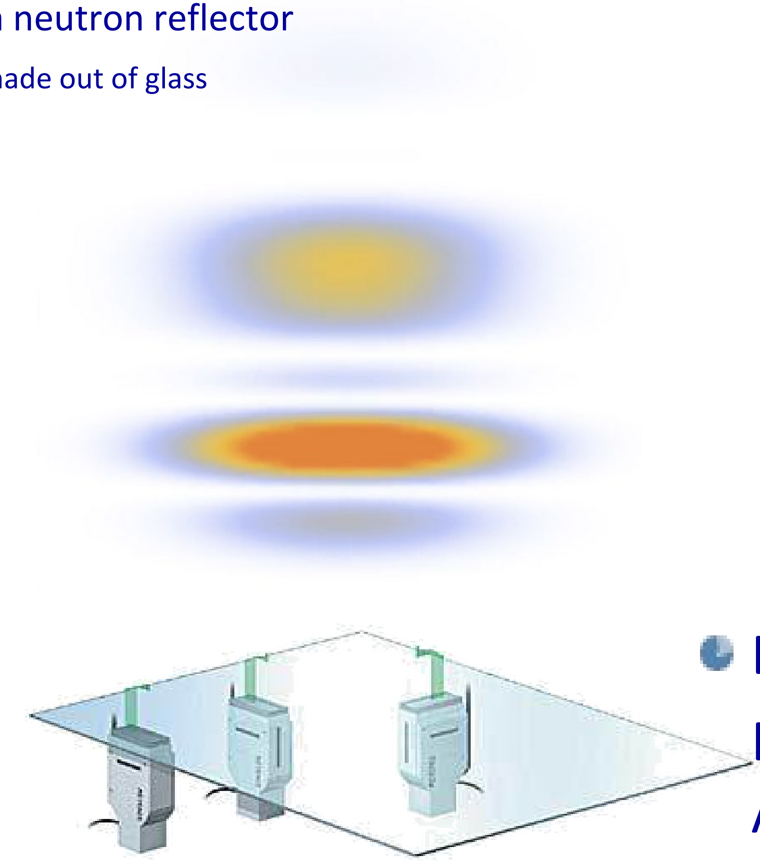




Nesvizhevsky et al.
Nature 415 299 (2002), Phys. Rev. D 67 102002 (2003).

Free Fall at Short Distances

- A simple gravitationally interacting quantum system
  - A neutron with mass and spin
    - falling in the Earth's gravity potential
  - and a neutron reflector
    - made out of glass



- Test the laws of gravity at small distances
- Search for hypothetical gravity-like interactions, string theories etc.
- High degree on Sensitivity regarding underlying theories about the expansion of the universe

- Example Rb

Energy shift for Rb Atom at r = 1 µm

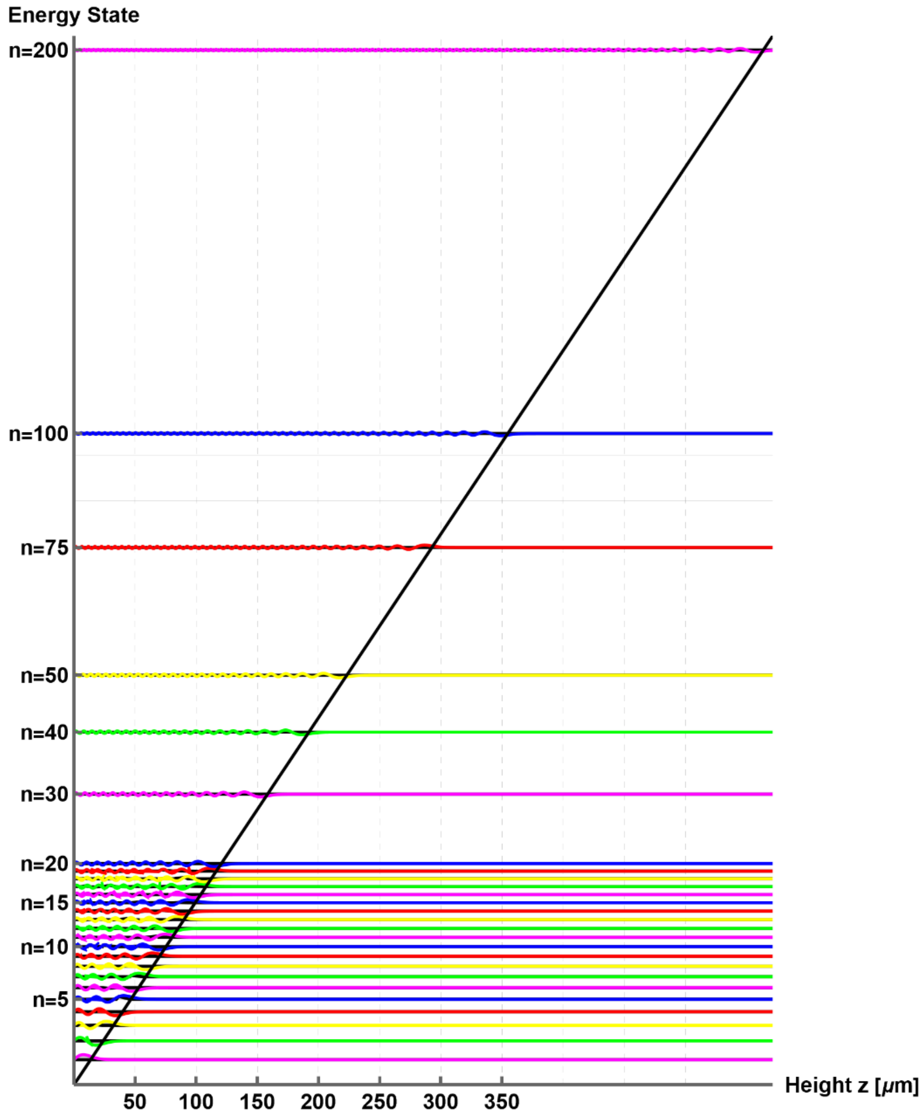
10^{-12} eV

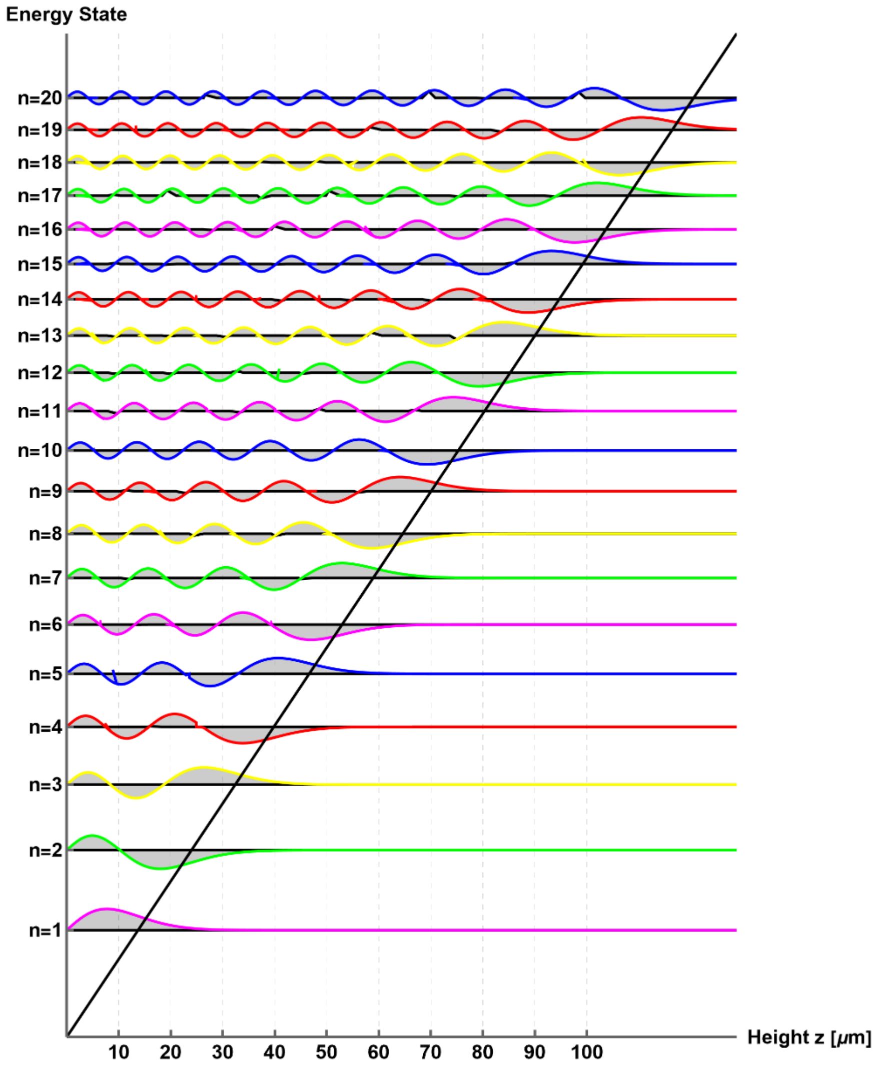
Neutron

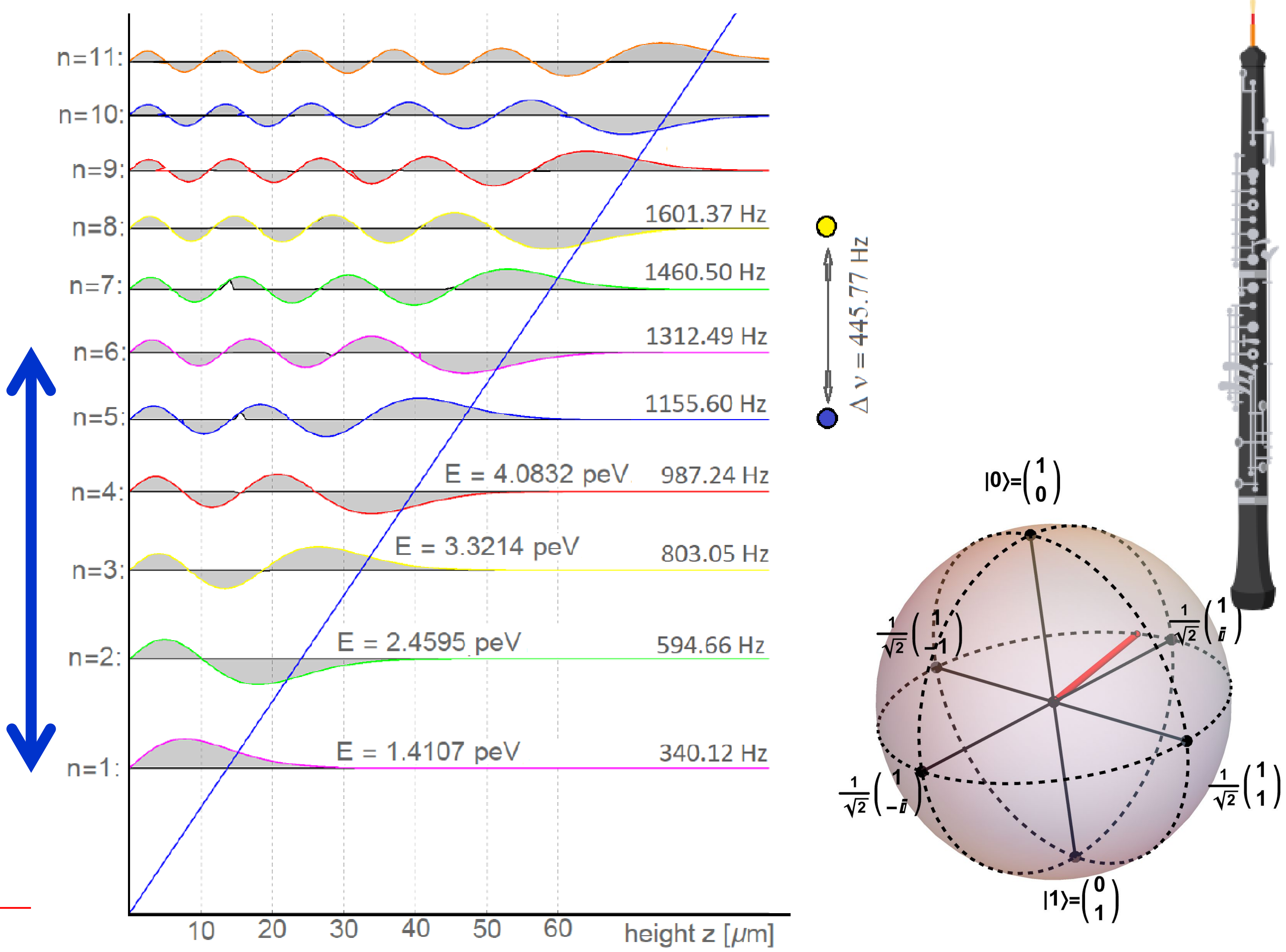
- Polarizability extremely small:
- 10^{-30} eV

Abele, Jenke, Lemmel, Nature 2019

Quantum Gravitational States of a Neutron

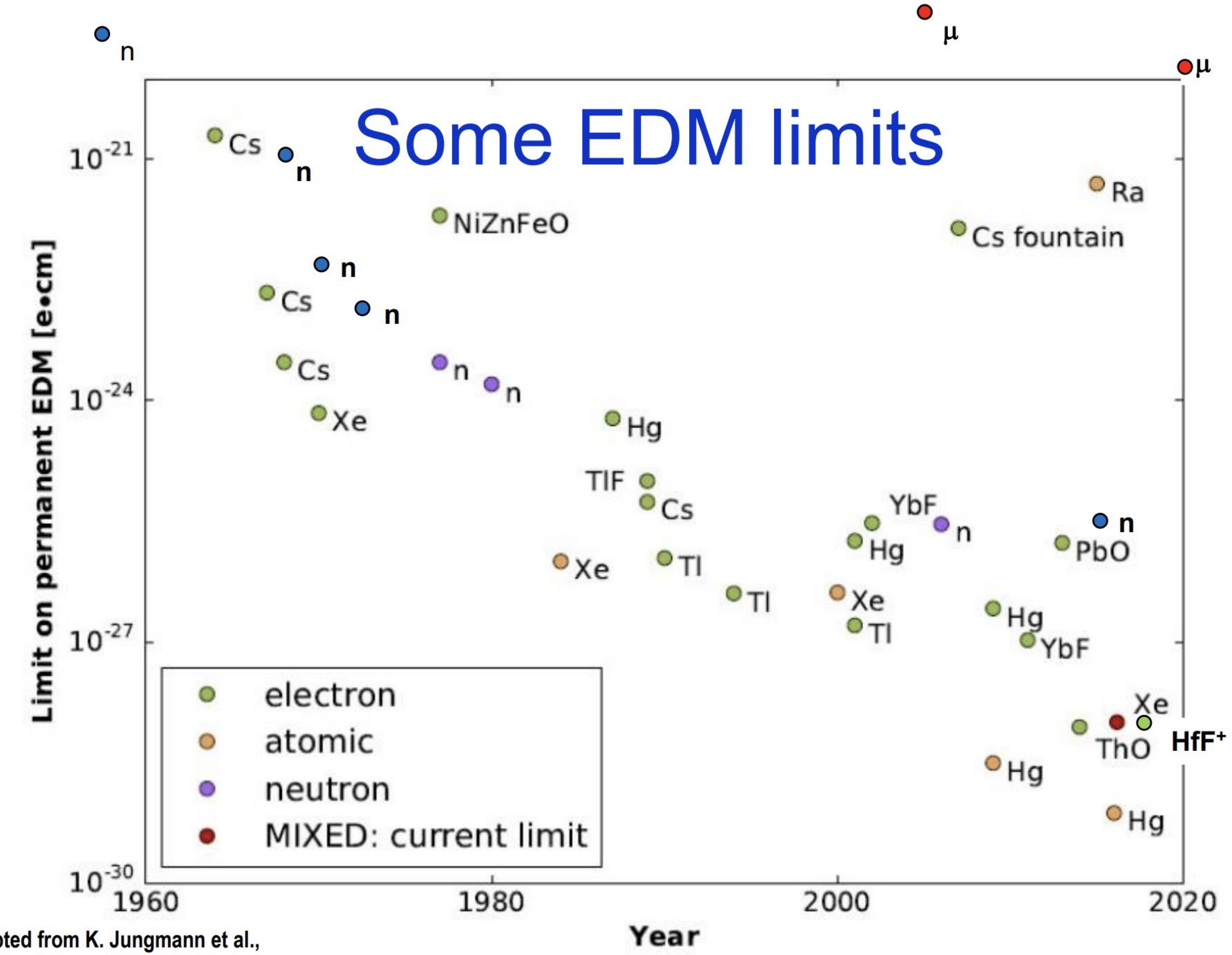





n=11:
n=10:
n=9:
n=8:
1601.37 Hz
n=7:
1460.50 Hz
n=6:
1312.49 Hz
n=5:
1155.60 Hz
n=4:
E = 4.0832 peV
987.24 Hz
n=3:
E = 3.3214 peV
803.05 Hz
n=2:
E = 2.4595 peV
594.66 Hz
n=1:
E = 1.4107 peV
340.12 Hz
10
20
30
40
50
60
height z [μm]
Δ ν = 445.77 Hz
|0⟩=(1 0)
|1⟩=(0 1)
1/√2 (1 i)
1/√2 (1 −1)
1/√2 (1 −i)
1/√2 (1 1)

10.06.2024

Some EDM limits



Adapted from K. Jungmann et al.,
JPS Conf. Proc. 18(2017)011017

Motivation for high precision tests with neutrons:

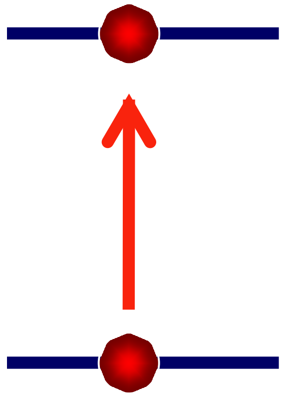
extreme sensitivity or precision

- Energy $\Delta E = 10^{-21}$ eV
  - Search for an electric dipole moment, neutron
  - $d_n < 3 \times 10^{-26}$ ecm
  - Ramsey's Spectroscopy Method of Separated Oscillating Field by NMR
  - Ramsey's Spectroscopy Method of Separated Oscillating Field by GRS

- Energy $\Delta E = 4 \times 10^{-18}$ eV, ACME
  - Search for an electric dipole moment, electron (ThO), $d_e < 9 \times 10^{-29}$ ecm

- Energy $\Delta E = 2 \times 10^{-15}$ eV
  - Rabi's Spectroscopy Method by GRS

$$E = h\nu$$



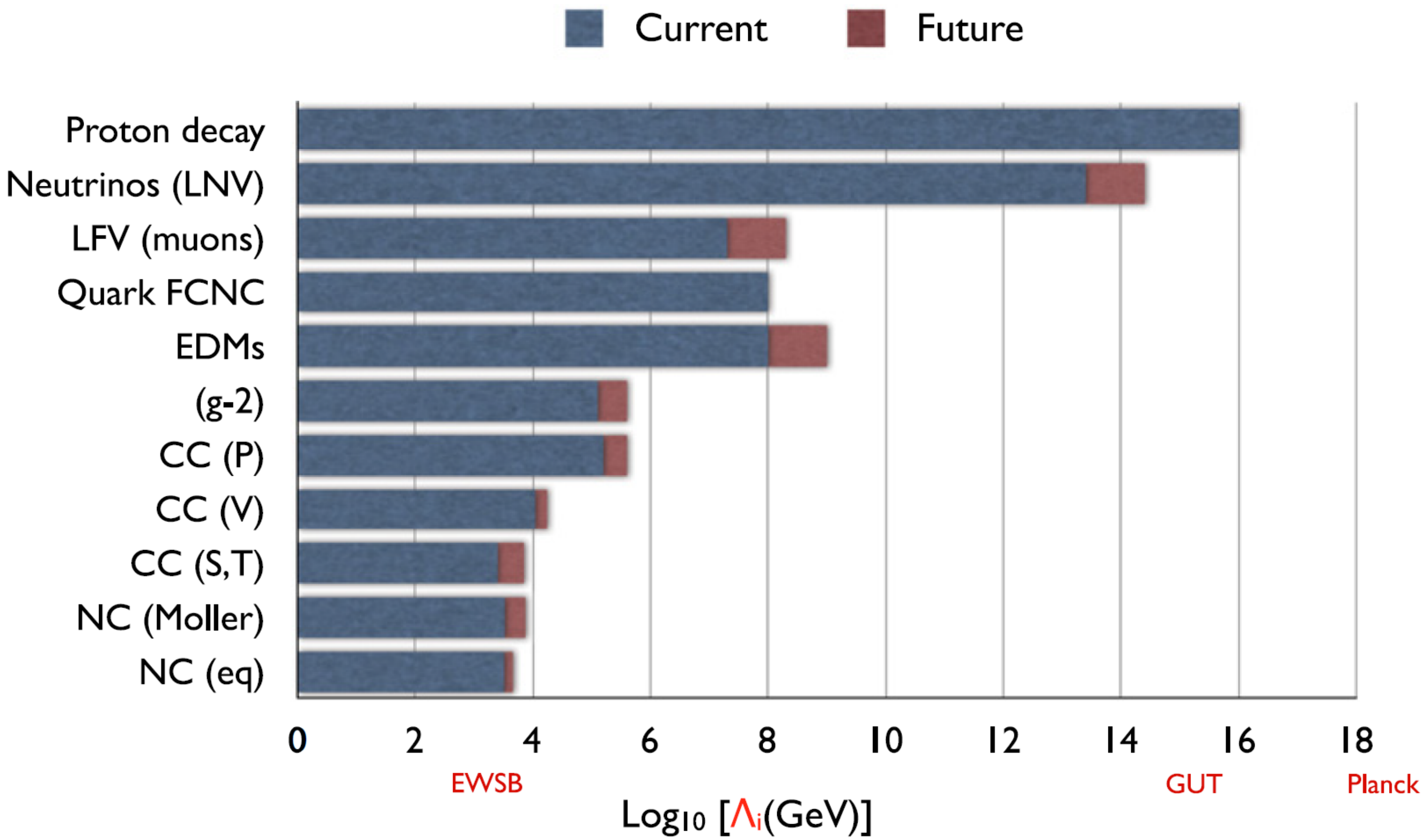
- All Spectroscopy methods so far use electromag fields or a coupling to a electromag. potential

Review Article:

H.A., The neutron. Its properties and basic interactions, Prog. Part. Nucl. Phys. 60 1-81 (2008)

Vincenzo Cirigliano, Ramsey-Musolf

- Low energy probes of physics beyond the standard model



- **Fig. 2.** Summary of current and future constraints on the effective new physics scale Λ_i defined in Eq. (3.59) arising from various low-energy observables. Note that the Λ_i absorb the Wilson coefficients and do not necessarily represent the masses of new degrees of freedom that become active at high energy scales.

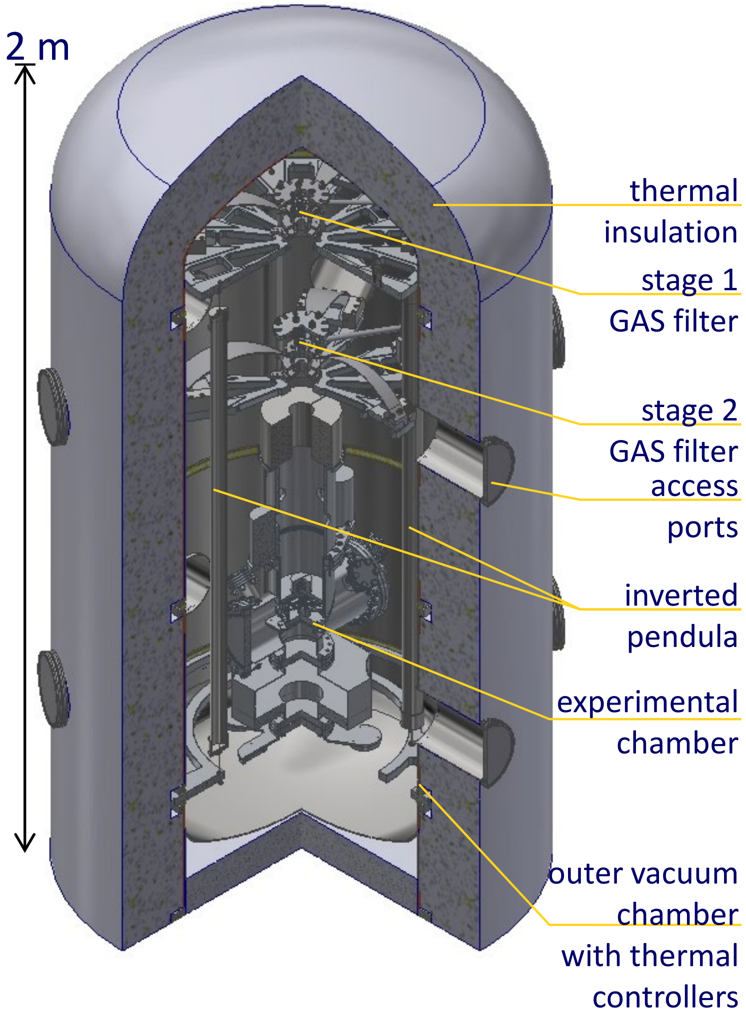
Resonant Spectroscopy: Dark Energy and Dark Matter scenarios

Gravity Resonance Spectroscopy

- How far does GRS constrain Dark Energy and Dark Matter models
  - Search for environment-dependent dilatons, H. Fischer et al., Physics of the Dark Universe 43, 101419 (2024)
  - Gravity Resonance Spectroscopy constrains dark matter and dark energy scenarios, T. Jenke et al., Physical Review Letters 112, 151105 (2014)
  - Acoustic Rabi oscillations between gravitational quantum states and impact on symmetron dark energy, G Cronenberg, et al., Nature Physics 14 (10), 1022-1026 (2018)
- Is gravity an entropic force (E. Verlinde)
  - Decoherence-Free Entropic Gravity for Dirac Fermion, Eric J. Sung et al., Phys. Rev. D 108, 104036 (2023)
  - Decoherence-free entropic gravity: Model and experimental tests, AJ Schimmoller, G McCaul, H Abele, DI Bondar, Physical Review Research 3, 033065 (2021)
- What about gravity theories based on geometries other than those of Riemann, Riemann-Cartan, etc. ("beyond-Riemann gravity")
  - Quantum gravitational states of ultracold neutrons as a tool for probing beyond-Riemann gravity, A. Ivanov, M. Wellenzohn, H. Abele, Phys. Lett. B. 822 (2021) 136640
- Is Lorentz Invariance violated?
  - Probing of violation of Lorentz invariance by ultracold neutrons in the Standard Model Extension, AN Ivanov, M Wellenzohn, H Abele, Phys. Lett. B, Physics Letters B 797, 134819 (2019)

René Sedmik: Casimir Force Measurements

CANNEX – Casimir And Non-Newtonian force EXperiment



Worldwide only force metrology platform operating in the geometry of plane parallel plates.

Recent progress:

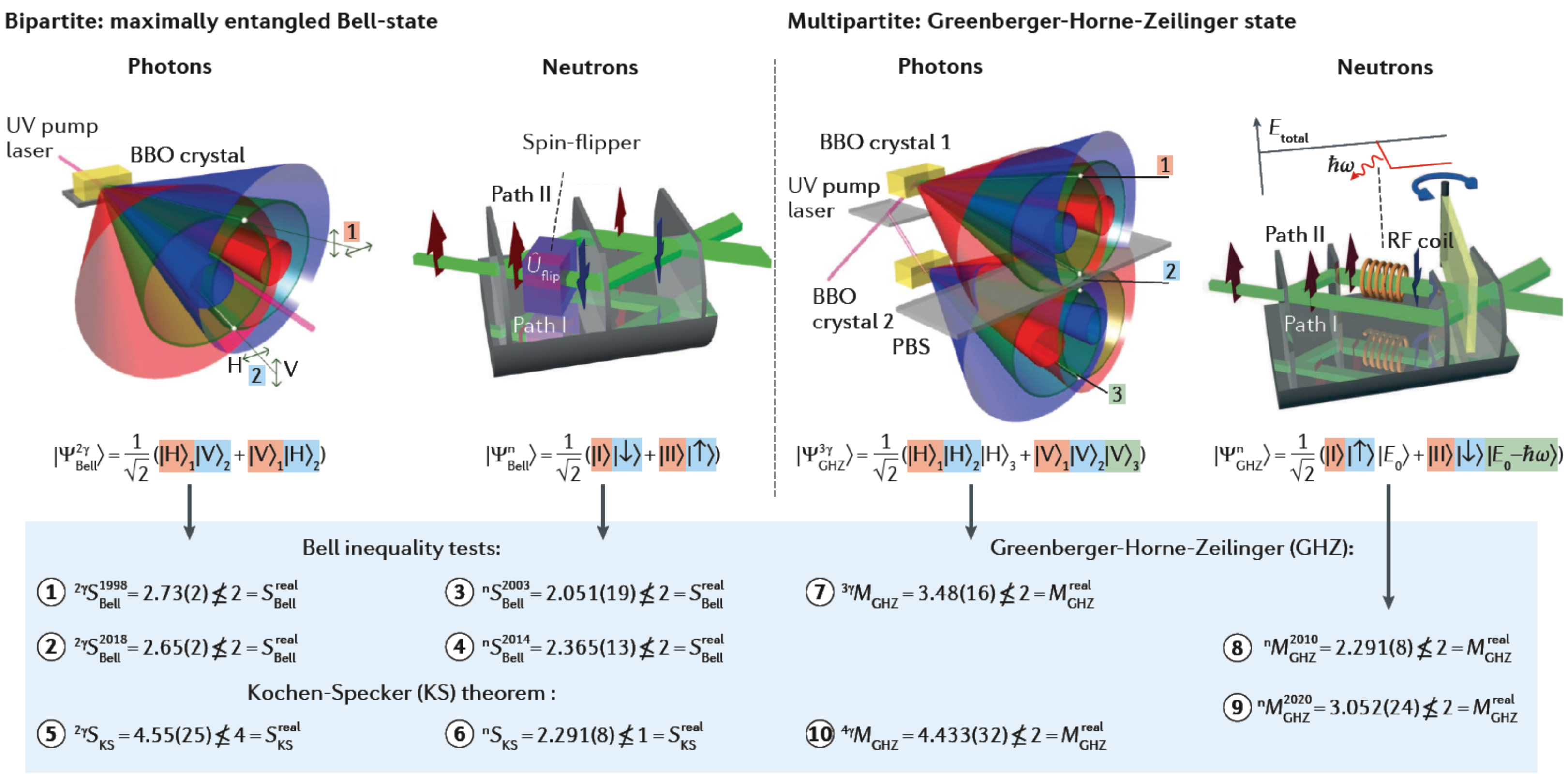
Design for two-staged active/passive seismic isolation system to form
"*the most quiet space in Austria*"

Updated core design for perfect thermal control with mK precision.
Prospective limits for chameleon, symmetron, dilaton dark energy, scalar axions, scalar-pseudoscalar interactions, Yukawa forces... as well as the most precise measurements of Casimir forces.

In preparation:

- Financing for construction phase

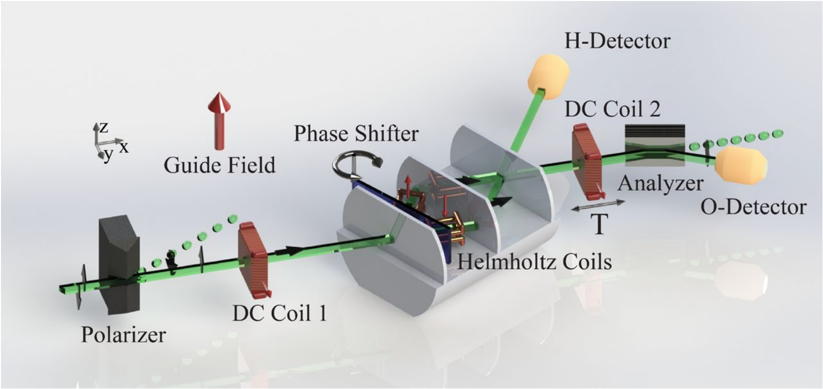
Hasegawa, Sponar et al.: Interferometer



- **Entanglement**
  - **Between path and spin**
  - **And path, spin and energy**
- **Spin Rotation Coupling**

Nature Review, in print

i) State Vector Reconstruction via weak values



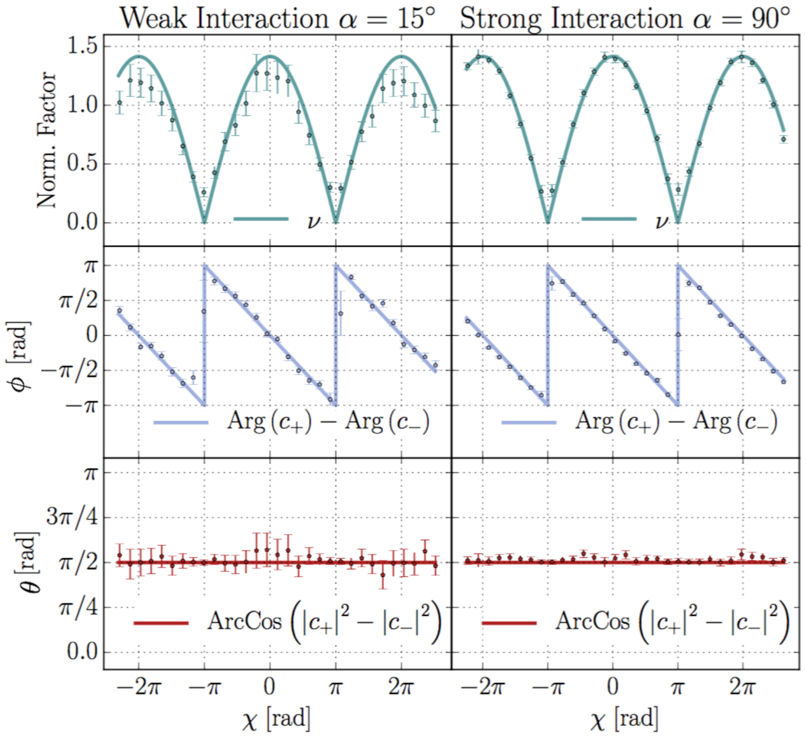
- general representation of a (pure) ***state vector*** $|\Psi_\mathrm{i}\rangle = \sum_j c_j |a_j\rangle$

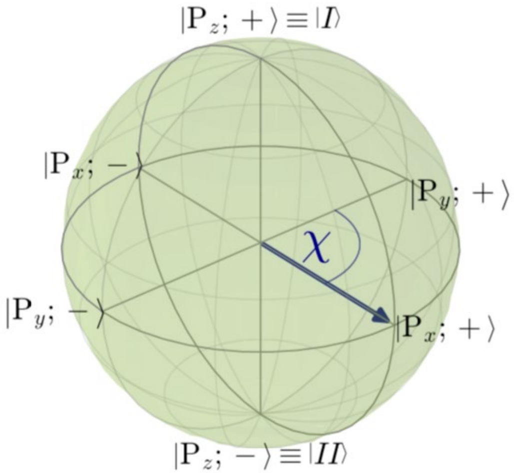
  with ***probability amplitudes*** $c_j = \langle a_j|\Psi_\mathrm{i}\rangle$

- ***weak value*** $\langle \hat{\Pi}_{a_j}\rangle_\mathrm{w} = \dfrac{\langle\Psi_\mathrm{f}|\hat{\Pi}_{a_j}|\Psi_\mathrm{i}\rangle}{\langle\Psi_\mathrm{f}|\Psi_\mathrm{i}\rangle} = \dfrac{\langle\Psi_\mathrm{f}|a_j\rangle\langle a_j|\Psi_\mathrm{i}\rangle}{\langle\Psi_\mathrm{f}|\Psi_\mathrm{i}\rangle}$

- ***probability amplitudes using w.v.*** $c_j = \langle a_j|\Psi_\mathrm{i}\rangle = \dfrac{\langle\Psi_\mathrm{f}|\Psi_\mathrm{i}\rangle}{\langle\Psi_\mathrm{f}|a_j\rangle}\langle \hat{\Pi}_{a_j}\rangle_\mathrm{w}$

$$|\Psi_\mathrm{i}\rangle = \sum_j c_j|a_j\rangle = \sum_j \frac{\langle\Psi_\mathrm{f}|\Psi_\mathrm{i}\rangle}{\langle\Psi_\mathrm{f}|a_j\rangle}\langle \hat{\Pi}_{a_j}\rangle_\mathrm{w}|a_j\rangle$$





T. Denkmayr, H. Geppert, H. Lemmel, M. Waegell, J. Dressel, Y. Hasegawa, and S. Sponar, *Phys. Rev. Lett.*, **118**, 010402 (2017)

ii) Commutator Relation - Experimental Test for Pauli Spin Observables

$$\langle\psi|[\hat{A},\hat{B}]|\psi\rangle = -8\mathrm{i}|\langle +_B|\psi\rangle|^2 \Im\left(\langle \Pi_A^+\rangle_{\mathrm{w}}^{\psi,+_B}\right)$$

Pauli Spin Observables:
(projective, dichotomic: $\sigma_i^2 = \mathbb{1}$, $i = x, y, z$)

$$\Pi_X^{\pm} = \frac{1}{2}(\mathbb{1} \pm X)$$

$\hat{A} = \sigma_z, \quad \hat{B} = \sigma_x$ **where** $\Pi_X^{\pm} = |\pm_X\rangle\langle\pm_X|$

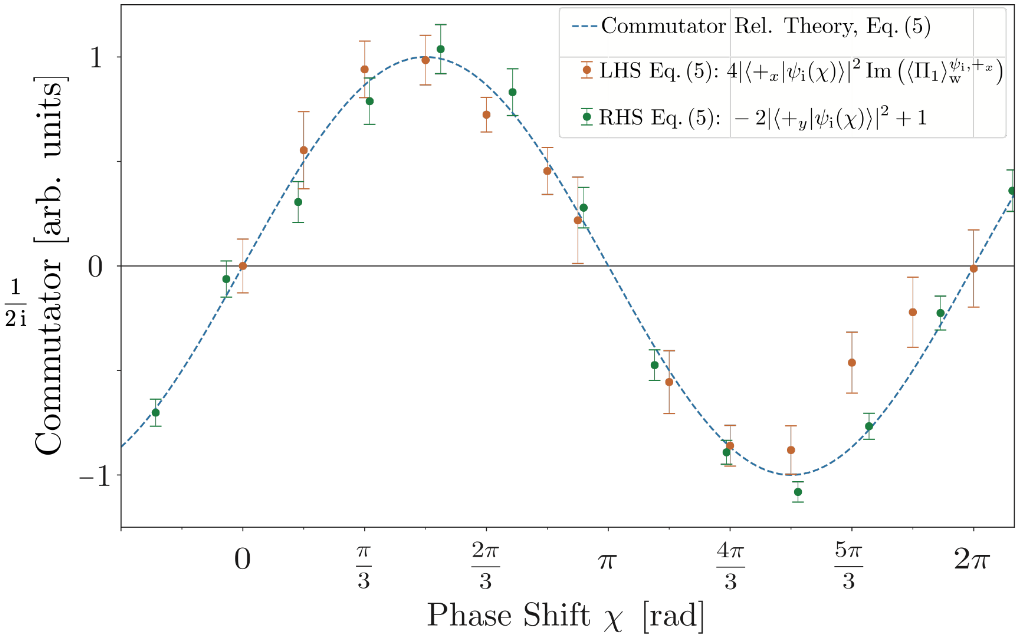
$$[\sigma_z, \sigma_x] = 2\mathrm{i}\sigma_y$$

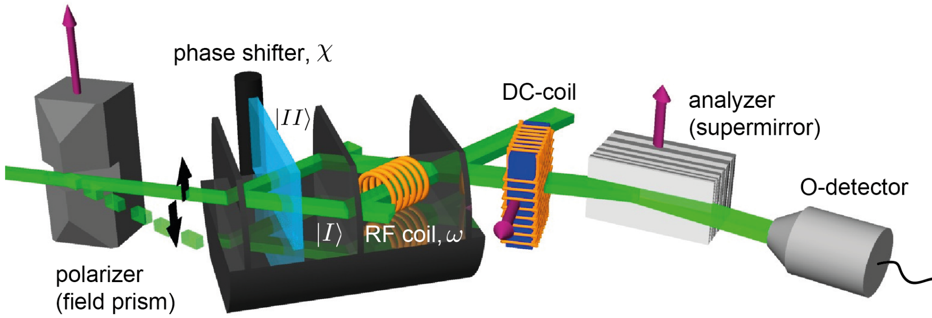
$$\rightarrow \quad \langle\psi|(\hat{\sigma}_z\hat{\sigma}_x - \hat{\sigma}_x\hat{\sigma}_z)|\psi\rangle = 2\mathrm{i}\langle\psi|\hat{\sigma}_y|\psi\rangle \quad \Big| \cdot \frac{1}{2\,\mathrm{i}}$$

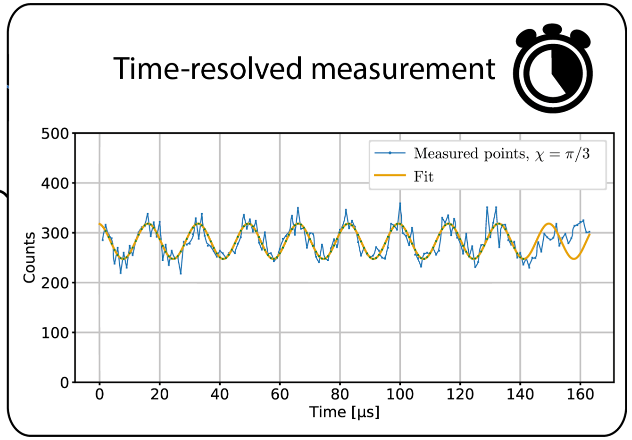
$$4|\langle +_x|\psi\rangle|^2 \; \Im\left(\langle \Pi_z^+\rangle_{\mathrm{w}}^{\psi,+_x}\right) = -2|\langle +_y|\psi\rangle|^2 + 1$$

can be measured

***PATH* (object system) and B: *SPIN* (probe system)**







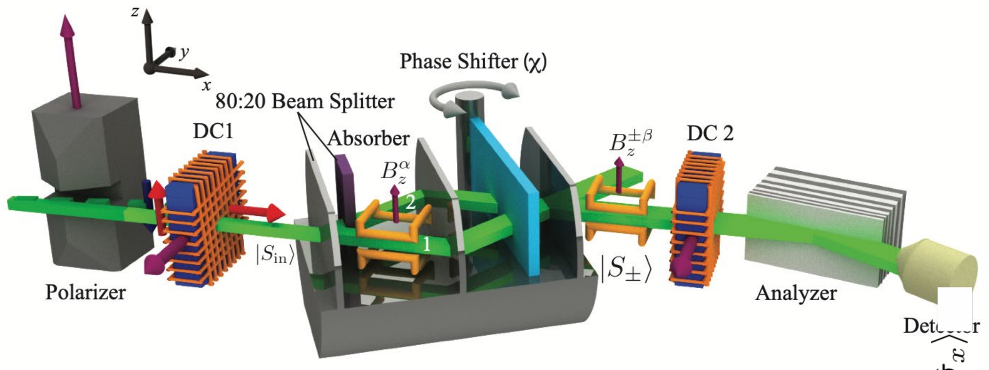
R. Wagner, W. Kersten, A. Danner, H. Lemmel, A. K. Pan, and S. Sponar, *Phys. Rev. Research*, **3**, 023175 (2021)

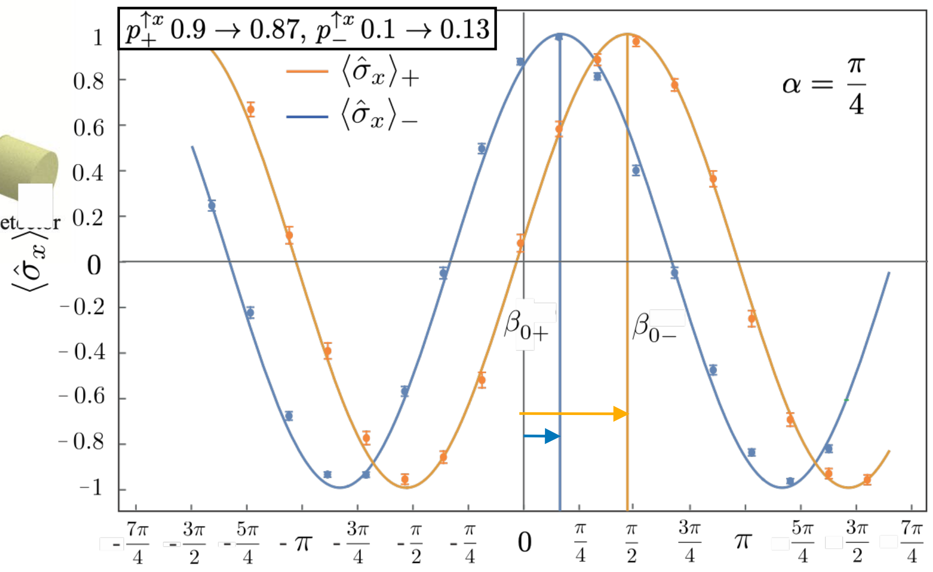
iii) ***Path Presence:*** *Feedback Compensation Scenario*

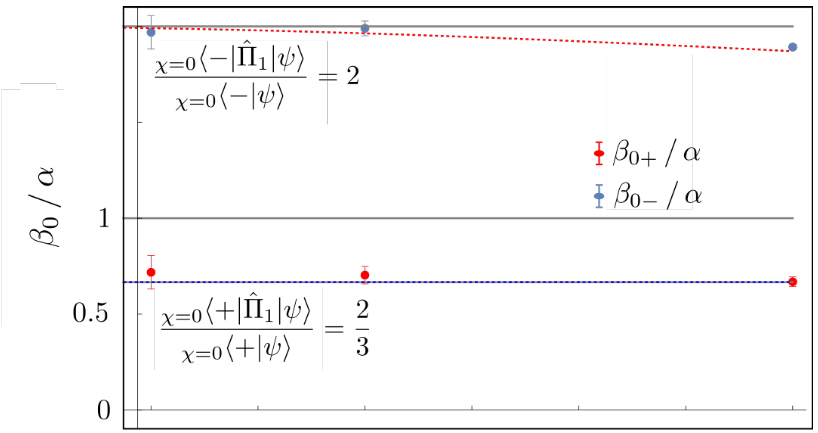
$$|\Psi_{\text{in}}\rangle = |\psi \otimes S\rangle := \big(a_1|1\rangle + a_2|2\rangle\big)|\uparrow_x\rangle \qquad |\Psi_{\pm}^{\text{out}}\rangle = \langle \pm|\psi\rangle\,|\pm\rangle|S_{\pm}\rangle$$

$$\rightarrow a_1 = \frac{2}{\sqrt{5}},\; a_2 = \frac{1}{\sqrt{5}} \qquad |\pm\rangle = |1\rangle + e^{i\chi_{\pm}}|2\rangle$$

$$\chi_+ = 0,\; \chi_- = \pi$$







$$\langle\hat{\sigma}_x\rangle_+ = \cos(\beta_+ - \omega_{1+}\,\alpha)$$
$$\langle\hat{\sigma}_x\rangle_- = \cos(\beta_- - \omega_{1-}\,\alpha)$$

- "**Compensation**" restores the initial spin state ($+x$) for ***all*** neutrons; analyzing the spin in x-direction, the ***variance*** $\Delta\hat{\sigma}_x$ ***vanishes*** and this means that the average value is valid for ***each individual neutron***
- **Path presence** equals the **weak value** of the path projector for small interaction α and is not a statistical average but applies to every individual neutron, ***" Verification of the Estimate "***

H. Lemmel, N. Geerits, A. Danner, H. F. Hofmann, and S. Sponar, *Physical Review Research* **4**, 023075 (2022)

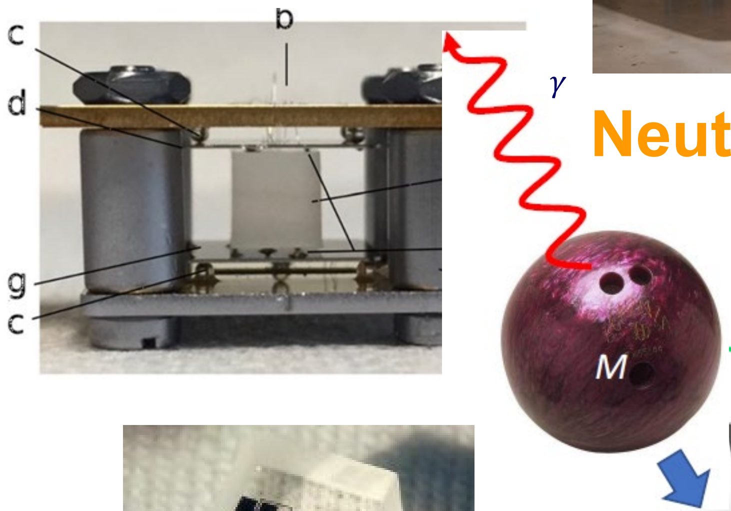
Jericha et al.: Betas & CRAB Experiment

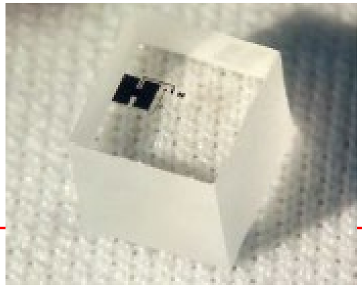
PERC
Magnet System

Delivery to FRM II

CRES

I. Pradler: Cyclotron Radiation Emission Spectroscopy

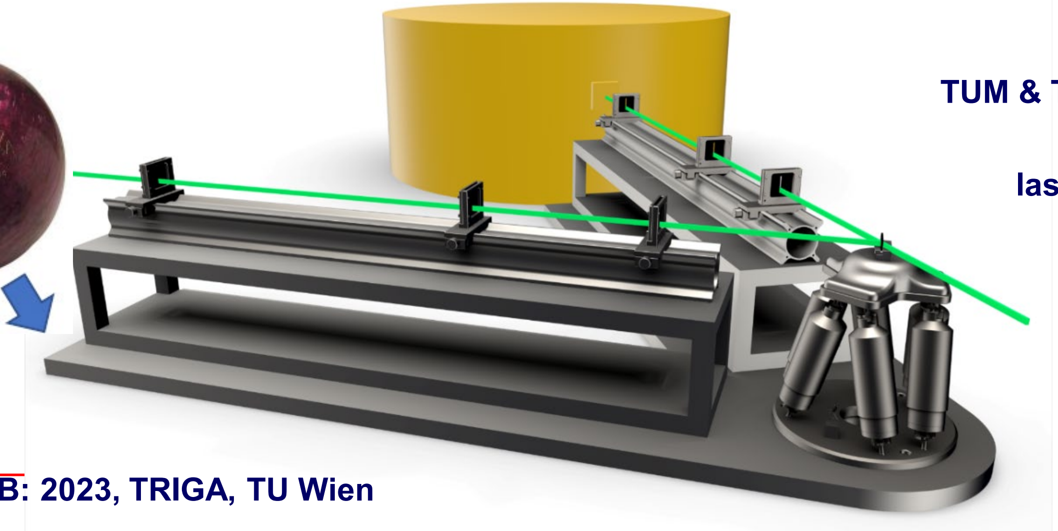




Neutrinos and Dark Matter CRC – Project N07

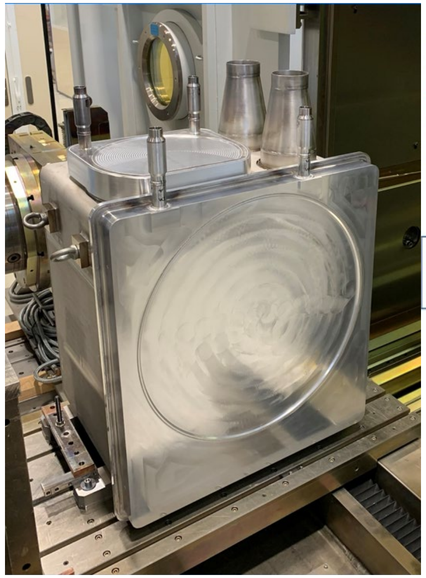
TUM & TU Wien

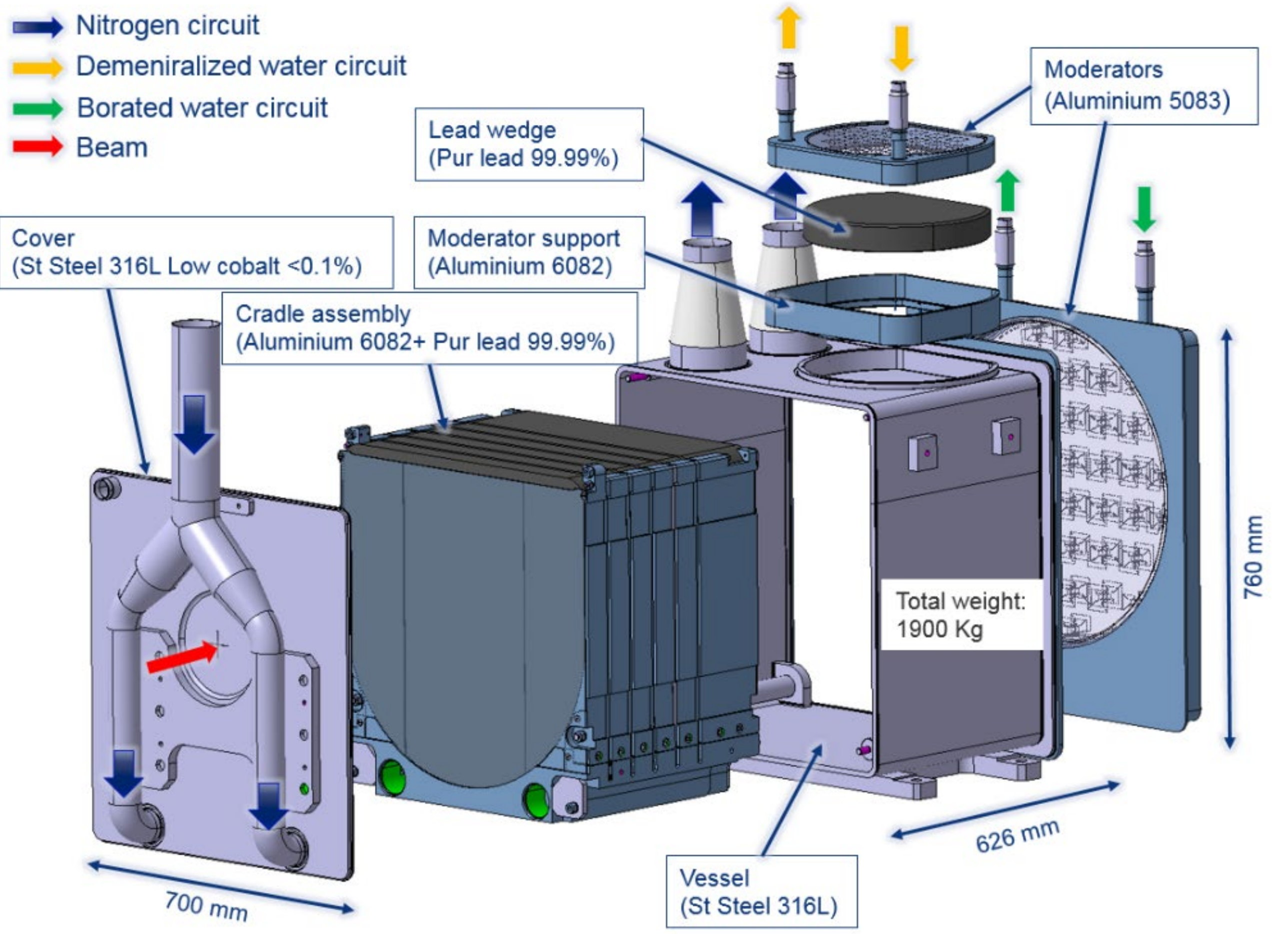
Review last 2 days



CRAB: 2023, TRIGA, TU Wien

Jericha: n_TOF @ CERN: Pb Spallation Target #3





- **Tests with cold nitrogen: operational – February 2021**
- **Installation in the target pit – March 2021**
- **Beamline installations – finished by end of June 2021**
- **1st proton beam on target – planned 19.07.2021**

Theory Group @ ATI, M. Pitschmann C. Käding, B. Koch

- Search for Dark Energy and Modified Gravity with Tabletop Experiments
- Standard Model Tests on the 10^{-4} level

Neutron Experiments at ESFRI Landmarks, Roadmap

- ILL 20/20, Institut Laue Langevin

"Neutron sources can have a serious impact on strategic areas such as particle physics, the fundamental quantum properties of the neutron, and cosmology" ESFRI Road Map p.164f

- 5/27 instruments for "Physique fondamentale"

→ **High Precision Road to Particle Physics at very low energies**

- European Spallation Source ERIC

„The ESS will deliver a neutron peak brightness of at least 30 times greater than the current state-of-the-art"

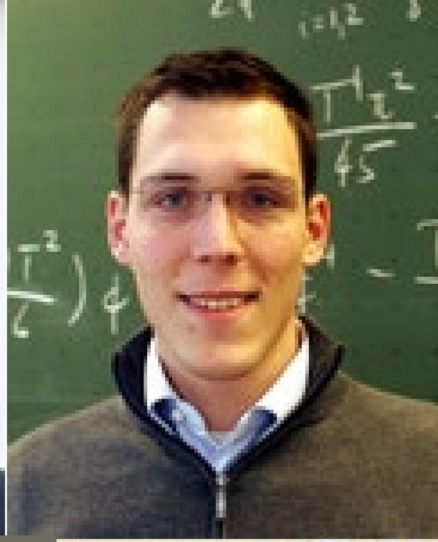
- **The inclusion of Nuclear Physics programmes at ESS is at stake**
- ANNI Proposal.

Longer Perspectives (2025+)

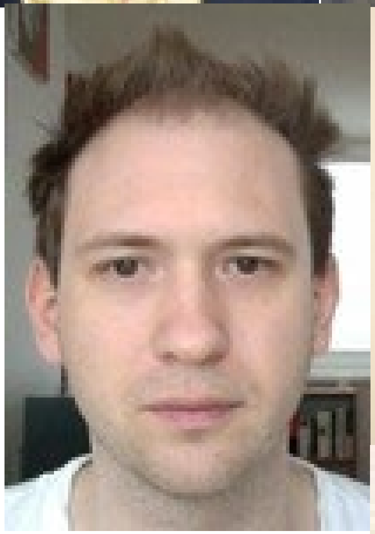
- Beta Decay @ PERC or ILL
  - CREScent @ PERC (Cyclotron Radiation Electron Spectroscopy)
  - Heavy Neutrino Mass Search @ 10 keV
- CREScent @ ESS (European Neutron Souce at Lund)
  - Application for Fundamental Physics Beamline
  - Factor 30 Increase compared to ILL
- qBOUNCE@ILL Bottle experiment -> 50 - 100 gain in sensitivity
- CANNEX@ATI
- NUCLEUS as a long term project






Neutronen- und Quantenphysik@ATI




H. Abele, J. Bosina, Y. Hasegawa, E. Jericha, C. Käding,
B. Koch,M. Pitschmann, I. Pradler, R. Sedmik,
S. Sponar, M. Suda, M. Zawisky