Aspects of

Fundamental Symmetries and Interactions

Physics at a Megawatt Proton Source, CERN, May 25-27, 2004

Klaus Jungmann, Kernfysisch Versneller Instituut,Groningen

- What is Fundamental
- Forces and Symmetries
- Fundamental Fermions
- Discrete Symmetries
- Properties of Known Basic Interactions
- ~ 1GeV versus ~ 30 GeV proton driver

$\Rightarrow$ only scratching some examples

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Drawing on :

- **Work of NuPECC Long Range Plan Working group on Fundamental Interactions, 2003 :**

  H. Abele (D), L. Corradi (I), P. Herczeg (USA), I.B. Khriplovich (RU), O. Nviliat (F), N. Severijns (B), L. Simons (CH), C. Weinheimer (D), H.W. Wilschut (NL), K. Jungmann (NL)

  H. Leeb (A), C. Bargholtz (S)

  Assisted by: W. Heil, P. Indelicato, F. Maas, K. Pachucki, R.G Timmermans, C. Volpe, K. Zuber

- **NSAC Long Range Plan 2002**
- **EURISOL Physics Case 2004**

Recommendations of NuPECC working group 2003

Physics Topics

- The Nature of Neutrinos
  - Oscillations / Masses / $0\nu2\beta$-decay
- T and CP Violation
  - edm's, D (R) coeff. in β-decays, D^0
- Rare and Forbidden Decays
  - $0\nu2\beta$-decay, n-n^{bar}, M-M^{bar}, $\mu\rightarrow e\gamma$,
  - $\mu \rightarrow 3e$, $\mu N \rightarrow N e$
- Correlations in β-decay
  - non V-A in β-decay
- Unitarity of CKM-Matrix
  - n-, π-β, (superallowed β), K-decays
- Parity Nonconservation in Atoms
  - Cs, Fr, Ra, Ba^+, Ra^+
- CPT Conservation
  - n, e, p, μ
- Precision Studies within The Standard Model
  - Constants, QCD,QED, Nuclear Structure

Adequate Environment

Human resources

- Theoretical Support
- Positions at Universities
  - Experimentalists and Theorists

Facilities

- High Power Proton Driver
  - Several MW
  - Target Research
- Cold and Ultracold Neutrons
- Low Energy Radioactive Beams
- Improved Trapping Facilities
- Underground Facilities

Recommendations Relating to a MW Proton Machine

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Recommendations Relating to a MW Proton Machine

Physics Topics

- Offer unique possibilities to gain inside into fundamental processes and into yet unexplained observed facts in nature
- Offer possibilities to measure needed fundamental constants with unprecedented accuracy

High Power Proton Driver

- To obtain sufficient particles
  - Statistics Limitations
  - Understanding Systematics
- To enable Novel Techniques

What are we concerned with ?

fundamental := " forming a foundation or basis, a principle, law etc. serving as a basis"

[Webbster's New World]

- ***Physicists in general*:**

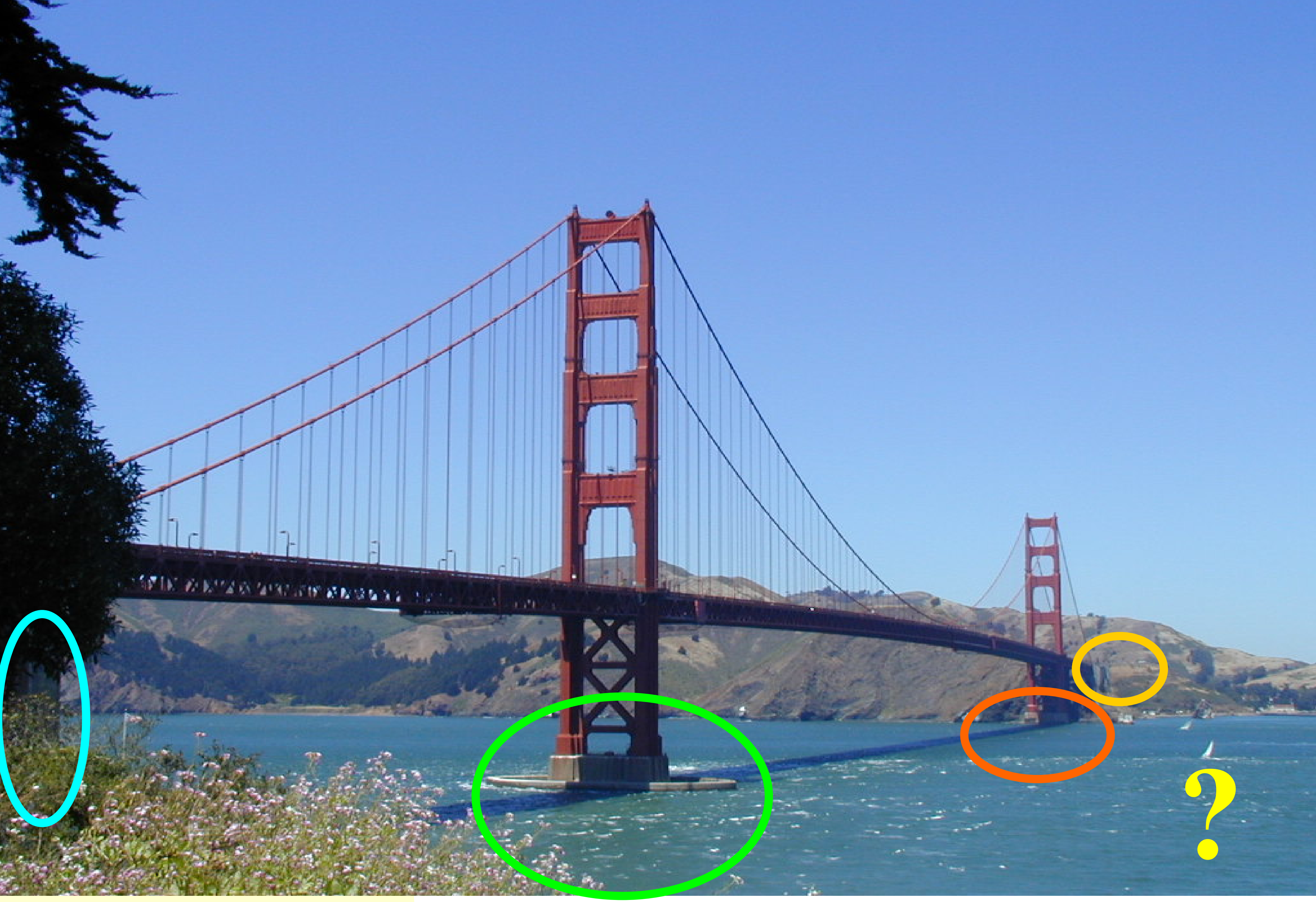
  have always a tendency to put their own activities as fundamental

  $\Rightarrow$ ***renormalization of meaning***

- ***Albert Einstein :***

  > I would like to know how God has made the world. I am *not* interested in *one or an other phenomenon*, *not* interested in the *spectrum of one or another element*. I would like to know *His Thoughts*, everything else are just details. <

  $\Rightarrow$ ***resembles literal meaning, i.e. basic, not deducible law***



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Forces and Symmetries

Local Symmetries ⇔ Forces

- **fundamental interactions**

Global Symmetries ⇔ Conservation Laws

- **energy**
- **momentum**
- **electric charge**
- **lepton number**
- **charged lepton family number**
- **baryon number**
- **…..**

What are we concerned with ?

fundamental := " forming a foundation or basis a principle, law etc. serving as a basis"

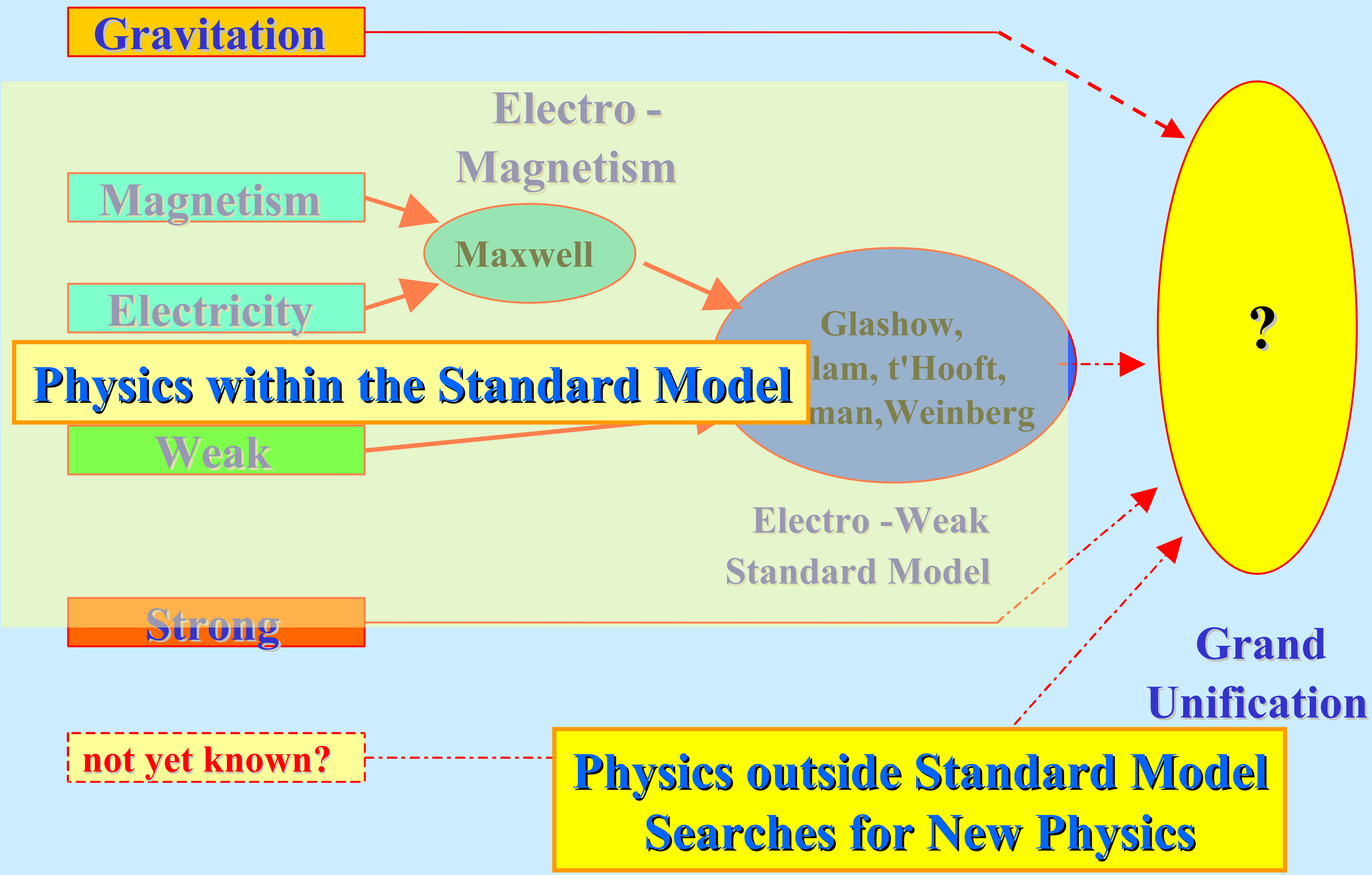
Standard Model

- 3 Fundamental Forces
  - Electromagnetic Weak Strong
- 12 Fundamental Fermions
  - Quarks, Leptons
- 13 Gauge Bosons
  - γ, W^+, W^-, Z^0, H, 8 Gluons

However

- many open questions
  - Why 3 generations ?
  - Why some 30 Parameters?
  - Why CP violation ?
  - Why us?
  - .....
- Gravity not included
- No Combind Theory of Gravity and Quantum Mechanics

Fundamental Interactions – Standard Model



Fundamental Fermions

- **Neutrinos**
  - **Neutrino Oscillations**
  - **Neutrino Masses**
- **Quarks**
  - **Unitarity of CKM Matrix**
- **Rare decays**
  - **Baryon Number**
  - **Lepton Number/Lepton Flavour**
- **New Interactions in Nuclear and Muon β-Decay**

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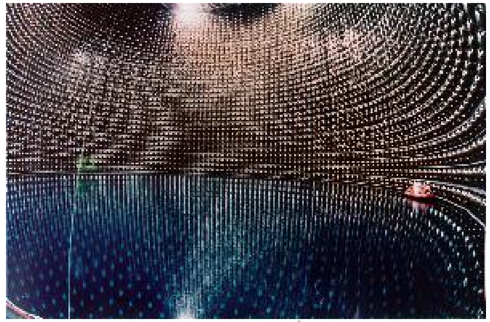
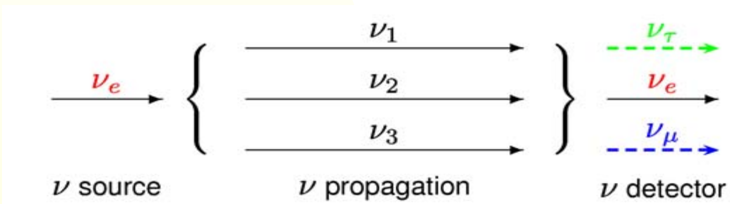
Neutrino-Experiments

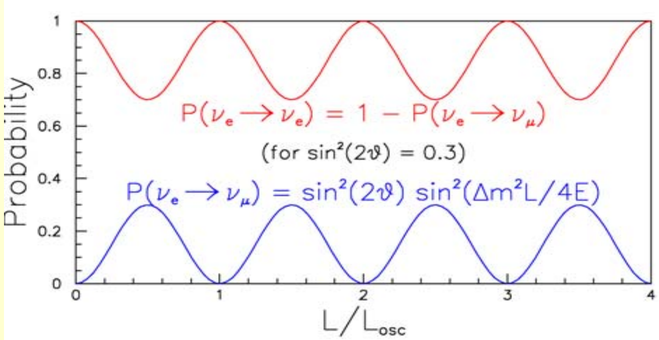
SNO



Superkamiokande



$$P(\nu_\alpha \to \nu_\beta) = \sin^2(2\Theta) * \sin^2\left(\frac{\Delta m_{ij}^2 * L}{4E}\right)$$



Recent observations could be explained by oscillations of massive neutrinos.

Many Remaining Problems

- **really oscillations ?**
- **sensitive to Δm^2**
- **Masses of Neutrino**
- **Nature of Neutrino**
  - **Dirac**
  - **Majorana**

  → Neutrinoless Double β-Decay
- **Direct Mass Measurements are indicated**

  → Spectrometer
- **Long Baseline Experiments**

  → β-beams

  → new neutrino detectors ?

Neutrino mixing and oscillation

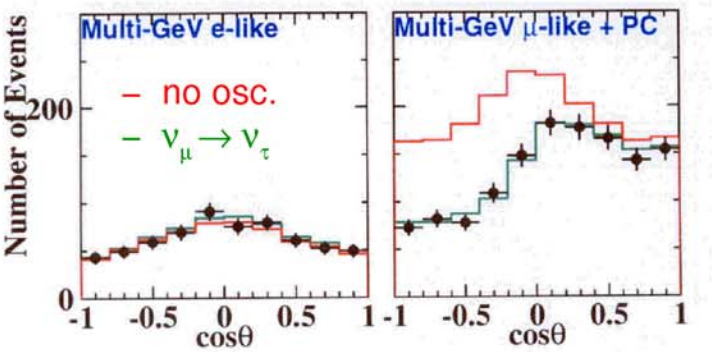
Neutrinos mix and oscillate ⇒non–zero neutrino masses:

Atmospheric neutrino data:

deficit of upgoing ν_μ

$\Rightarrow \nu$ oscillation: $\nu_\mu \rightarrow \nu_\tau$

($\Delta m^2 \approx 2.5 \cdot 10^{-3}\, eV^2$. $\sin 2(2\theta) \approx 1$)

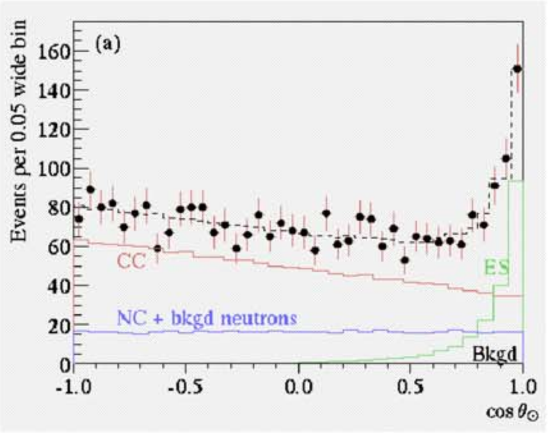


Solar neutrino data:

SNO: Solar Model ≈ NC > ES > CC

⇒ indirect signal for ν_μ, ν_τ

$\Rightarrow$ ν oscillation



Future: discovery → precision

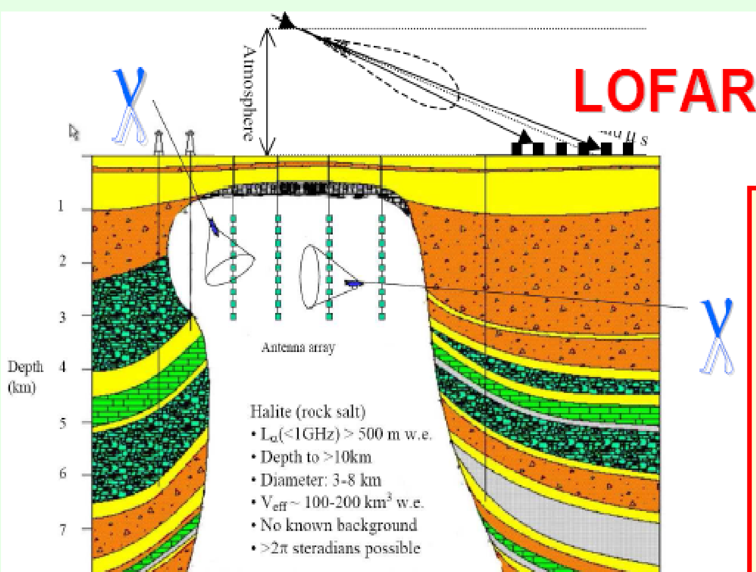
continue efforts to measure $U_{\alpha i}$

(solar, long baseline reactor and accelerator ν)

Neutrino-Experiments
Are there new detection schemes ?

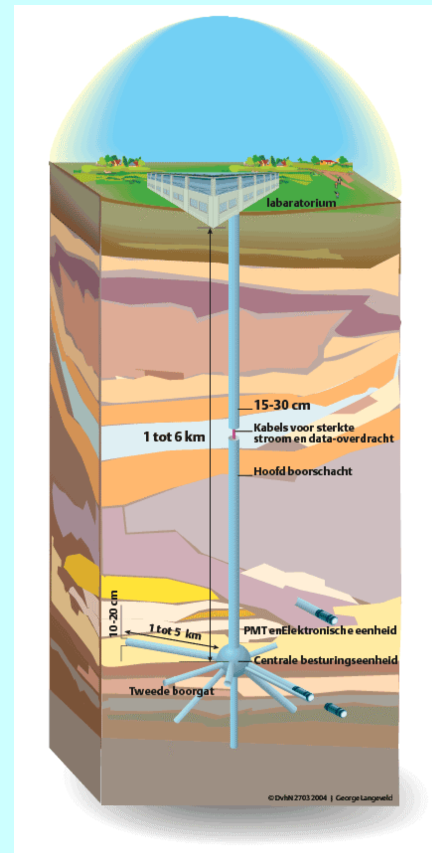
- **Water Cherenkov**
- **Scintillators**
- **....**

- **Air shower ?**
- **Salt Domes ?**



Only for Non-Accelerator Neutrinos ?

- **Directional sensitivity for low energies ?**



Fundamental Fermions

- Neutrinos
  - Neutrino Oscillations
  - Neutrino Masses
- **Quarks**
  - **Unitarity of CKM Matrix**
- Rare decays
  - Baryon Number
  - Lepton Number/Lepton Flavour
- New Interactions in Nuclear and Muon β-Decay

Unitarity of Cabbibo-Kobayashi-Maskawa Matrix

CKM Matrix couples weak and mass quark eigenstaes:

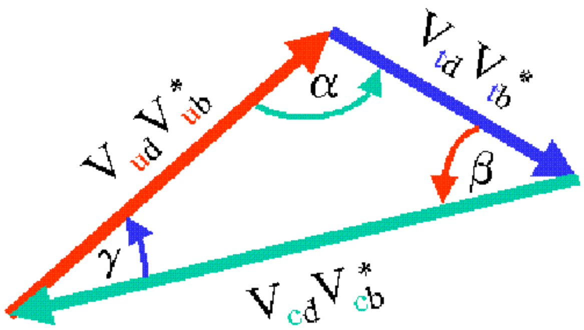
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} =$$

$$\begin{pmatrix} \mathbf{0.9739(5)} & \mathbf{0.221(6)} & 0.0036(12) \\ 0.223(4) & 0.9740(8) & 0.041(3) \\ 0.008(4) & 0.0041(4) & 0.9992(2) \end{pmatrix}$$

Unitarity:

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 - \Delta$$



Often found:

Nuclear β-decays

$\Delta = 0.0032\ (14)$

Neutron decay

$\Delta = 0.0083(28)$

$\Delta = 0.0043(27)$

?

If you pick your favourite V_{us} !

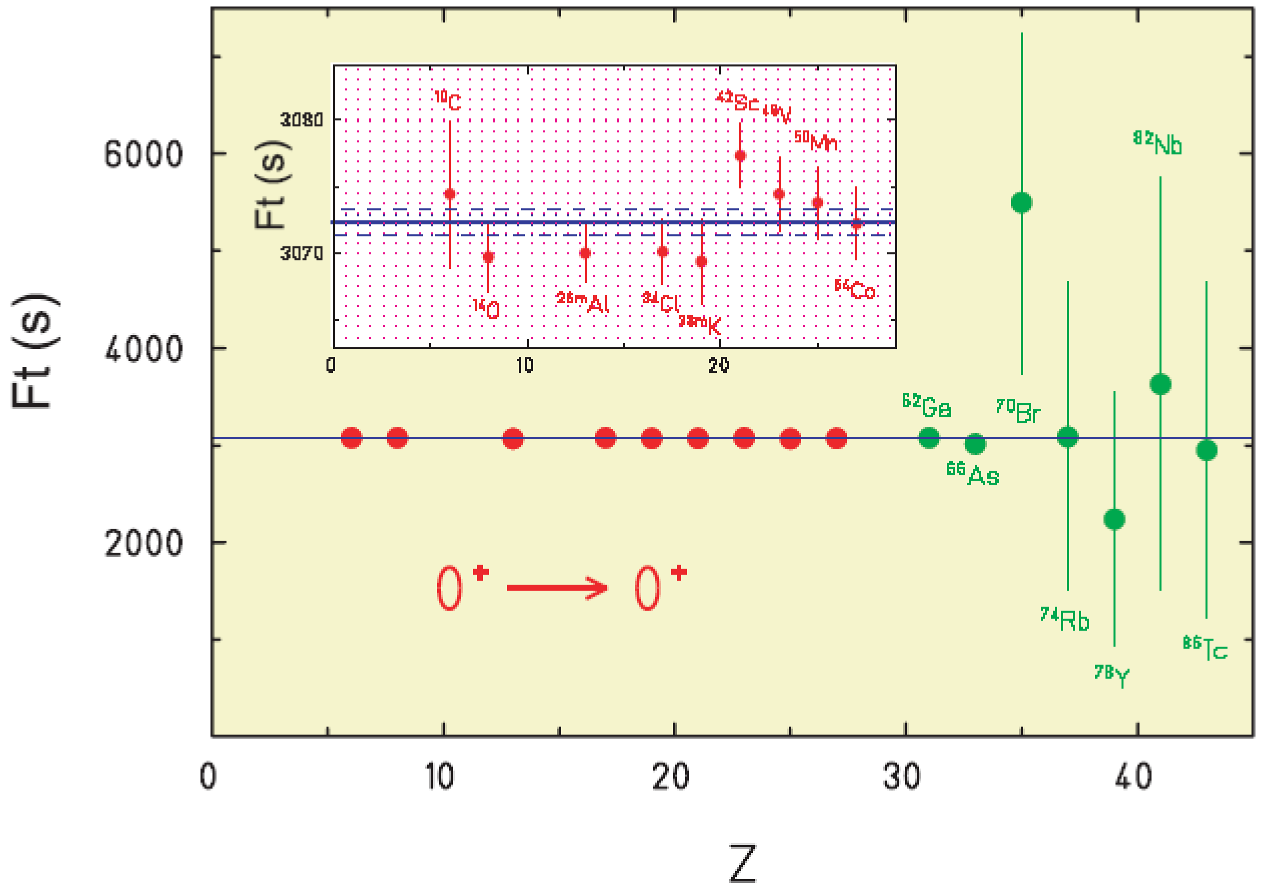
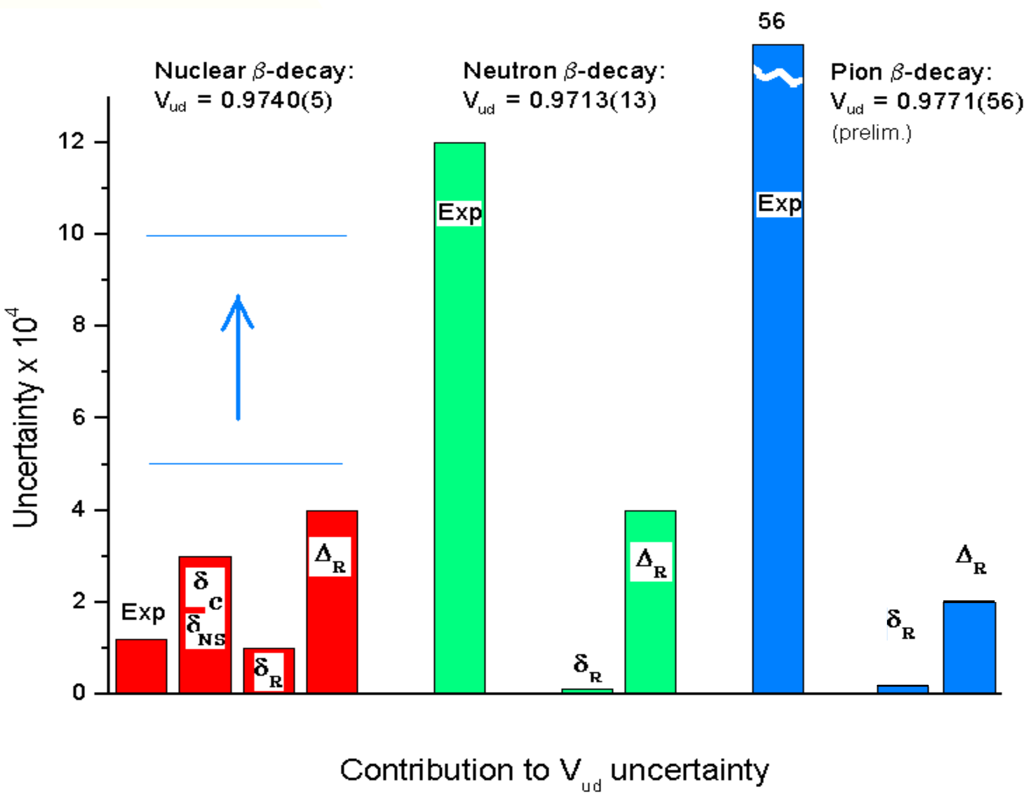
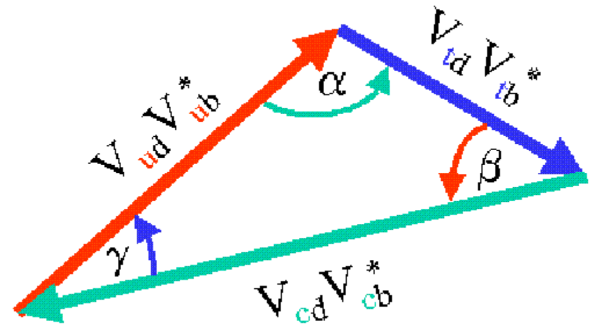


Fig. 42: Super-allowed 0+ ⟶ 0+ transitions which allow us to test the CVC hypothesis of the weak interaction. The values for the heavier nuclei have been measured using the relatively weak intensities from present radioactive beam facilities. Using these data to check the theoretically determined corrections needs higher statistical precision.

Unitarity of Cabbibo-Kobayashi-Maskawa Matrix

Experimental Possibilities





Nuclear β-decays

$\Delta = 0.0032\ (14)$

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?

CKM Unitarity

- **May relate to New Physics**

  Heavy Quark Mixing, Z‘,Extra Dimensions, Charged Higgs, SUSY, exotic muon decays, ... , more generations !

- **Unfortunatetly: Situation is a mess !**

Numbers Compiled by W. Marciano, March ‘04

V_{ud} :	**superallowed β-decays**	**0.9740(3)(4)**
	neutron decay	**0.9729(4)(11)(4)**
	pion-β decay	**0.9737(39)(2)**

V_{us} :	**Hyperons**	$\Delta = 0.0019\ (16)$	
	K^{+}_{e3}	$\Delta = 0.0014\ (17)$	
	K^{0}_{e3}	$\Delta = 0.0054\ (14)$	Problem !

- **What can be done?**
  - ➢ **Improve reliability of experiments independently**

    pion- β decay (theory clean!) , maybe: neutron- decay
  - ➢ **Analyse existing K data, K_{e3} experiments**
  - ➢ **Search for exotic muon decays**
  - ➢ **Improve Theory**

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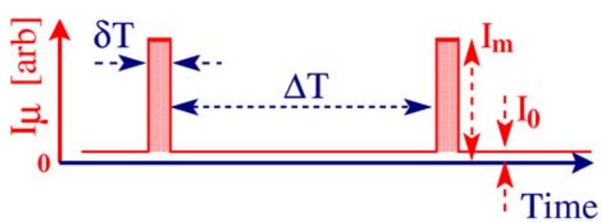
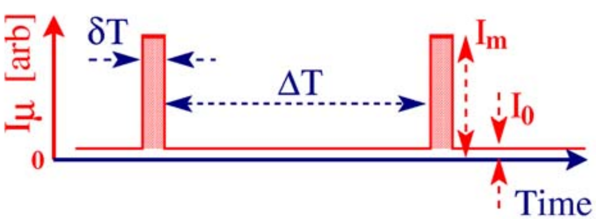
Muon Physics Possibilities at Any High Power Proton Driver i.e. ≥ 4 MW

Type of Experiment	Physics Issues	Possible Experiments	previously established accuracy	present activities (proposed accuracy)	projected for NUFACT @ CERN
"Classical" Rare & Forbidden Decays	Lepton Number Violation; Searches for New Physics: SUSY, L-R Symmetry, R-parity violation,.....	$\mu^- N \to e^- N$ $\mu \to e\gamma$ $\mu \to eee$ $\mu^+ e^- \to \mu^- e^+$	6.1×10^{-13} 1.2×10^{-11} 1.0×10^{-12} 8.1×10^{-11}	PSI, proposed BNL (5×10^{-17}) proposed PSI (2×10^{-14}) completed 1985 PSI completed 1999 PSI	$< 10^{-18}$ $< 10^{-15}$ $< 10^{-16}$ $< 10^{-13}$
Muon Decays	G_F; Searches for New Physics; Michel Parameters	τ_μ $transv.Polariz.$	18×10^{-6} 2×10^{-2}	PSI (2x), RAL (1×10^{-6}) PSI, TRIUMF (5×10^{-3})	$< 10^{-7}$ $< 10^{-3}$
Muon Moments	Standard Model Tests; New Physics; CPT Tests T- resp. CP-Violation in 2nd lepton generation	$g_\mu - 2$ edm_μ	1.3×10^{-6} $3.4 \times 10^{-19}\, e\, cm$	BNL (3.5×10^{-7}) proposed BNL ($10^{-24}\, e\, cm$)	$< 10^{-7}$ $< 5 \times 10^{-26}\, e\, cm$
Muonium Spectroscopy	Fundamental Constants, μ_μ,m_μ,α; Weak Interactions; Muon Charge	M_{HFS} M_{1s2s}	12×10^{-9} 1×10^{-9}	completed 1999 LAMPF completed 2000 RAL	5×10^{-9} $< 10^{-11}$
Muonic Atoms	Nuclear Charge Radii; Weak Interactions	$\mu^-\ atoms$	$depends$	PSI, possible CERN ($< r_p >$to 10^{-3})	new nuclear structure
Condensed Matter	surfaces, catalysis bio sciences ...	surface μSR	n/a	PSI, RAL (n/a)	high rate

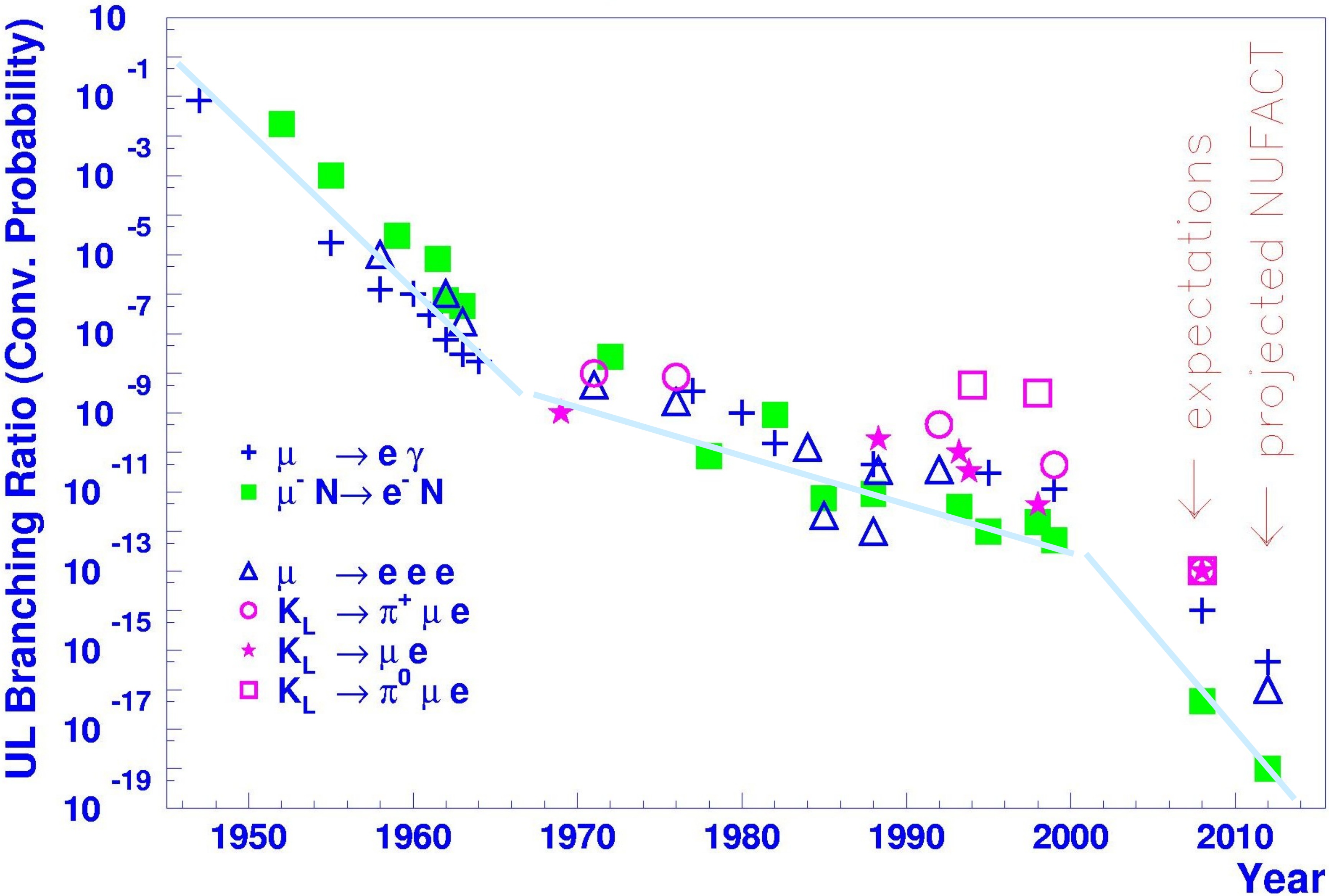


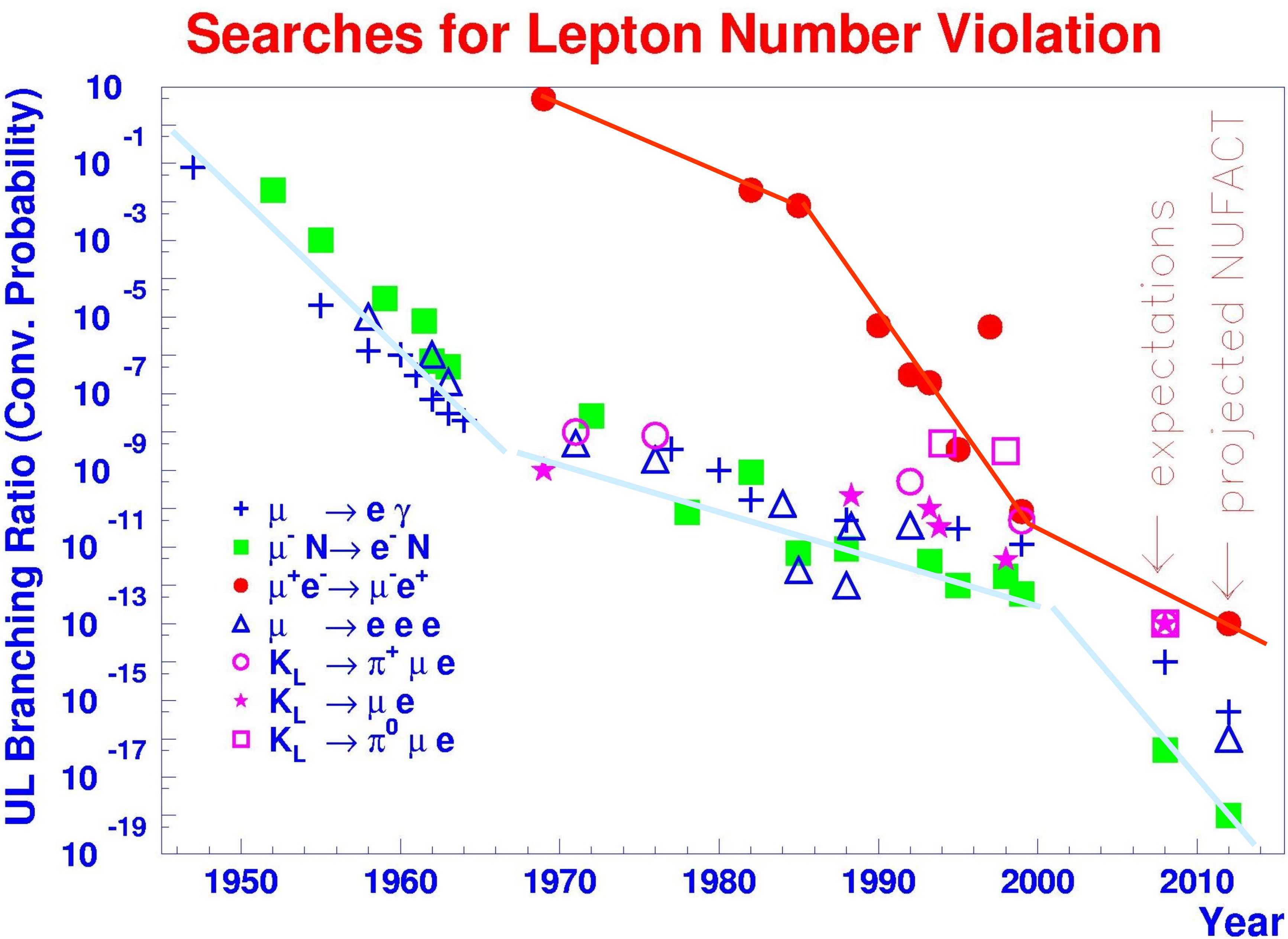
Muon Physics Possibilities at Any High Power Proton Driver i.e. ≥ 4 MW

Experiment	q_μ	$\int I_\mu dt$	I_0/I_μ	δT [ns]	ΔT [μs]	E_μ [MeV]	$\Delta p_\mu/p_\mu$ [%]
$\mu^- N \rightarrow e^- N^\dagger$	$-$	10^{19}	$< 10^{-10}$	≤ 100	≥ 1	< 20	< 10
$\mu^- N \rightarrow e^- N^\ddagger$	$-$	10^{19}	n/a	n/a	n/a	< 20	< 10
$\mu \rightarrow e\gamma$	$+$	10^{17}	n/a	n/a	n/a	1...4	< 10
$\mu \rightarrow eee$	$+$	10^{17}	n/a	n/a	n/a	1...4	< 10
$\mu^+ e^- \rightarrow \mu^- e^+$	$+$	10^{16}	$< 10^{-4}$	< 1000	≥ 20	1...4	1...2
τ_μ	$+$	10^{14}	$< 10^{-4}$	< 100	≥ 20	4	1...10
$transvers.polariz.$	$+$	10^{16}	$< 10^{-4}$	< 0.5	> 0.02	30-40	1...3
$g_\mu - 2$	$\pm$	10^{15}	$< 10^{-7}$	≤ 50	$\geq 10^3$	3100	10^{-2}
edm_μ	$\pm$	10^{16}	$< 10^{-6}$	≤ 50	$\geq 10^3$	$\leq$1000	$\leq 10^{-3}$
M_{HFS}	$+$	10^{15}	$< 10^{-4}$	≤ 1000	≥ 20	4	1...3
M_{1s2s}	$+$	10^{14}	$< 10^{-3}$	≤ 500	$\geq 10^3$	1...4	1...2
$\mu^- atoms$	$-$	10^{14}	$< 10^{-3}$	≤ 500	≥ 20	1...4	1...5
$condensed\ matter$ $(incl.bio\ sciences)$	$\pm$	10^{14}	$< 10^{-3}$	< 50	≥ 20	1...4	1...5



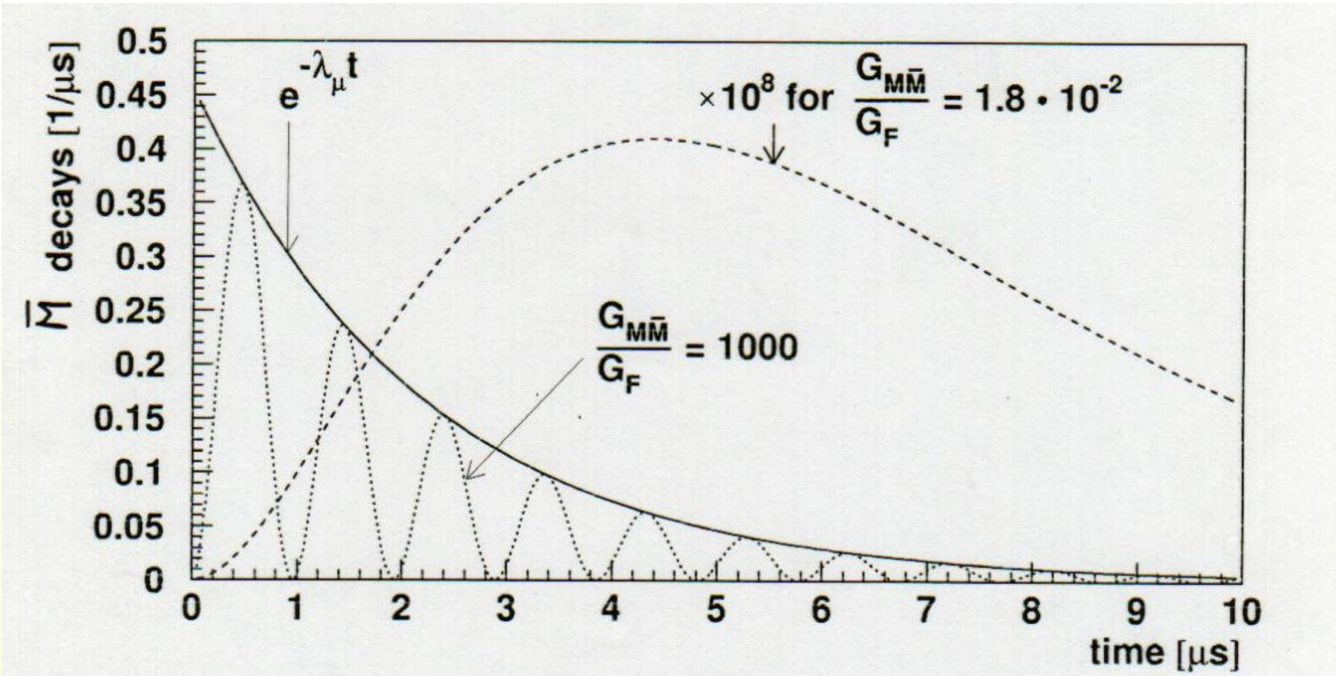
Searches for Lepton Number Violation





Searches for Lepton Number Violation
UL Branching Ratio (Conv. Probability)
Year
μ → e γ
μ⁻ N → e⁻ N
μ⁺e⁻ → μ⁻e⁺
μ → e e e
K_L → π⁺ μ e
K_L → μ e
K_L → π⁰ μ e
expectations
projected NUFACT

Old Muonium for Muonium-Antimuonium Conversion ?



- **$P(\bar{M}) \propto \sin^2 [const * (G_{M\bar{M}}/G_F)*t]*\exp[-\lambda_\mu*t]$**
- **Background $\propto \exp(-\ n\ \lambda_\mu*t)$; n-fold coincidence detection**
- **For $G_{M\bar{M}} << G_F$ M gains over Background**
- **$P(\bar{M})$ / Background $\propto t^2 * \exp[+(n-1)*\ \lambda_\mu*t]$**

⇒ Pulsed ACCELERATOR

Fundamental Fermions

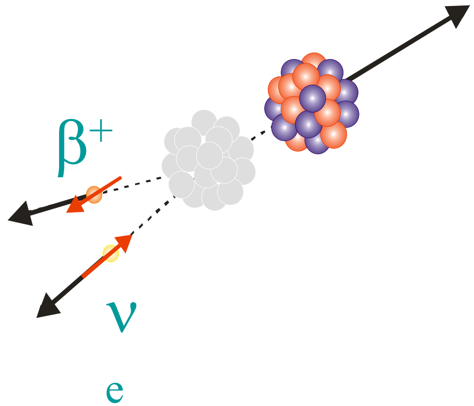
- Neutrinos
  - Neutrino Oscillations
  - Neutrino Masses
- Quarks
  - Unitarity of CKM Matrix
- Rare decays
  - Baryon Number
  - Lepton Number/Lepton Flavour
- **New Interactions in Nuclear and Muon β-Decay**

New Interactions in Nuclear and Muon β-Decay

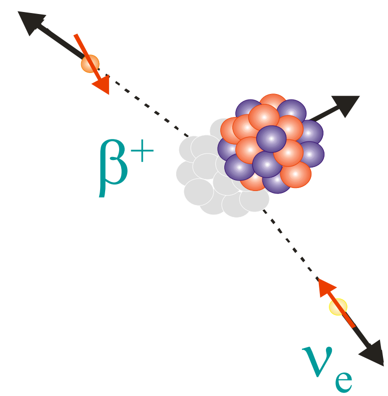
In Standard Model: Weak Interaction is V-A

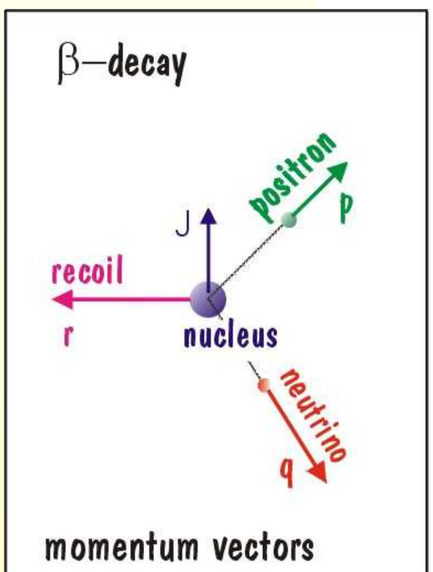
In general β-decay could be also S , P, T

Vector [Tensor]



Scalar [Axial vector]





$$\begin{aligned}\frac{d^2W}{d\Omega_e\, d\Omega_\nu} \sim\ & 1 + a\,\frac{\boldsymbol{p}\cdot\hat{\boldsymbol{q}}}{E} + b\,\Gamma\,\frac{m_e}{E} \\ & + \langle \boldsymbol{J}\rangle \cdot \left[A\,\frac{\boldsymbol{p}}{E} + B\,\hat{\boldsymbol{q}} + D\,\frac{\boldsymbol{p}\times\hat{\boldsymbol{q}}}{E}\right] \\ & + \langle \boldsymbol{\sigma}\rangle \cdot \left[G\,\frac{\boldsymbol{p}}{E} + Q\,\langle \boldsymbol{J}\rangle + R\,\langle \boldsymbol{J}\rangle \times \frac{\boldsymbol{p}}{E}\right]\end{aligned}$$

Discrete Symmetries

- **Parity**
  - **Parity Nonconservation in Atoms**
  - **Nuclear Anapole Moments**
  - **Parity Violation in Electron-Scattering**
- **Time Reversal and CP-Violation**
  - **Electric Dipole Moments**
  - **R and D Coefficients in β-Decay**
- **CPT Invariance**

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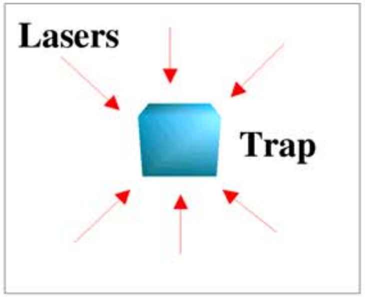
Parity non–conservation experiments

e–q interactions at low momentum transfer
q–q interactions via anapole moments
Precision tests of neutral current couplings

Tools : Laser spectroscopy
Traps



Atomic PNC

E = neV – keV

Electron-
Scatte

E = 100 Me

Meson–n
PNC effe
Structure

Tools : P
G

→ **Beautiful confirmation of Standard Model in the past !**

→ **Only little chances to contribute to forefront (except leptoquark scenarios)**

→ **Usefull for measureing neutron distributions**

→ **Usefull to explore e.g. anapole moments**

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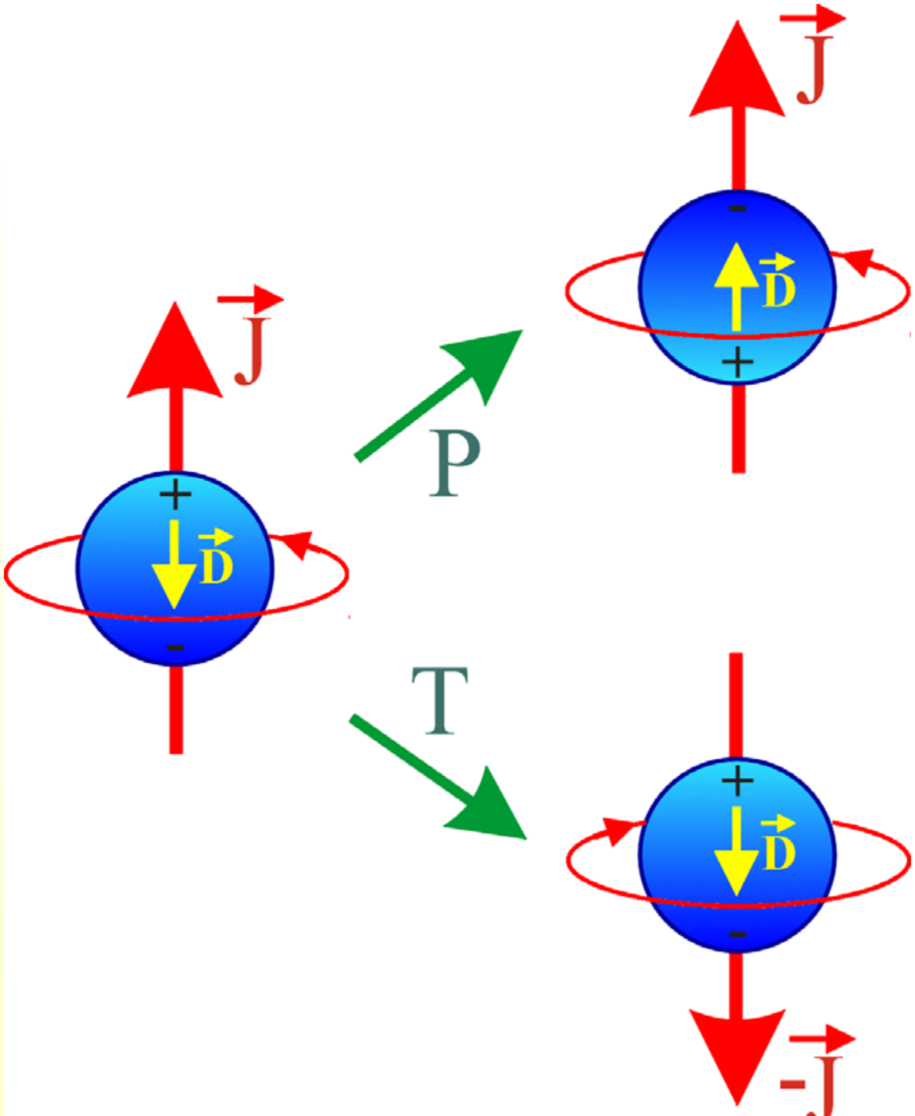
- CPT Invariance



EDM violates:

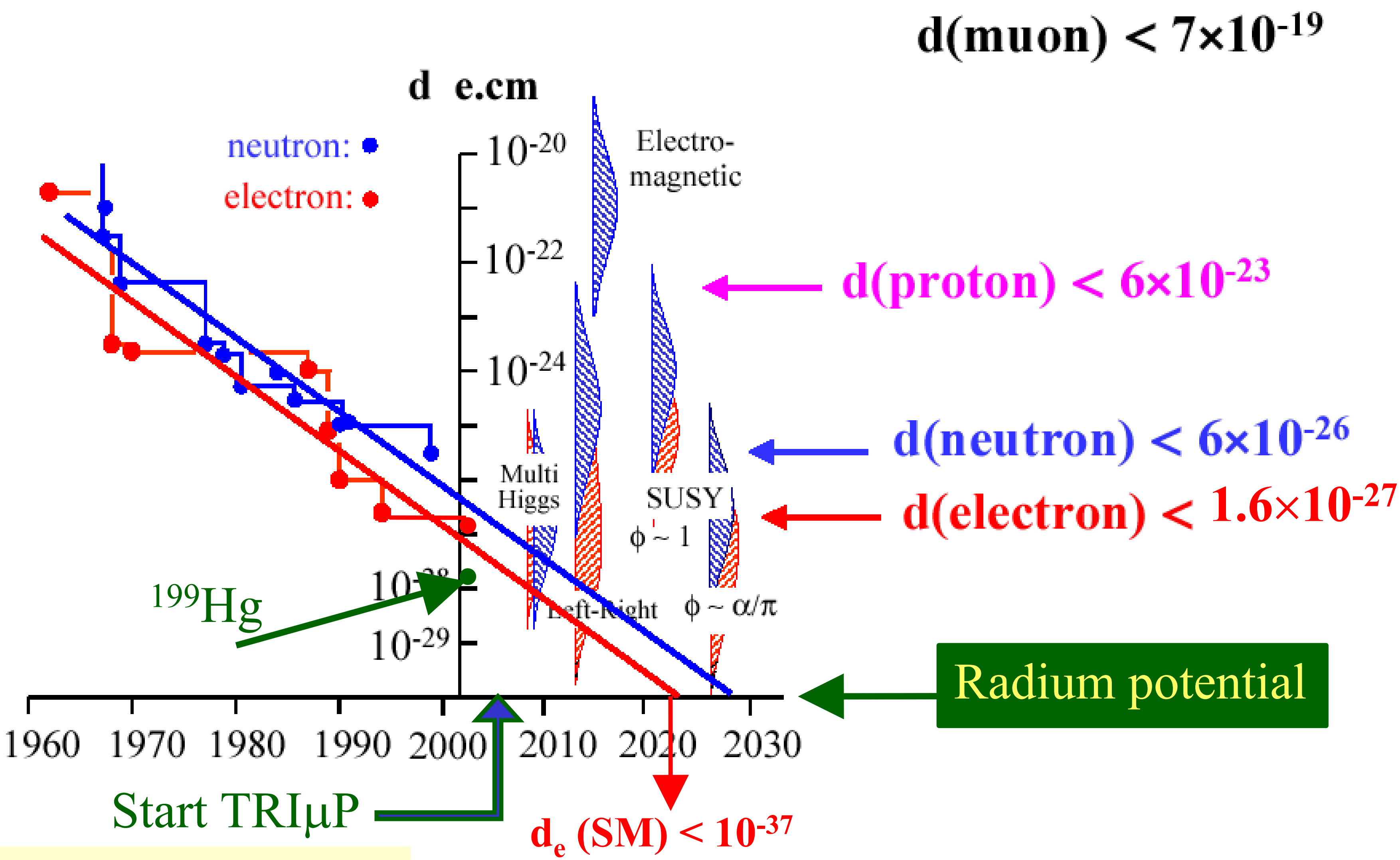
- **Parity**
- **Time reversal**
- **CP- conservation**

if CPT conservation assumed

Any observed EDM:

- **Sign of New Physics beyond Standard Theory**

Some EDM Experiments compared



EDM: What Object to Choose ?

particle	limit on edm $\lvert d\rvert$ [e cm] (95% C.L.)	system	improvement factor	new physics limits [e cm]
e	1.9×10^{-27}	^{205}Tl	> 1	10^{-27}
μ	1.05×10^{-19}	rest frame E	10^3	10^{-22}
τ	3.1×10^{-16}	$(e^+e^- \to \tau^+\tau^-\gamma)$	10^4	10^{-20}
p	6.5×10^{-23}	^{205}Tl-F	10^4	5×10^{-26}
n	7.5×10^{-26}	ultracold neutrons	> 1	5×10^{-26}
Λ	1.5×10^{-16}	rest frame E	10^7	10^{-23}
^{199}Hg	2.1×10^{-28}	^{199}Hg	> 1	10^{-28}
Ξ^0	?	as Λ	?	10^{-23}

Table 1: Current limits on edm's, converted to a common 95% confidence limit. The improvement factor indicates how much the measurement needs to be improved to yield new physics limits. No data in the charmed sector

^{205}Tl: d = -585 d_e

^{199}Hg:
d ∝ nucl×atom

Ra: Ra/Hg=$(10^{>1})(10^{>3})$

Precession frequency ω due to a particle with anomalous magnetic moment $a = g/2 - 1$ and edm d

$$\omega = -\frac{e}{m}\left[a\mathbf{B} - a\frac{\gamma}{\gamma+1}\mathbf{v}(\mathbf{v}\cdot\mathbf{B}) - \left(a - \frac{1}{\gamma^2-1}\right)\mathbf{v}\times\mathbf{E}\right]$$
$$-\frac{d}{2}\left[\mathbf{E} - \frac{\gamma}{\gamma+1}\mathbf{v}(\mathbf{v}\cdot\mathbf{E}) + \mathbf{v}\times\mathbf{B}\right]$$

Theoretical input needed

EDMs – Where do they come from ?

(are they just “painted“ to particles? Why different experiments?)

■ electron	intrinsic ?
■ quark	intrinsic ?
■ muon	second generation different ?
■ neutron/ proton	from quark EDM ? property of strong interactions ? new interactions ?
■ deuteron	basic nuclear forces CP violating? pion exchange ?
■ ^{6}Li	many body nuclear mechanism ?
■ heavy nuclei (e.g. Ra, Fr)	enhancement by CP-odd nuclear forces, nuclear “shape“
■ atoms	can have large enhancement, sensitive to electron or nucleus EDMs
■ molecules	large enhancement factors , sensitive to electron EDM
■	

Generic EDM Experiment

Preparation of "pure" $\vec{J}$ state	→	Interaction with $\vec{E}$ - field	→	Analysis of state
Polarization		Spin Rotation		Determination of Ensemble Spin average

electric dipole moment: $\vec{D} = \eta \, \mu_x \, c^{-1} \, \vec{J}$

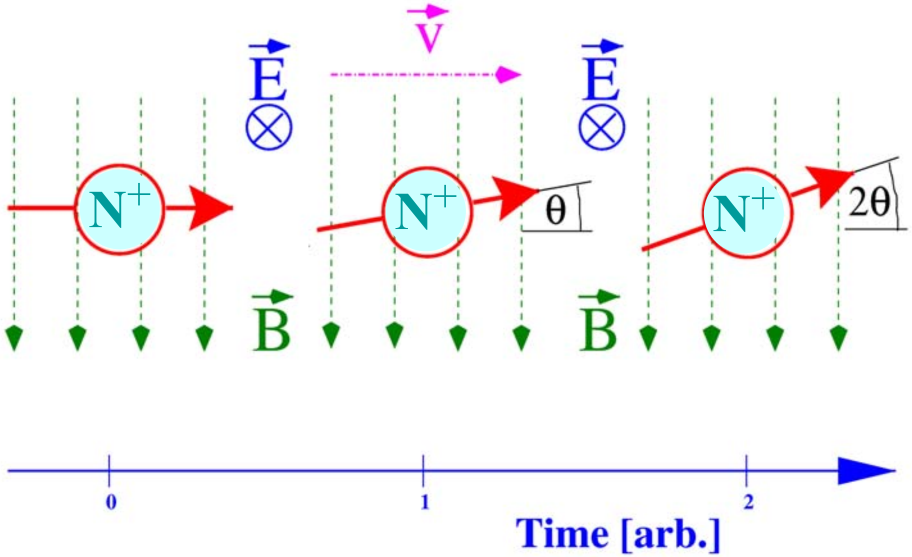
Spin precession : $\vec{\omega}_e = \dfrac{\vec{D}\bullet\vec{E}}{\hbar} \, \dfrac{\vec{E}\times\vec{J}}{|\vec{E}\times\vec{J}|}$

Example: $D=10^{-24}$ e cm, E=100 kV/cm, J=1/2

$\omega_e = 15.2$ **mHz**

How does a ring edm experiment work ?

- Exploit huge motional electric fields for relativistic particles in high magnetic fields
- stop g-2 precession
- observe spin rotation

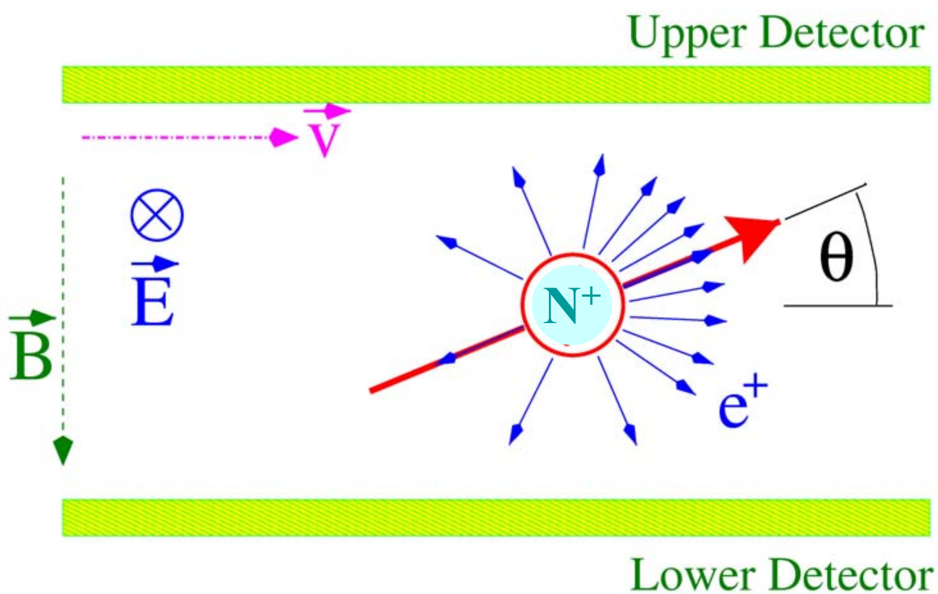


- Concept works
- also for (certain)
- Nuclei:

d, ^{6}Li, ^{213}Fr, . .

For muons exploit decay asymmetry

- One could use β-decay
- In general: any sensitive polarimeter works



One needs for a successful experiment:

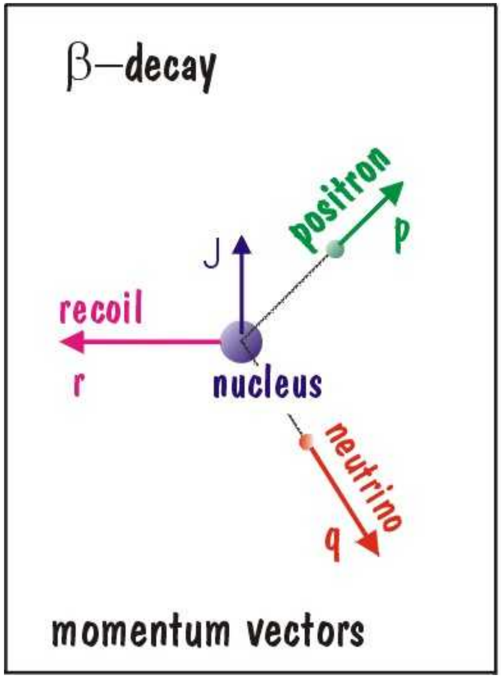
- polarized, fast beam
- magnetic storage ring
- polarimeter

Some Candidate Nuclei

Nucleus	Spin J	μ/μ_N	Reduced Anomaly a	$T_{1/2}$
$^{139}_{57}La$	7/2	+2.789	-0.0305	
$^{123}_{51}Sb$	7/2	2.550	-0.1215	
$^{137}_{55}Cs$	7/2	+2.8413	0.0119	30y
$^{223}_{87}Fr$	3/2	+1.17	<0.02	22 min
$^{6}_{3}Li$	1	+0.8220	-0.1779	
$^{2}_{1}H$	1	+0.8574	-0.1426	
$^{75}_{32}Ge$	1/2	+0.510	+0.195	82.8 m
$^{157}_{69}Tm$	1/2	+0.476	0.083	3.6 m

Time Reversal Violation in β-decay: Correlation measurements

$$\frac{d^2W}{d\Omega_e d\Omega_\nu} \sim 1 + a\frac{\mathbf{p}\cdot\hat{\mathbf{q}}}{E} + b\Gamma\frac{m_e}{E} + \langle \mathbf{J}\rangle\cdot\left[A\frac{\mathbf{p}}{E} + B\,\hat{\mathbf{q}} + D\frac{\mathbf{p}\times\hat{\mathbf{q}}}{E}\right] + \langle \boldsymbol{\sigma}\rangle\cdot\left[G\frac{\mathbf{p}}{E} + Q\langle \mathbf{J}\rangle + R\langle \mathbf{J}\rangle\times\frac{\mathbf{p}}{E}\right]$$



R and ***D*** test both **T**ime **R**eversal **V**iolation

- ***D*** → most potential
- ***R*** → scalar and tensor (EDM, *a*)
- technique *D* measurements yield *a*, *A*, *b*, *B*

$$\langle \vec{J}\cdot\vec{p}\times\vec{q}\rangle \neq 0 \;\; ?$$

Discrete Symmetries

- Parity
  - Parity Nonconservation in Atoms
  - Nuclear Anapole Moments
  - Parity Violation in Electron-Scattering
- Time Reversal and CP-Violation
  - Electric Dipole Moments
  - R and D Coefficients in β-Decay
- **CPT Invariance**

CPT – Violation
Lorentz Invariance Violation

What is best CPT test ?

often quoted:

- K^0- $\overline{K^0}$ mass difference (10^{-18})
- e^- - e^+ g- factors ($2 * 10^{-12}$)
- **We need an interaction with a finite strength !**

New Ansatz (Kostelecky)

- K^0 $\approx 10^{-18}$ GeV/c^2
- n $\approx 10^{-30}$ GeV/c^2
- p $\approx 10^{-24}$ GeV/c^2
- e $\approx 10^{-27}$ GeV/c^2
- μ $\approx 10^{-23}$ GeV/c^2
- Future: Anti hydrogen $\approx 10^{-18}$ GeV/c^2

CPT tests

$$r_K = \frac{|m_{K^0} - m_{\overline{K}^0}|}{m_{K^0}} \leq 10^{-18}$$

$$r_e = \frac{|g_{e^-} - g_{e^+}|}{g_{avg}} = 1.2 \cdot 10^{-3} \cdot \frac{|a_{e^-} - a_{e^+}|}{a_{avg}} \leq 2 \cdot 10^{-12}$$

? Are they comparable- Which one is appropriate ?

$\Rightarrow$ Use common ground, e.g. energies

generic CPT and Lorentz violating DIRAC equation

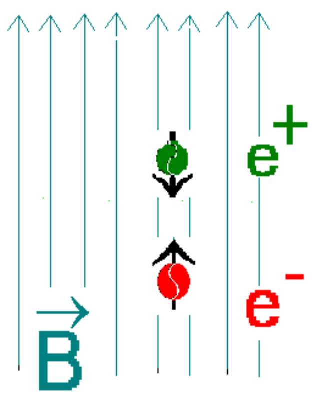
$$(i\gamma^\mu D_\mu - m - a_\mu\gamma^\mu - b_\mu\gamma_5\gamma^\mu - \frac{1}{2}H_{\mu\nu}\sigma^{\mu\nu} + ic_{\mu\nu}\gamma^\mu D^\nu + id_{\mu\nu}\gamma_5\gamma^\mu D^\nu)\psi = 0$$

$$iD_\mu \equiv i\partial_\mu - qA_\mu$$

a_μ, b_μ break CPT

$a_\mu, b_\mu, c_{\mu\nu}, d_{\mu\nu}, H_{\mu\nu}$ break Lorentz Invariance

Leptons in External Magnetic Field



$$\Delta\omega_a = \omega_a^{l^-} - \omega_a^{l^+} \approx -4b_3^l$$

$$r_l = \frac{|E^{l^-}_{spin\ up} - E^{l^+}_{spin\ down}|}{E^{l^-}_{spin\ up}} \approx \frac{\hbar\Delta\omega_a}{m_l c^2}$$

Bluhm , Kostelecky, Russell, Phys Rev. D **57**,3932 (1998)

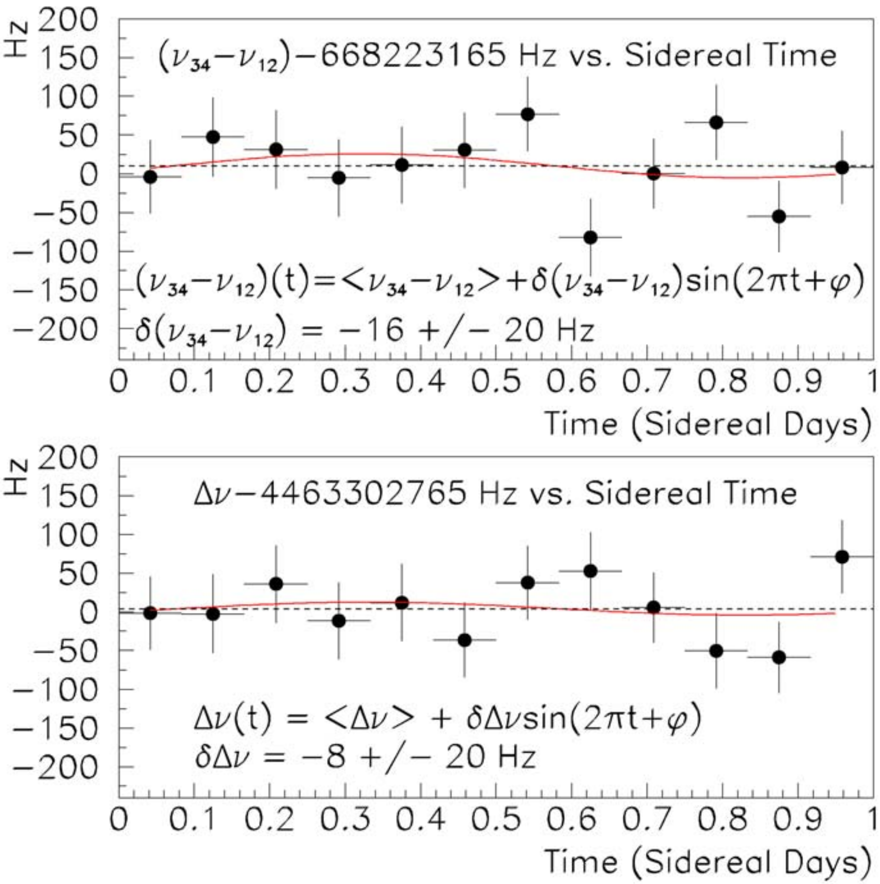
For g-2 Experiments :

$$r_l = \frac{\hbar\omega_c}{m_l c^2} \cdot \frac{|a_{l^-} - a_{l^+}|}{a_{avg}}$$

Dehmelt, Mittleman, Van Dyck, Schwinberg, hep-ph/9906262

$\Rightarrow$ *electron* $r_e \leq 1.2 \cdot 10^{-21}$ *muon* $r_\mu \leq 3.5 \cdot 10^{-24}$

CPT and Lorentz Invariance from Muon Experiments



V.W. Hughes et al., Phys.Rev. Lett. 87, 111804 (2001)

Muonium:

new interaction below

$2 * 10^{-23}$ GeV

Muon g-2:

new interaction below

$4 * 10^{-22}$ GeV (CERN)

15 times better expected from BNL when analysis will be completed

Properties of Known Basic Interactions

- **Electromagnetism and Fundamental Constants**
  - QED, Lamb Shift
  - Muonium and Muon g-2
  - Muonic Hydrogen and Proton Radius
  - Exotic Atoms
  - Does α_{QED} vary with time?

- **QCD**
  - Strong Interaction Shift
  - Scattering Lengths

- **Gravity**
  - Hints of strings/Membranes?

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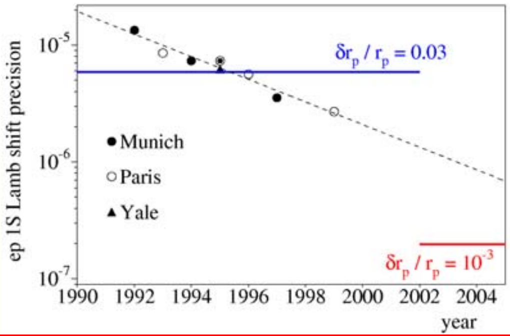
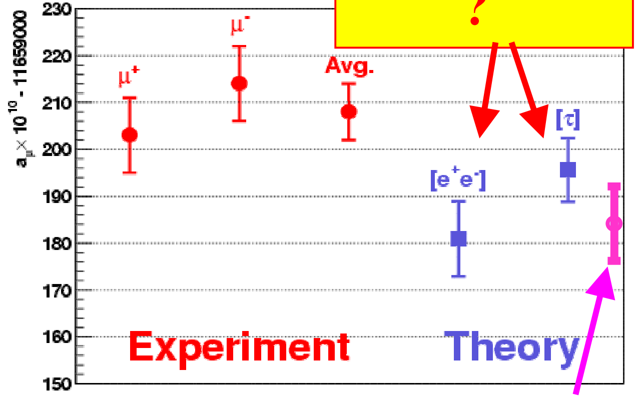
Properties of known Basic Interactions

"Proton Radius"



Muonic Hydrogen Lamb Shift

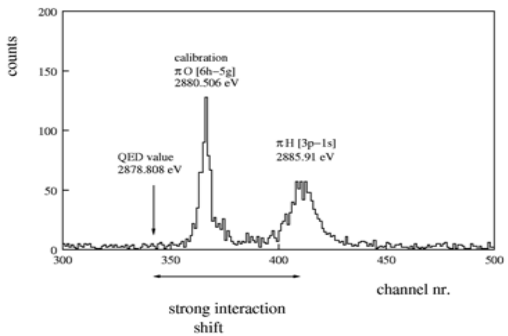
Muon g-2



ρ^0, ρ^+ mass difference overlooked ?

Newest Theory Offer:
2.4 σ from Experiment

Strong Interaction Shift



Pionic Hydrogen

Search for New Physics

What are the hardronic corrections?

- $e^+ + e^- \rightarrow$ hadrons
- $e^+ + e^- \rightarrow \gamma$ + hadrons

New activities Planned

- statistics limited experiment
- J-PARC, BNL
- Fundamental constants needed
- Muonium

Properties of Known Basic Interactions

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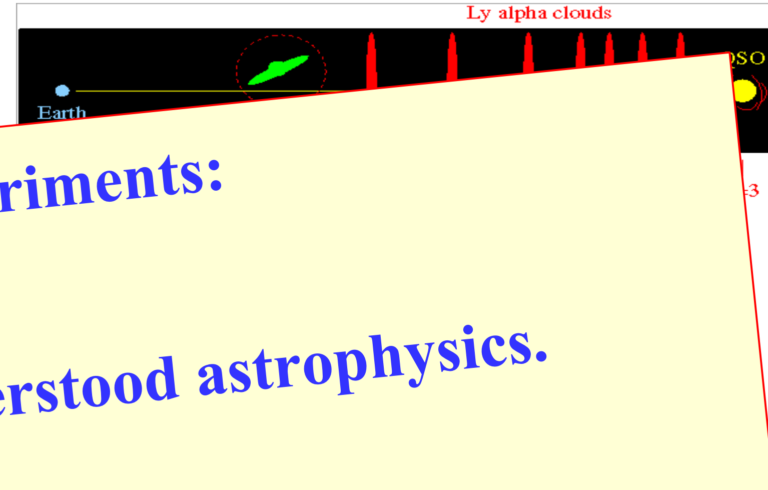
Time Variation of α



Idea (Webb, Flambaum et al.):

Relativistic Corrections to atomic level en…

$\Delta E \propto Z$ …

- **New Atomic Physics laboratory experiments:**

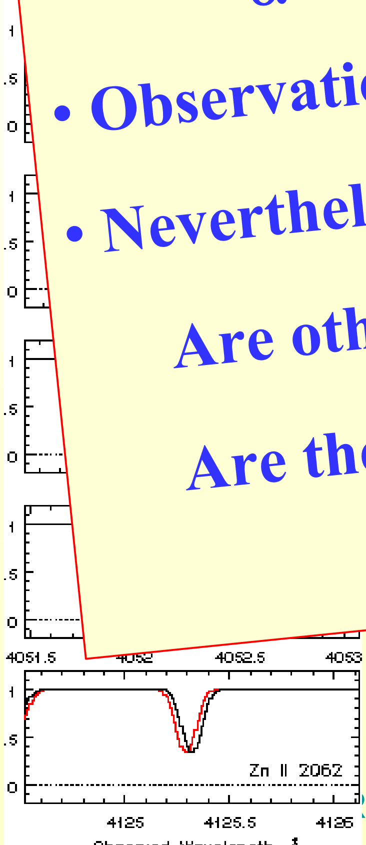
  α 'stable' at this level

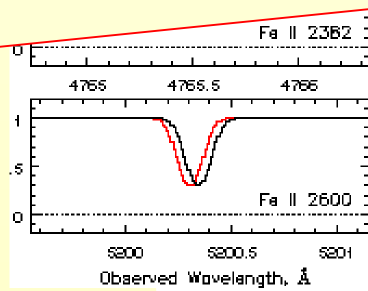
- **Observation may be due to not understood astrophysics.**

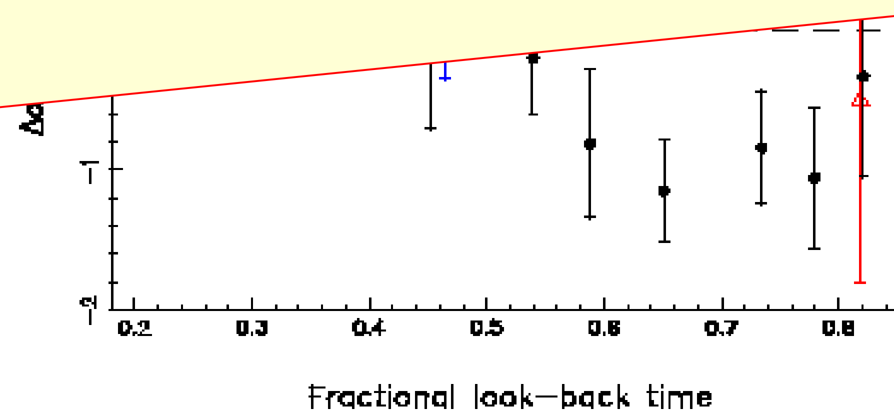
- **Nevertheless:**

  Are other Constants and Ratios of Constants stable in time?

  Are the parameters of fundamental fermion families stable ?







Properties of Known Basic Interactions

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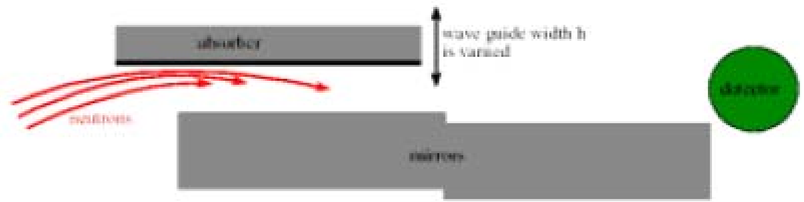
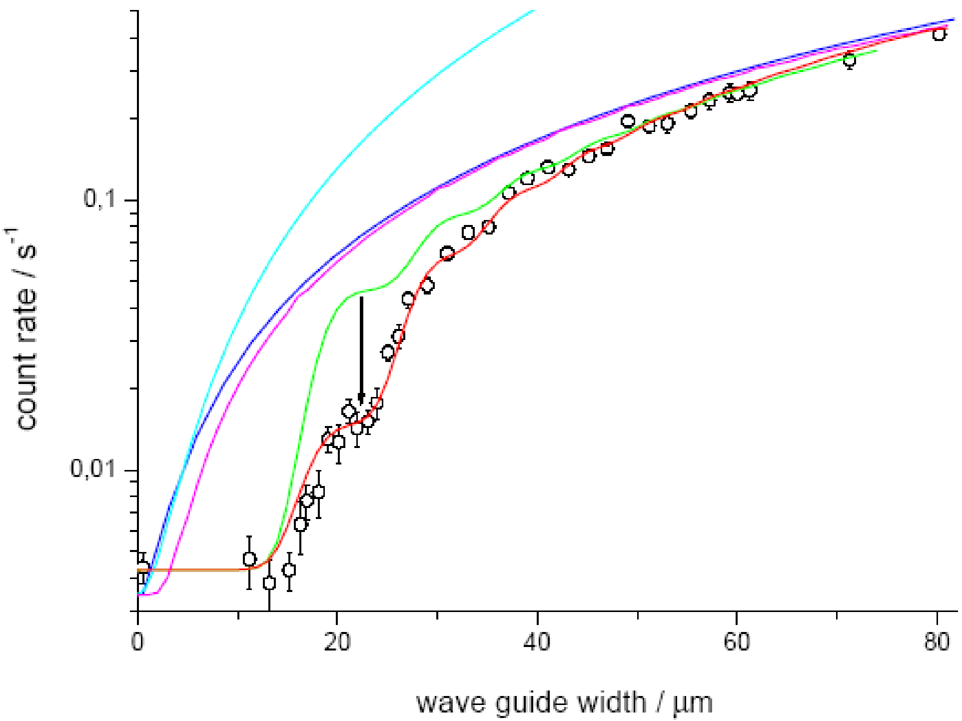
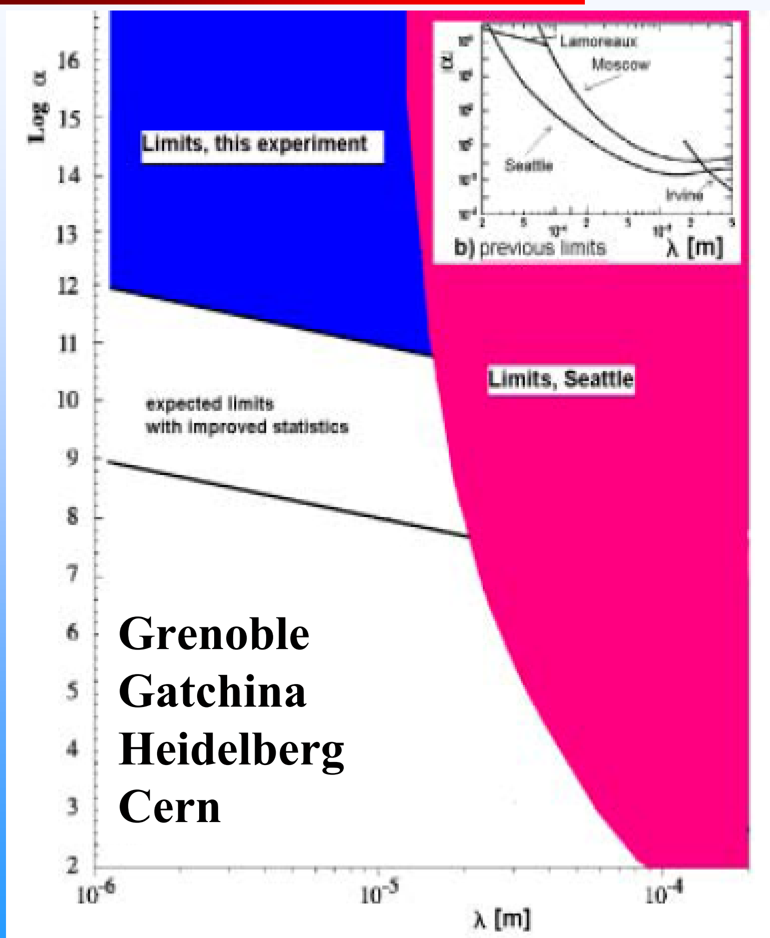
Standing Waves of Ultra Cold Neutrons in a gravitational field





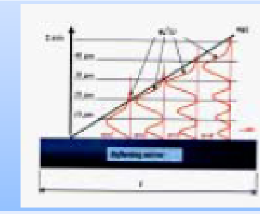
Standing Waves of Ultra Cold Neutrons

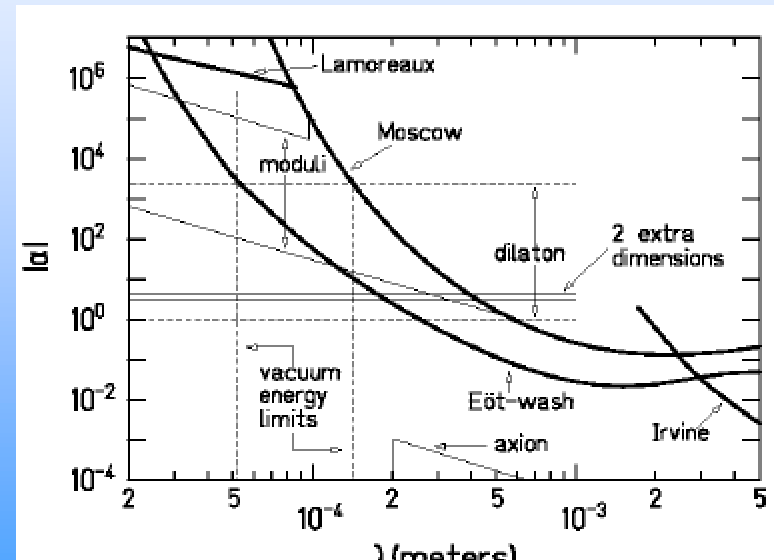


Grenoble
Gatchina
Heidelberg
Cern

Non Newtonian Gravity

$$g\prime(z,\lambda) = 2\pi \cdot \rho\alpha\lambda G \cdot e^{-|z|/\lambda}$$





Best Test 1 to 5 μm

Recommendations

Physics Topics	High power Proton Driver ~ 1GeV	High power Proton Driver ~ 30 GeV
The Nature of Neutrinos		
– Oscillations / Masses / $0\nu2\beta$-decay	⊗	⊗
T and CP Violation		
– edm's, D (R) coeff. in β-decays, D^0	⊗	⊗
Rare and Forbidden Decays		
– $0\nu2\beta$-decay, $n\text{-}n^{bar}$, $M\text{-}M^{bar}$, $\mu\rightarrow e\gamma$,	⊗	
– $\mu \rightarrow 3e$, $\mu N\rightarrow N e$	⊗	
Correlations in β-decay		
– non V-A in β-decay	⊗	
Unitarity of CKM-Matrix		
– n-, π-β, (superallowed β), K-decays	⊗	⊗
Parity Nonconservation in Atoms	-	-
– Cs, Fr, Ra, Ba^+, Ra^+		
CPT Conservation		
– n, e, p, μ	⊗	⊗
Precision Studies within The Standard Model		
– Constants, QCD, QED, Nuclear Structure	⊗	⊗

Conclusion
Particle Physics –Nuclear Physics ?

- Gregory Breit,

  when asked at Yale whether a new colleague should be an atomic theorist, a nuclear theorist, an astro-physcist or work in the then new field of particle physics:

  > There are only Good Theorists and bad ones <

- Accordingly:

  It‘s time to build jointly a powerful machine to serve Good Physics. A Multi-Megawatt Proton Driver has a very Large Potential to serve Good Physics, particularly in the merging fields of nuclear, particle and astro-physics.

Thank YOU !

SPARES

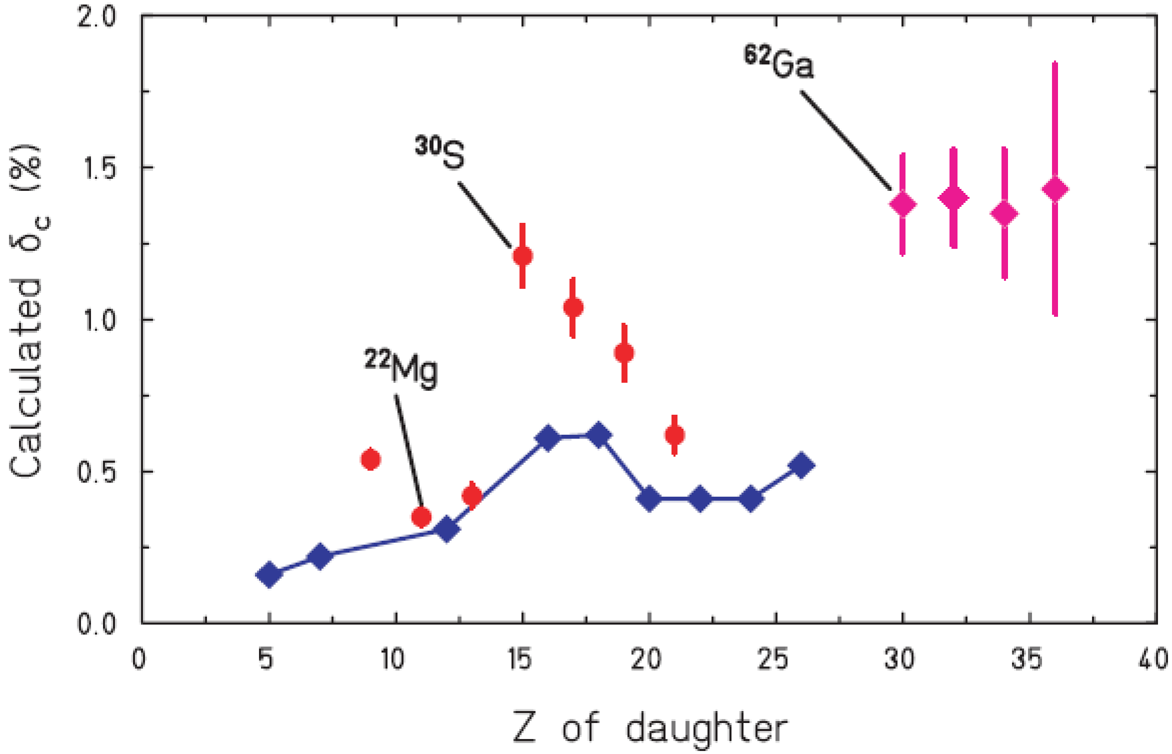
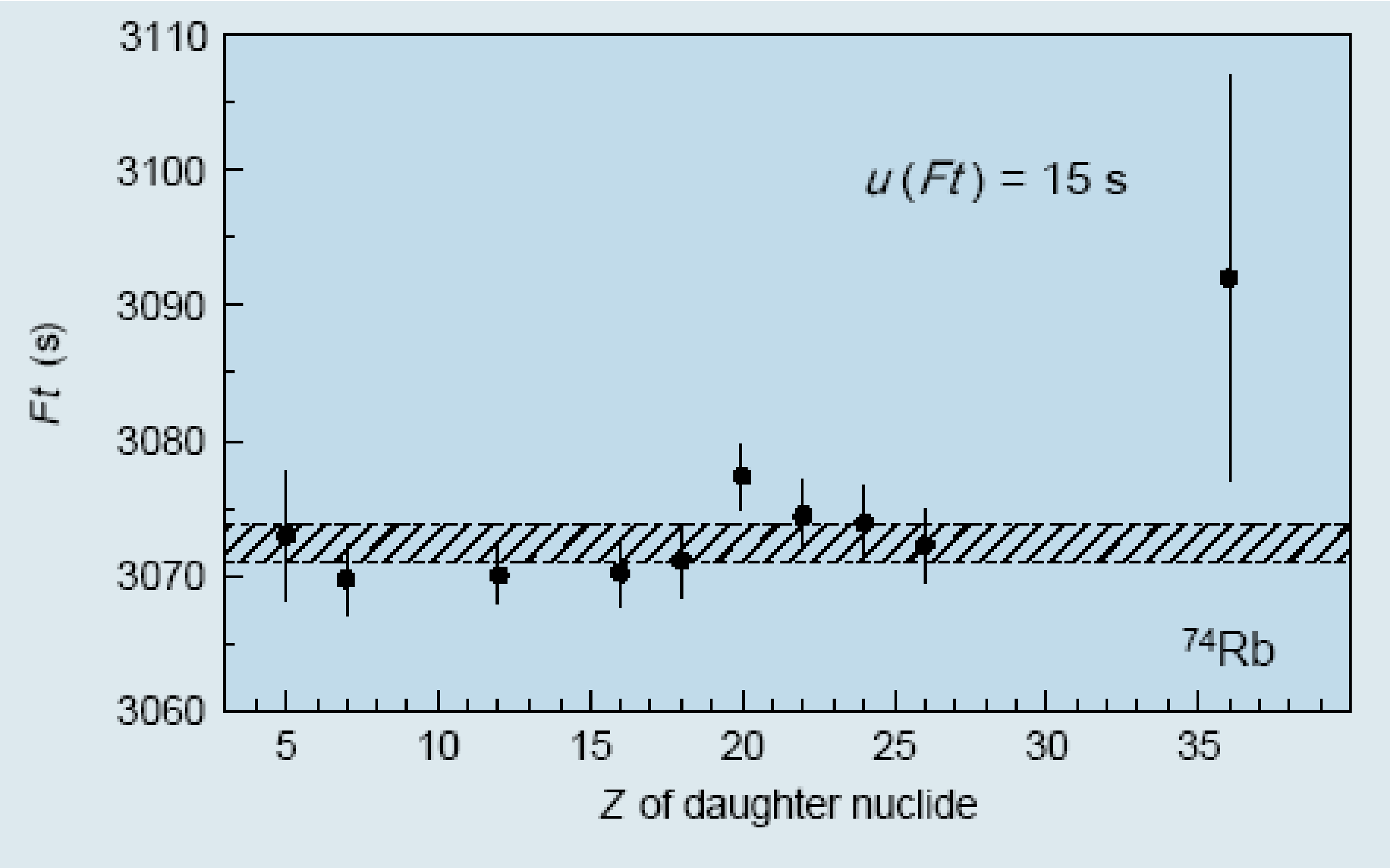
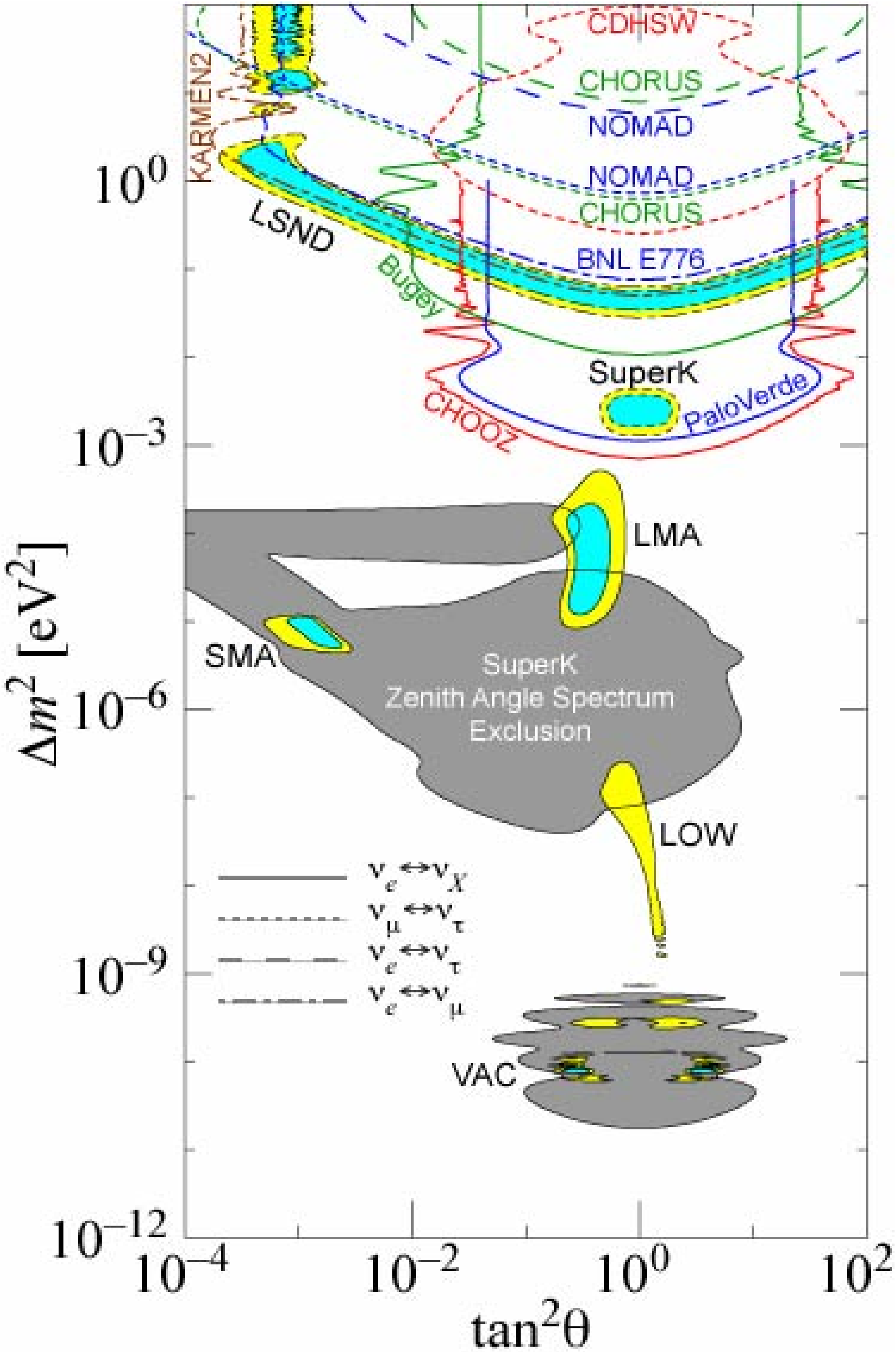
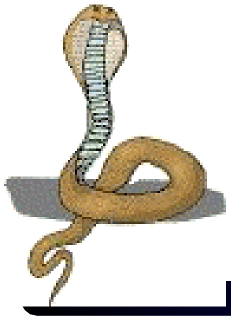


Fig. 43: Calculated Coulomb corrections as a function of the atomic number of the daughter nucleus. The blue diamonds correspond to the nine best known super-allowed transitions. The red dots present the corrections for the $T_z = -1$ emitters between ^{18}Ne and ^{42}Ti. The pink diamonds are the corrections for the $T_z = 0$ transitions from ^{62}Ga to ^{74}Rb [215].


3110
3100
3090
3080
3070
3060
Ft (s)
u (Ft) = 15 s
74Rb
5
10
15
20
25
30
35
Z of daughter nuclide


CDHSW
CHORUS
NOMAD
NOMAD
CHORUS
BNL E776
KARMEN2
LSND
Bugey
SuperK
CHOOZ
PaloVerde
LMA
SMA
SuperK
Zenith Angle Spectrum
Exclusion
LOW
VAC
$\nu_e \leftrightarrow \nu_X$
$\nu_\mu \leftrightarrow \nu_\tau$
$\nu_e \leftrightarrow \nu_\tau$
$\nu_e \leftrightarrow \nu_\mu$
10^0
10^{-3}
10^{-6}
10^{-9}
10^{-12}
Δm^2 [eV^2]
10^{-4}
10^{-2}
10^0
10^2
$\tan^2\theta$

K. Zuber, Univ. of Oxford



Cobra - The idea

K. Zuber, Phys. Lett. B 519,1 (2001)

Use large amount of CdTe (CdZnTe)
Semiconductor Detectors

Many approaches to neutrinoless double β-decay

Are there attempts to collaborate and concentrate ?

Detector array

10 kg CdTe (upgrade easily possible)

7 isotopes (especially 116Cd and 130Te)

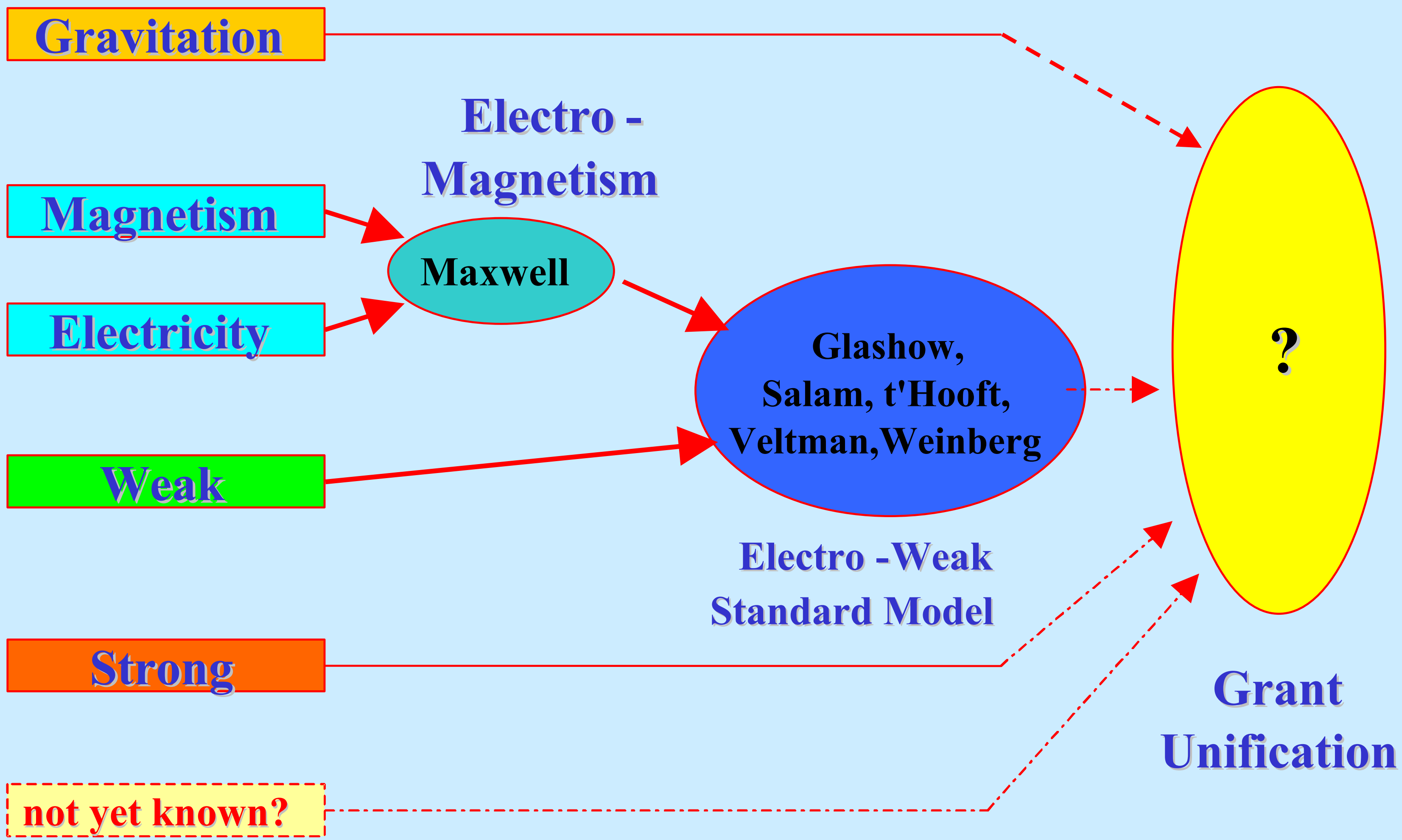
Mass limits for both below 1 eV

Study of double electron capture modes

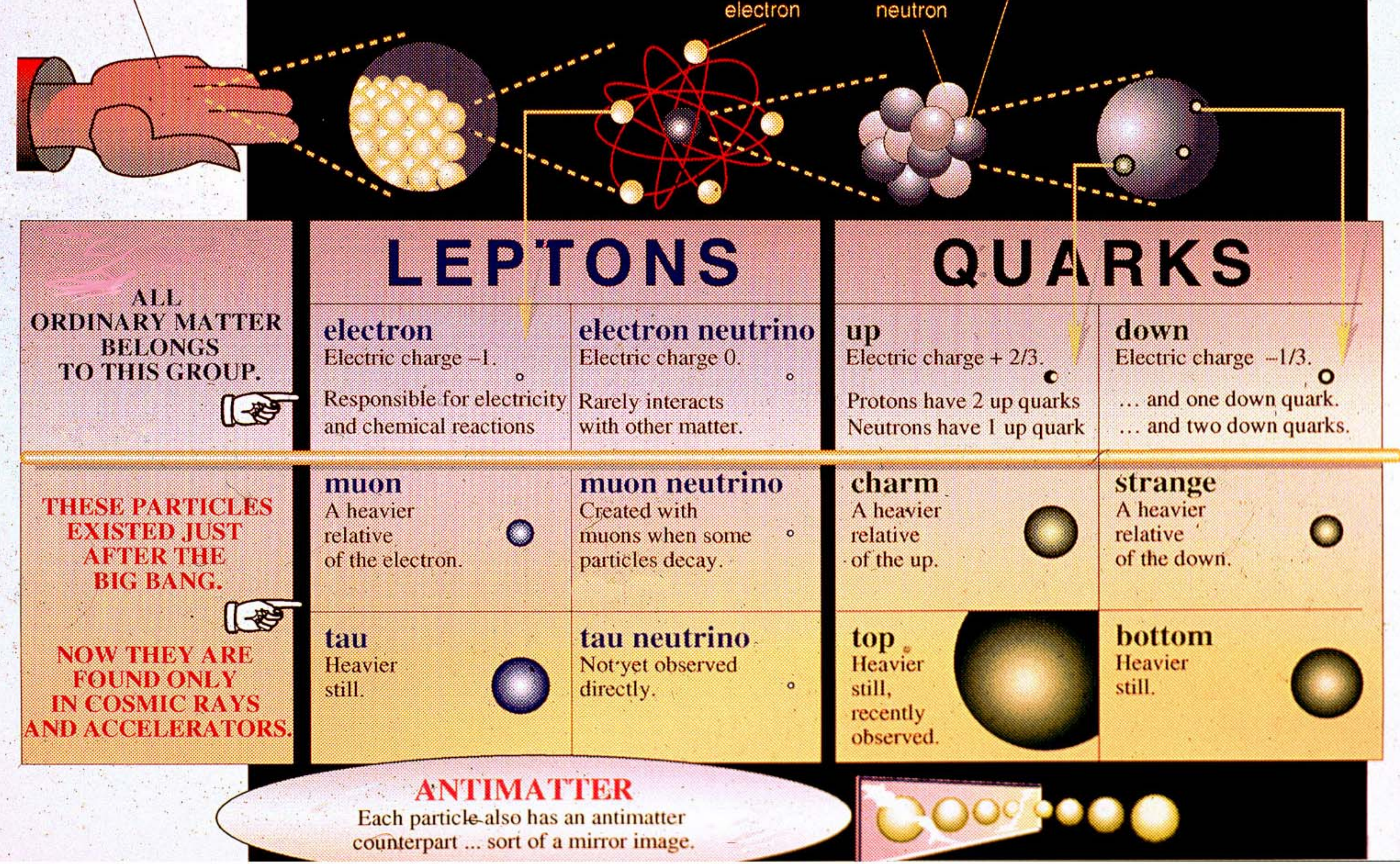
Future option: Pixel CdTe (Tracking)
Isotopical enrichment

First results: nucl-ex/0301007

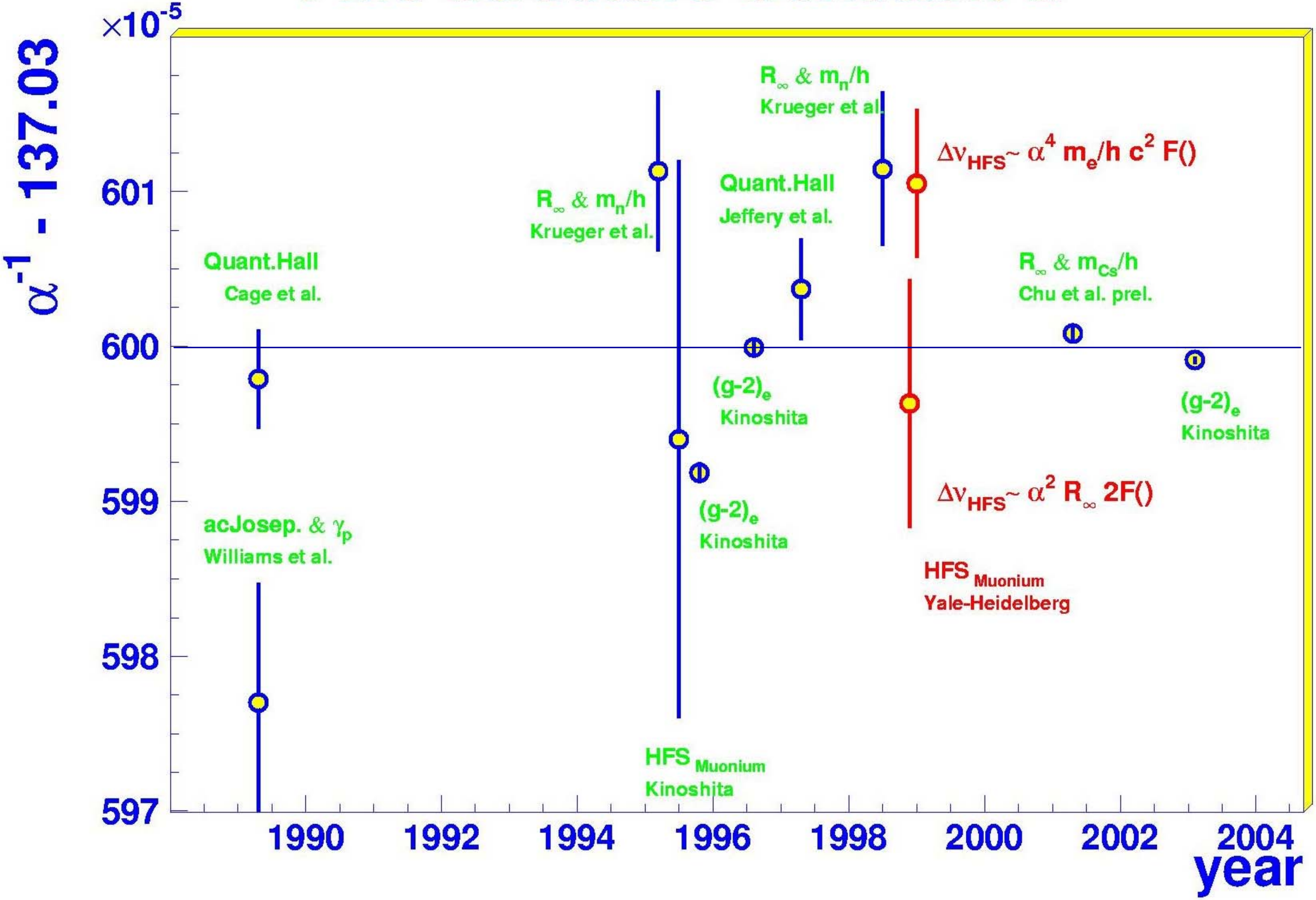
Fundamental Interactions – Standard Model



Physics within the Standard Model --- Searches for New Physics


electron
neutron
LEPTONS
QUARKS
ALL ORDINARY MATTER BELONGS TO THIS GROUP.
electron
Electric charge –1.
Responsible for electricity and chemical reactions
electron neutrino
Electric charge 0.
Rarely interacts with other matter.
up
Electric charge + 2/3.
Protons have 2 up quarks
Neutrons have 1 up quark
down
Electric charge –1/3.
… and one down quark.
… and two down quarks.
THESE PARTICLES EXISTED JUST AFTER THE BIG BANG.
NOW THEY ARE FOUND ONLY IN COSMIC RAYS AND ACCELERATORS.
muon
A heavier relative of the electron.
muon neutrino
Created with muons when some particles decay.
charm
A heavier relative of the up.
strange
A heavier relative of the down.
tau
Heavier still.
tau neutrino
Not yet observed directly.
top
Heavier still, recently observed.
bottom
Heavier still.
ANTIMATTER
Each particle also has an antimatter counterpart ... sort of a mirror image.

Fine Structure Constant α



K. Jungmann, 11-2003

Sensitivity

$$d_N = \eta \cdot 5 \cdot 10^{-15}\,ecm$$

$$\rightsquigarrow\; d_N = 10^{-24}\,ecm \;\hat{=}\; \eta = 2 \cdot 10^{-10}$$

Error in η:

$$\sigma_\eta = \frac{1}{\gamma \cdot \tau_i \cdot P_{beam} \cdot A_{detector} \cdot \frac{v}{c} \cdot \mu_K \cdot B \cdot \sqrt{2 \cdot N_N}}$$

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \approx 1.5$$

$$\tau_i = 1\,sec$$

$$P_{beam} \approx 0.5$$

$$A_{detector} \approx 0.1$$

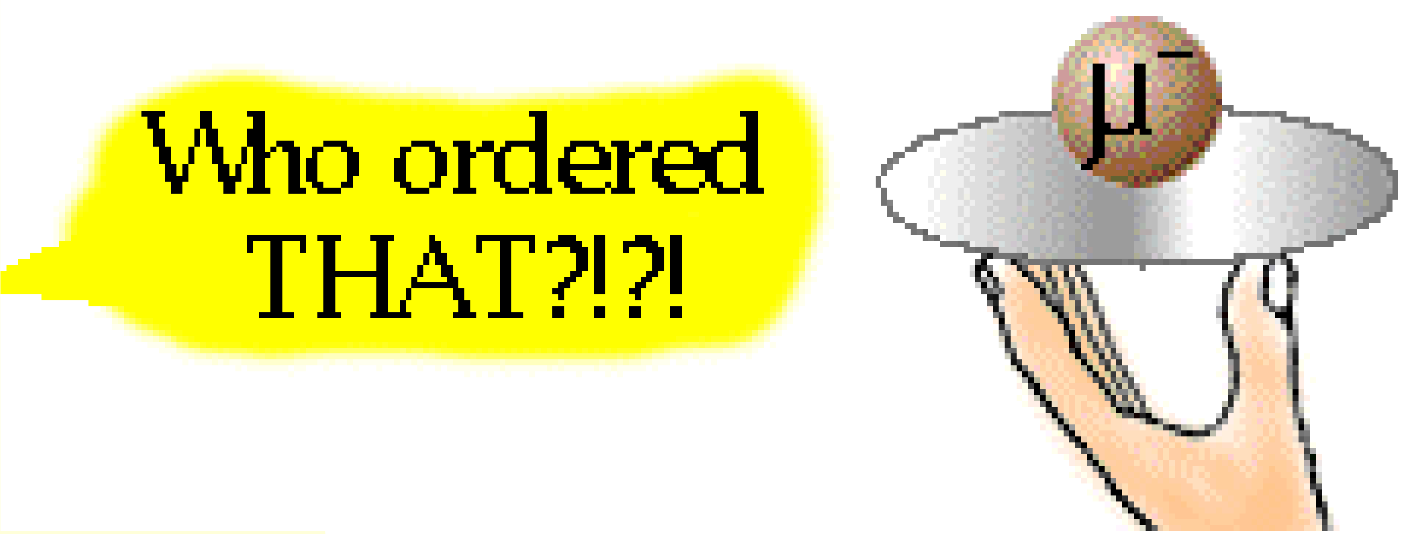
$$\frac{v}{c} = 75\%$$

$$B = 1\,T$$

$$\mu_K = 7.66\,\frac{MHz}{T}$$

$$\Rightarrow \sigma_\eta = \frac{1.65}{\sqrt{N_N}} \cdot 10^{-5}$$

Need ~10^{10} observed Nuclei to compete with neutron EDM


Who ordered
THAT?!?!
μ⁻