What if?

or

On the interplay between Serendipity, Intuition and Conjecture.

Benjamin Grinstein

FPCP 2010

May 29

Torino, Italy

Wilczek's Litany

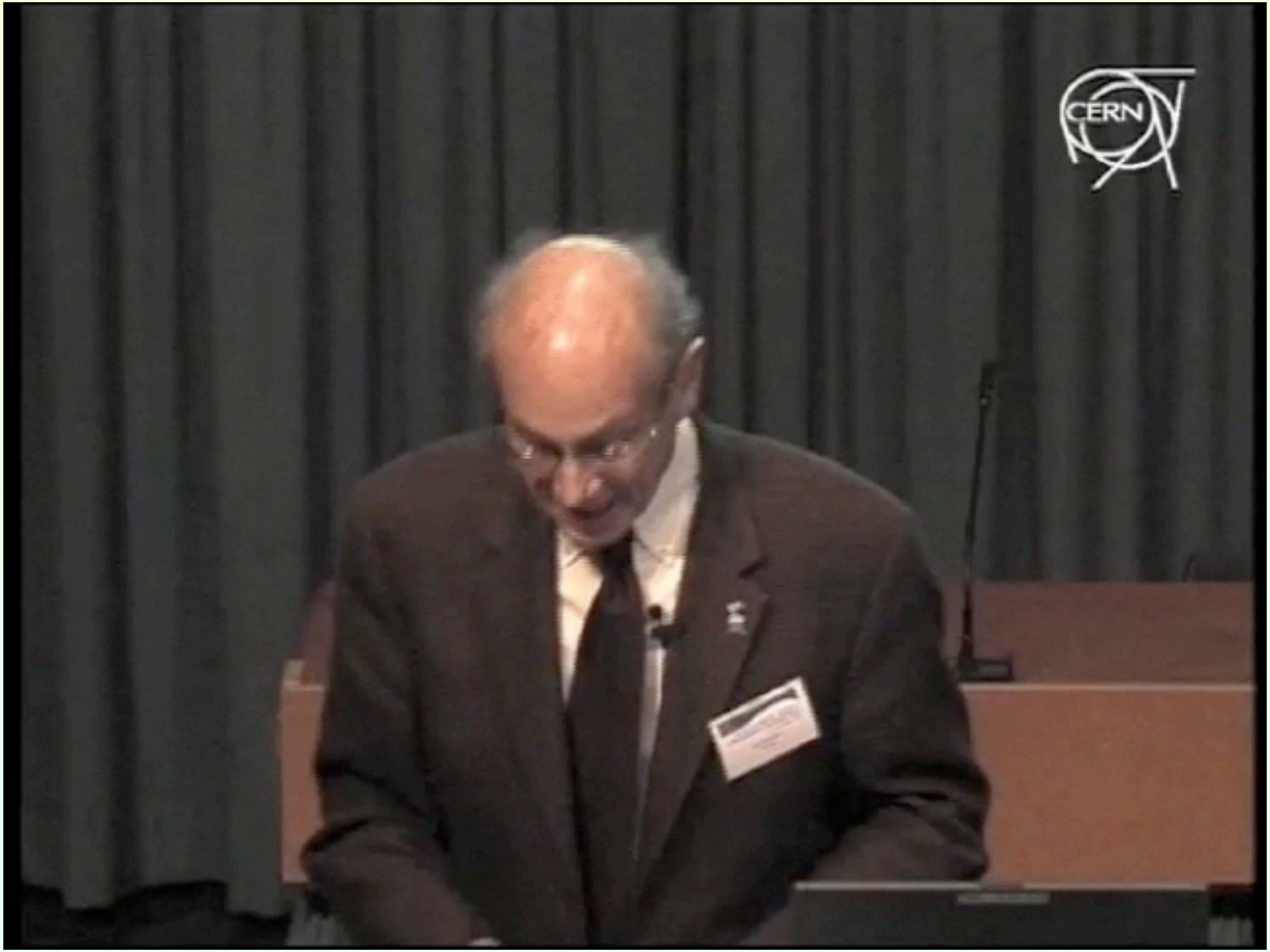
arXiv:1003.4672v1 {hep-ph}

Particle Physics Today:

- The SM is in great shape
- FP & CP is well described by CKM

Shortcomings of the SM

- Why these groups and representations (specially hypercharge?)
- Existence of small non-zero neutrino masses, appears gratuitous
- Gravity
- Dark matter? Dark Energy?
- Why is θ so small?
- Flavor ...



The Discovery of CP Violation: a Surprise -- Prof. Jim Cronin
From the Proton Synchroton to the Large Hadron Collider - 50 Years of Nobel Memories in High-Energy Physics, CERN 2009

A Little History: the Origins of FP&CP

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湯川 秀樹 (Yukawa Hideki)

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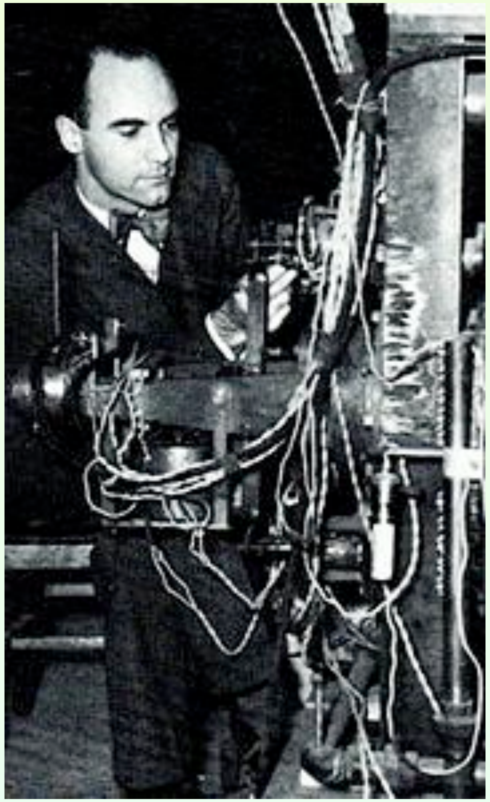

Carl David Anderson

The *mesotron*

(1936)

became

the *mu-meson*

(1947)

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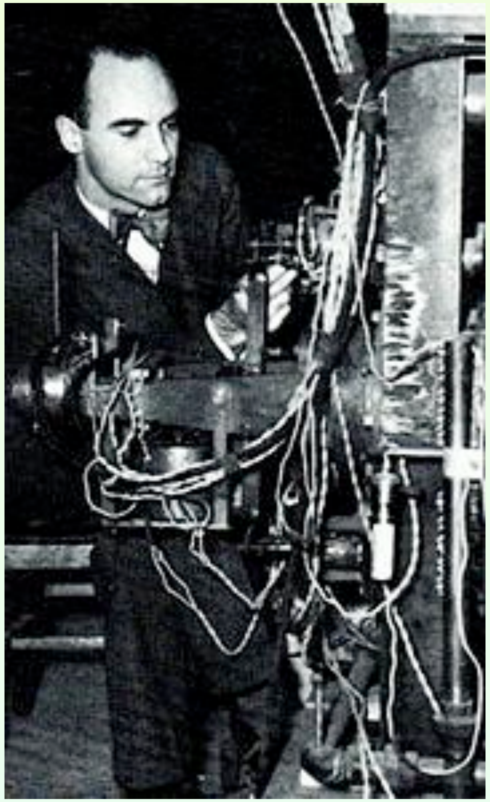

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Who ordered that?

- I.I. Rabi

湯川 秀樹 (Yukawa Hideki)

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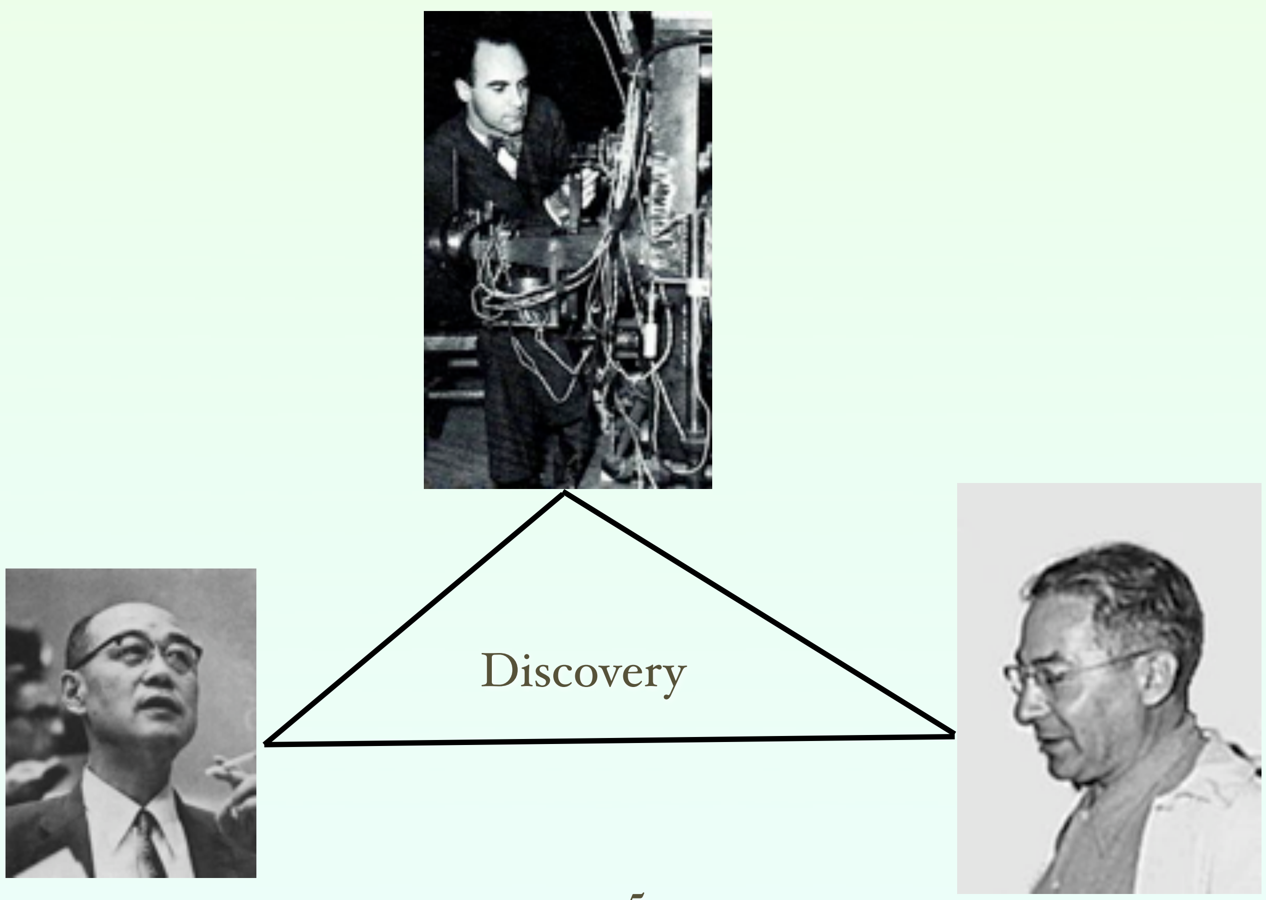
A theoretical idea (right or wrong) can motivate a good experiment.

Intuition needed to follow the right path.

Luck cannot hurt.



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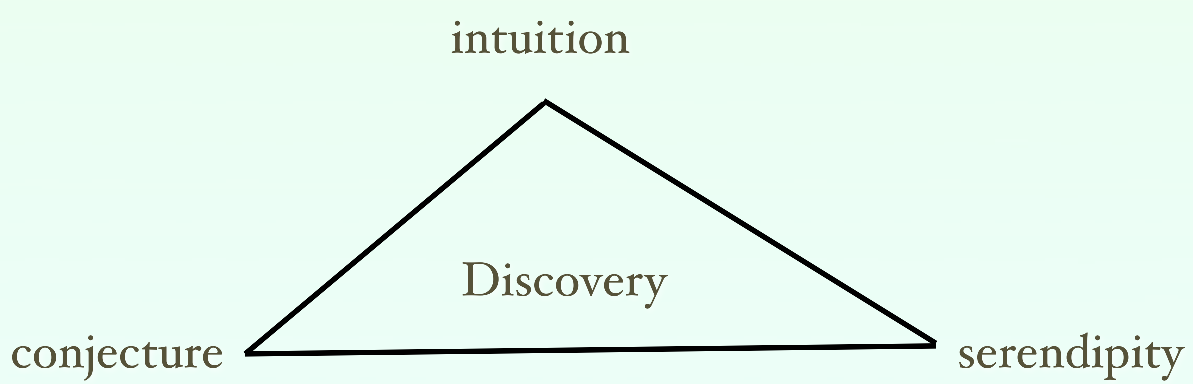

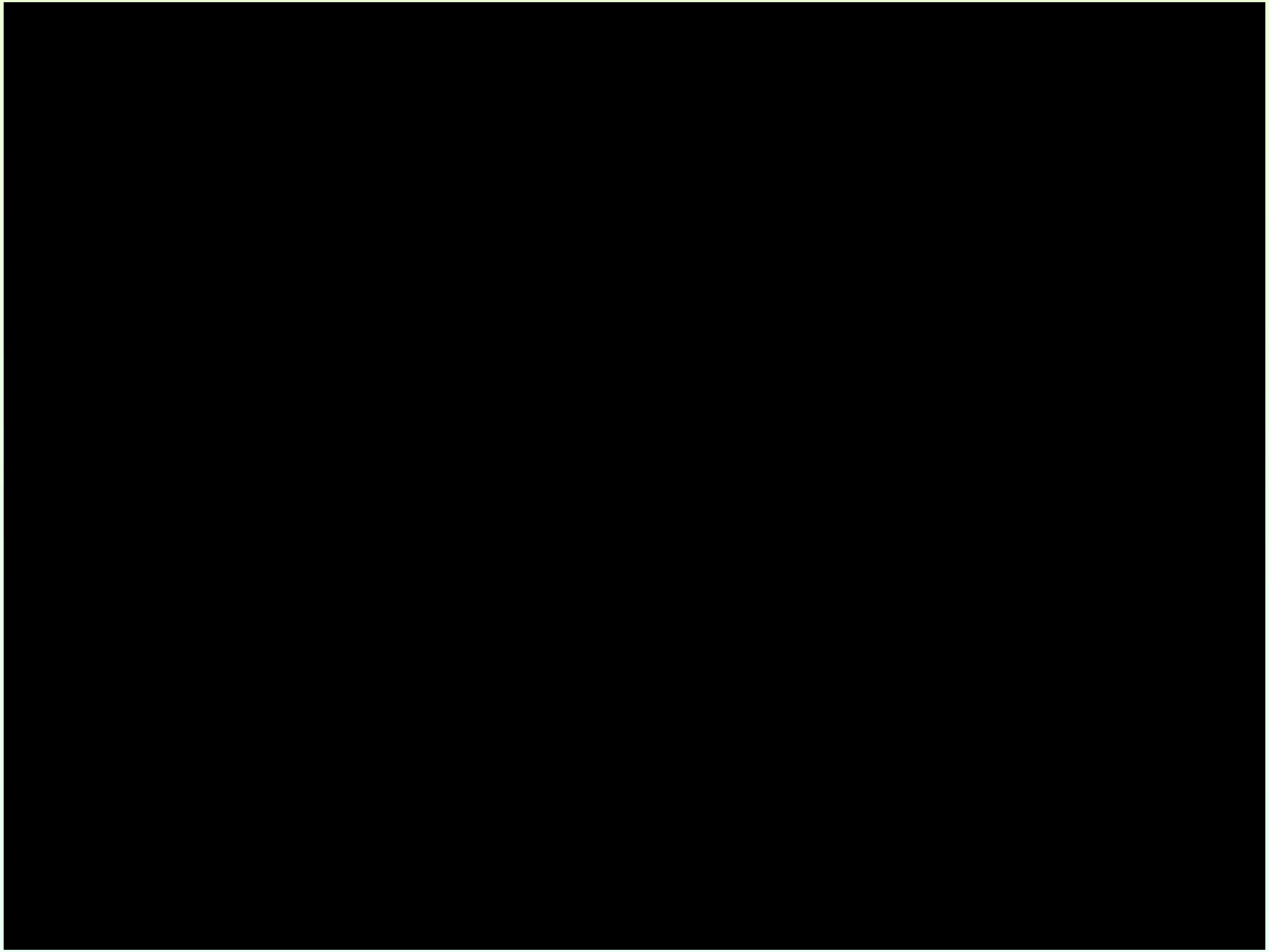

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So I propose to you to take a sampling of non-mainstream (aka “crazy”) ideas

Some have well motivated theory

Some don’t

The only criterion is that confirmation of any would result in a

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Paradigm Shift

Paradigm shift (or **revolutionary science**) is the term first coined by Thomas Kuhn in his influential book *The Structure of Scientific Revolutions* (1962) to describe a change in basic assumptions within the ruling theory of science. It is in contrast to his idea of *normal science*.

The term *paradigm shift*, as a change in a fundamental model of events, has since become widely applied to many other realms of human experience as well, even though Kuhn himself restricted the use of the term to the hard sciences.

Non-paradigm shifts

- Supersymmetry, flavons, technicolor, unphysics, Little Higgs, ...
  - Basic principles remain intact
  - Sure, they require additional fields and interactions
  - Sure, would be exciting and interesting

- Extra-dimensions
  - If generalized duality is general, cannot distinguish form above

Violation of CPT and/or QM

L. Maiani, in the DAΦNE Physics Handbook, Vol. I
S. Ellis et al, PLB293(1992)142 ("EHNS")
P. Huet & M.E. Peskin, NPB434(1995)3

- Local, hermitian QFT implies CPT
  - Theories of Quantum Gravity (strings, loop QG) are non-local
  - Black Holes cannot carry discrete "charge"

- QM implies pure states do not evolve into mixed states
  - Because of Black Holes information loss Hawking proposed a generalization of QM which allows pure to mix evolution
  - Page showed this leads to CPT violation
  - Weinberg's "testing QM:" non-associative matrix QM

S.W. Hawking, PRD 14 (1975) 2460
D.N. Page, Gen. Rel. Grav. 14 (1982)
S.Weinberg, PRL62 (1989) 485;
Annals Phys.194:336,1989.

- Eberhard: test existence of unitary S-matrix
  - Phenomenological analysis of QM violation
  - Tests in neutral K's by Carither's *et al*

P. H. Eberhard, CERN 72-1, unpub
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expected size of parameters: $\frac{m_K^2}{M_{Pl}} \sim 10^{-19}\ \mathrm{GeV}$

$$|K_S\rangle \propto (1+\epsilon_S)|K^0\rangle + (1-\epsilon_S)|\bar{K}^0\rangle \qquad \epsilon_S = \epsilon + \Delta \quad m_S - \tfrac{i}{2}\Gamma_S = \bar{m} - \tfrac{i}{2}\bar{\Gamma} - d$$

$$|K_L\rangle \propto (1+\epsilon_L)|K^0\rangle + (1-\epsilon_L)|\bar{K}^0\rangle \qquad \epsilon_L = \epsilon - \Delta \quad m_L - \tfrac{i}{2}\Gamma_L = \bar{m} - \tfrac{i}{2}\bar{\Gamma} + d$$

$$d = \Delta m - \tfrac{i}{2}\Delta\Gamma$$

Define, as usual:

$$R_{+-}(\tau) = \frac{N(K(\tau)\to\pi^+\pi^-)}{N(K(\tau=0)\to\pi^+\pi^-)}$$

$$\delta(\tau) = \frac{N(K(\tau)\to\pi^-\ell^+\nu) - N(K(\tau)\to\pi^+\ell^-\bar{\nu})}{N(K(\tau)\to\pi^-\ell^+\nu) + N(K(\tau)\to\pi^+\ell^-\bar{\nu})}$$

Then:

$$\delta(\tau) = \frac{2\cos(\Delta m\tau)e^{-(\bar{\Gamma}+\alpha-\gamma)\tau} + 2\mathrm{Re}\,\epsilon_S^- e^{-\Gamma_S\tau} + 2\mathrm{Re}\,\epsilon_L^+ e^{-\Gamma_L\tau}}{e^{-\Gamma_S\tau} + e^{-\Gamma_L\tau}}$$

$$R_{+-}(\tau) = e^{-\Gamma_S\tau} + R_L e^{-\Gamma_L\tau} + 2|\bar{\eta}_{+-}|\cos(\Delta m\,\tau + \phi_{+-})e^{-(\bar{\Gamma}+\alpha-\gamma)\tau}$$

For pure K_L beam

$$\delta_L = 2\mathrm{Re}\,\epsilon_L^+$$

$$R_L = |\epsilon_L^-|^2 + \frac{\gamma}{\Delta\Gamma} + 4\frac{\beta}{\Delta\Gamma}\,\mathrm{Im}\left(\frac{\epsilon_L^- d}{d^*}\right)$$

where

$$\epsilon_{L,S}^{\pm} = \epsilon_{L,S} \pm \frac{\beta}{d}$$

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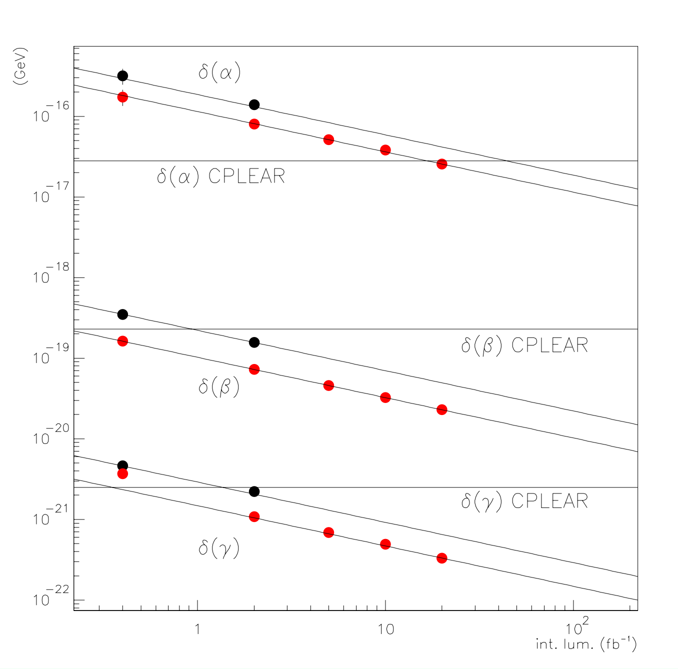
I apologize for the plot being so dim, I do not know how to fix it.



KLOE reach, with and without the insertion of an inner tracker with vertex resolution of 0.25 τ_S (to be compared with the present KLOE vertex resolution, 0.9 τ_S).

Venanzoni, arXiv:1001.3591v1 [hep-ex]
CPLEAR, Phys. Reports 374 (2003) 165

Violations to Lorentz Invariance

D. Mattingly, Living Rev.Rel.**8**(2005)5

SME (QED part): $\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} - \frac{1}{4}(k_F)_{\mu\nu\lambda\sigma}F^{\mu\nu}F^{\lambda\sigma}$

same as anisotropic medium:

V. A. Kostelecky & M. Mewes, PRD66(2002)056005

$$\begin{pmatrix}\vec{D}\\ \vec{H}\end{pmatrix} = \begin{pmatrix}1+\kappa_{DE} & \kappa_{DB}\\ \kappa_{HE} & 1+\kappa_{HB}\end{pmatrix}\begin{pmatrix}\vec{E}\\ \vec{B}\end{pmatrix}$$

$$(\kappa_{DE})^{jk} = -2(k_F)^{0j0k},$$

$$(\kappa_{HB})^{jk} = \frac{1}{2}\epsilon^{jpq}\epsilon^{krs}(k_F)^{pqrs}, \quad (\kappa_{DB})^{jk} = -(\kappa_{HE})^{kj} = (k_F)^{0jpq}\epsilon^{kpq}.$$

Define

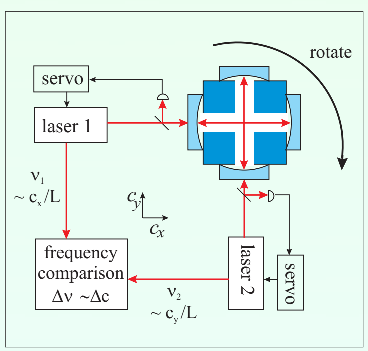
$$(\tilde{\kappa}_{e-})^{jk} = \frac{1}{2}(\kappa_{DE} - \kappa_{HB})^{jk} - \frac{1}{3}\delta^{jk}(\kappa_{DE})^{ll},$$

$$(\tilde{\kappa}_{o+})^{jk} = \frac{1}{2}(\kappa_{DB} + \kappa_{HE})^{jk},$$

$e(o)$: parity even (odd)

$+(-)$: boost (in)dependent

S. Herrmann et al, arXiv: 1002.1284 [physics.class-ph]
P.L. Stanwix etal, PRD **74**(2006) 081101(R)
Ch. Eisele et al, PRL**103**(2009)090401



The frequencies of two lasers, each stabilized to one of two orthogonal cavities, are compared during active rotation of the setup.

	this work	Stanwix *et al.* [1]
κ_{e-}^{XY}	-0.31 ± 0.73	29 ± 23
κ_{e-}^{XZ}	0.54 ± 0.70	-69 ± 22
κ_{e-}^{YZ}	-0.97 ± 0.74	21 ± 21
$\kappa_{e-}^{XX} - \kappa_{e-}^{YY}$	0.80 ± 1.27	-50 ± 47
κ_{e-}^{ZZ}	-0.04 ± 1.73	1430 ± 1790
$\beta_{\oplus}\kappa_{o+}^{XY}$	-0.14 ± 0.78	-9 ± 26
$\beta_{\oplus}\kappa_{o+}^{XZ}$	-0.45 ± 0.62	-44 ± 25
$\beta_{\oplus}\kappa_{o+}^{YZ}$	-0.34 ± 0.61	- 32 ± 23

Scale of Lorentz violation? (Origin of Lorentz Violation?)

- Doubly Special Relativity (DSP): In addition to speed of light being boost invariant there is an invariant length scale, the Planck Length, or an invariant energy, the Planck Mass-Scale
- Non-commutative spacetime: A quantum mechanical theory, it assumes $[x^\mu, x^\nu] = \theta^{\mu\nu}$. The parameter $\theta^{\mu\nu}$ is dimensionfull and sets the scale of Lorentz violation. Again it is taken to be (the appropriate power of) the Planck Length.
- Rainbow (energy dependent) metric, κ-Minkowski, Hopf-algebras, spacetime foam, etc

---

How to construct a DSP: non-linear realization of the Lorentz group

$$F : P \to \mathcal{P} \qquad P = \{(p^0, \vec{p})\} = \text{ Physical} \qquad \mathcal{P} = \{(\pi^0, \vec{\pi})\} = \text{ Linear, unphysical}$$

$$p' = F^{-1}(\Lambda F(p))$$

So take $F(p_P) = 0(\infty)$ where p_P is a special momentum, *eg*, with $p^0 = \kappa$

Example:

$$\frac{E^2 - c^2\mathbf{p}^2}{(1 - E/\kappa)^2} = c^4 m^2,$$

$$E' = \frac{E\cosh\xi + c\,p_1\sinh\xi}{\Delta}, \qquad p'_1 = \frac{p_1\cosh\xi + E\sinh\xi/c}{\Delta},$$

$$p'_2 = \frac{p_2}{\Delta}, \qquad p'_3 = \frac{p_3}{\Delta},$$

$$\Delta = 1 + \frac{E(\cosh\xi - 1) + c\,p_1\sinh\xi}{\kappa},$$

High energy parametrization:

$$E \approx p + \frac{m^2}{p} - \frac{1}{2}\frac{E^2}{\kappa}$$

Energy dependent speed of light!
Limits from Gamma-Ray-Bursts

$$\Delta t \approx (\Delta E/\kappa) L$$

Analysis gives:

$$\kappa > 1.3 \times 10^{18} GeV \approx 0.10 M_{\mathrm{Planck}}$$

GRB	Redshift	Duration	counts$\vert_{\mathrm{LAT}}$	$E_{\max}$	t_i^{LAT}	t_f^{LAT}
080916C	4.35	Long	Strong	13 GeV	4.5 s	$>10^3$ s
081024B		Short		3 GeV	0.2 s	
090510	0.9	Short	Strong	>1 GeV	<1 s	$\gtrsim$ 60 s
090328	0.7	Long		>1 GeV		$\approx$ 900 s
090323	4	Long	Strong	>1 GeV		$>10^3$ s
090217		Long			~1 s	$\approx$ 20 s
080825C		Long	Weak	0.6 GeV	3 s	>40 s
081215A			Weak	0.2 GeV		

Fermi LT data, from reference above

Amelino-Camelia & L. Smolin, PRD 80, 084017 (2009)

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Fermi LT data, from reference above

M. Coraddu & S. Mignemi, arXiv: 0911.4241

No QFT yet. Instead consider generalized Klein-Gordon
Determine energies

$$E = \frac{-\frac{c^4 m^2}{\kappa} \pm \sqrt{\left(1 - \frac{c^4 m^2}{\kappa^2}\right) c^2 \mathbf{p}^2 + c^4 m^2}}{1 - c^4 m^2/\kappa^2}.$$

do NR expansion and interpret ± as that for a particle/hole (ie, antiparticle)

$$m^{\pm} = \pm \frac{m}{1 \pm \frac{c^2 m}{\kappa}}$$

B. Grinstein, FPCP 2010

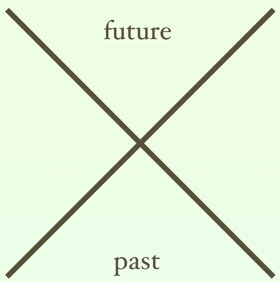
Bound from K0:

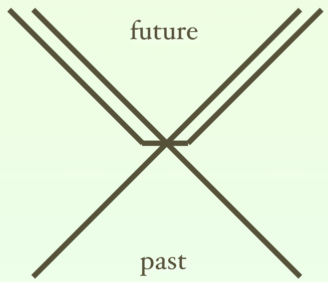
$$\kappa > \frac{2c^2 m}{(\Delta m/m)_{\text{max, exp}}} \approx 1.1 \times 10^{18} \text{ GeV}$$

(coincidentally same as above!)

Acausality and Nonlocality

- Metaphysical causality holds
- Modern view
  - Special Relativity
  - Locality
- Drop locality: Grandfather paradox?
- QM: Schrodinger equation
  - Get $\psi(x,t)$ given $\psi(x,0)$.
  - Lorentz covariance $\Rightarrow$ QFT
- Causality in QFT
  - Confusion (commutators? analyticity? blah...)
  - Schrodinger evolution + Lorentz covariance $\overset{?}{\Rightarrow}$ Causality in QFT
- Ah, find examples ...
  - Lee-Wick quantization of higher derivative QFT





$$\mathcal{L}_{\rm SM} + \ell^2 (D^2 H)^* (D^2 H)$$

Sutra of cause and effect in the Past and Present (Kako genzai inga kyō), Japan, 8 century AD

Weird behavior of LW resonances: acausal or non-local?

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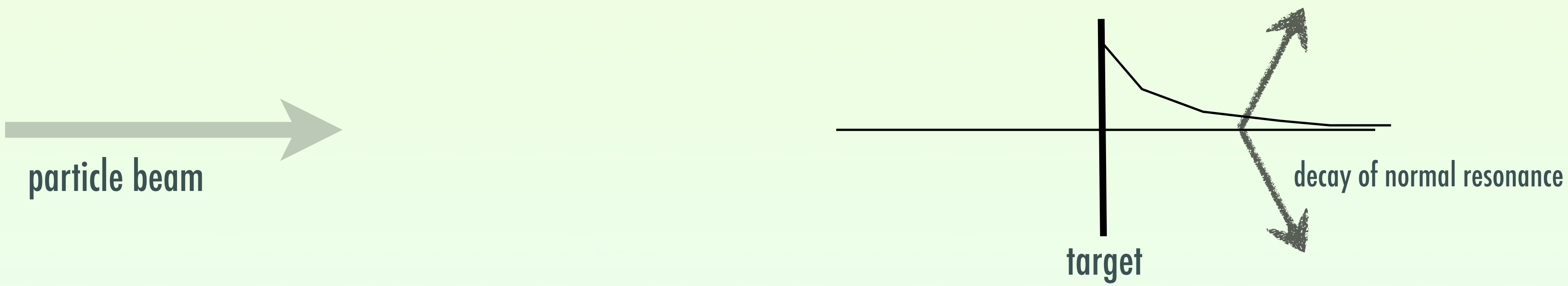

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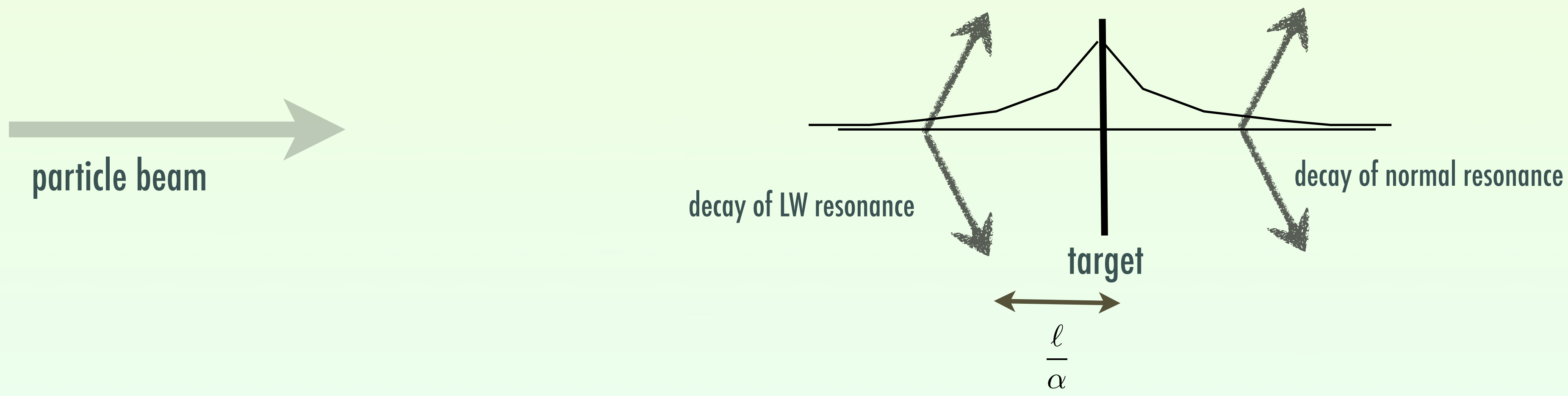

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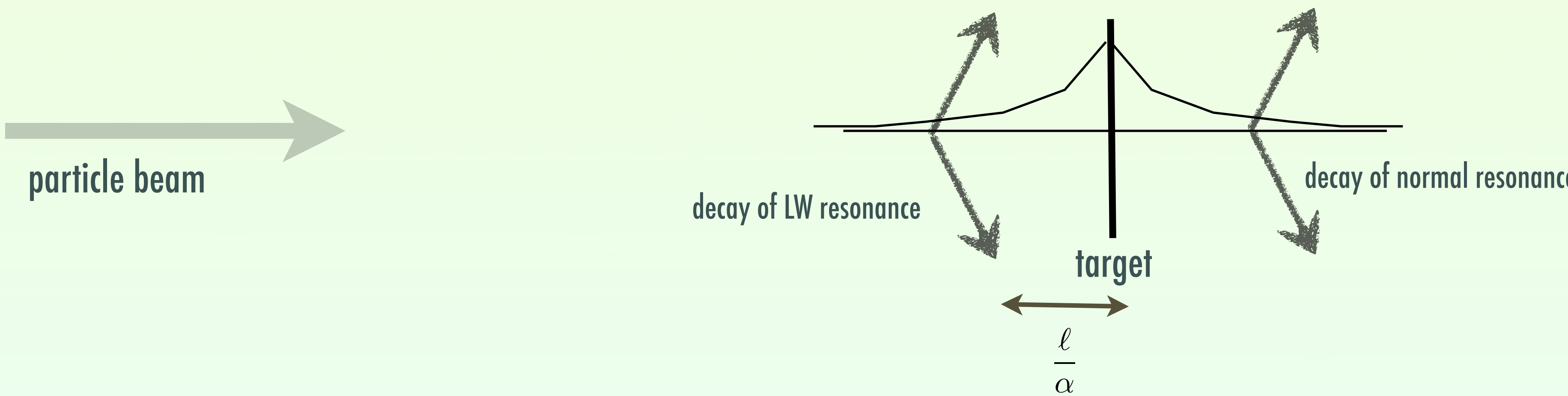
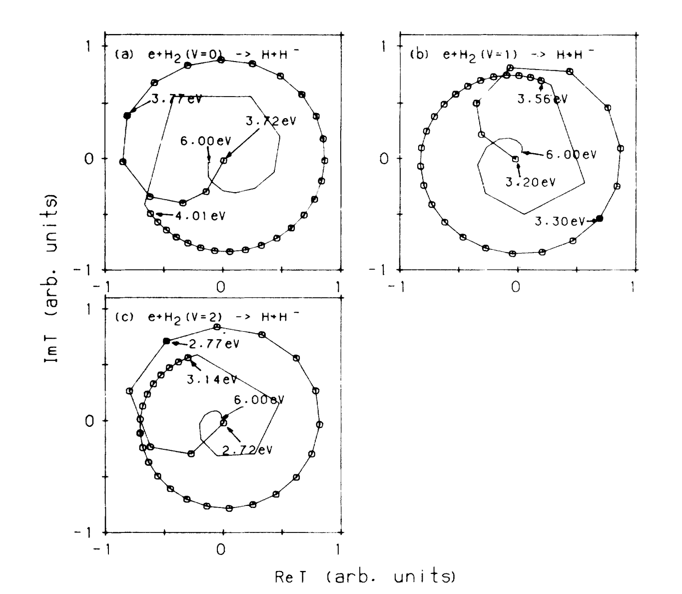


Better chance experimentally:
Clockwise Phase shift

FIG. 5. Argand diagram of transition amplitude for $e+H_2 \rightarrow H+H^-$. The solid circles denote the electron collision energies E_k where the peaks of the total cross sections occur. The open circles are placed at an interval of 0.01 eV. For (a) $v=0$, the peak position is located at $E_k=3.77$ eV; for (b) $v=1$, the peak position is located at $E_k=3.30$ eV; and for (c) $v=2$, the peak position is located at $E_k=2.77$ eV. The Argand diagram is plotted in an arbitrarily normalized scale.



CK Lutrus and S H Suck Salk, PRA **39** (1989) 391

Final remarks

- SM is in great shape
- SM is incomplete
  - Explanation for: hierarchy, neutrino mass, dark stuff, baryogenesis…
  - Theory of flavor? Q-gravity? Unification/SUSY?
- Great excitement ahead of us

- The excitement could be greater
  - In the "blood" of FPCP to test for *fundamental* principles: what if!
  - I do not advocate any of the avenues I described above
  - Theory may be garbage
  - Nature may require new paradigms
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FPCP: Fundamental Physics - Challenge Principles

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Fin