T Violation

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3 kinds of non-invariance t to -t

1. Global --expanding Universe

2. Macro –increasing entropy

3. Micro – T-violation - in particle physics

   T: t to –t **and** in states <-> out states

Universal non-invariance

Universe is expanding

- non-trivial metric of space-time

Expansion is accelerating

–cosmological constant?

Preferred frame of CMB!

None of this destroys local Lorentz Invariance of microscopic laws of physics!

Entropy Increase

For an “isolated system”

– a probability based argument

nothing to do with expansion of Universe

For the Universe as a whole?

is it meaningful?

what “prepares” the initial state?

Inflationary cosmology

Inflation provides an effectively ordered “initial” state from a random starting point

CMB temperature fluctuations map residual density fluctuations which evolve to structure

Now to particle physics

Many talks in this meeting:

T, CPT, CP

Dipole moments

Lorentz violation

CPT Assumptions

Hermiticity

Lorentz invariance

Locality

All true in any Lagrangian field theory

Strong CP and T violation

Theta parameter of QCD violates T and CP

-- initial state condition rather than lagrangian parameter – theta vacuum

--limit on edm says it is small (or zero)

why is it so small?

Peccei-Quinn solution --hint

Cosmological question:

Quarks are massless in early Universe

Can remove theta by chiral rotation

What remembers?

Answer –Higgs couplings

Can we construct a Higgs potential that automatically gives real masses once theta is rotated away?

Yes –by adding a U(1) symmetry

Consequence:axions

Invisible Axions

two Higgs doublets and U(1)

-> axion plus charged Higgs

not experimentally viable

For “invisible” axions

also a singlet and possibly another doublet

-> some additional massive particles

Axions as dark matter?

Light but not thermal (relativistic)

--from coherent initial axion field

LBNL search is reaching interesting sensitivity

CP and T violation in quark physics

Once a theory satisfies CPT

3 “types” of CP violation

What are corresponding T violations?

CP Violation in the mixing

Clearly also T violation

eg in K states

|A(K to $\bar{K}$)| not equal |A($\bar{K}$ to K)|

Seen as expected by LEAR

just a different way to measure epsilon

Direct CP violation

eg B to K pi

If we could construct time reversed process

Expect:

Rate f to i not equal to rate i to f

instead: equal to rate $\bar{i}$ to $\bar{f}$

Not directly tested.

CP violation from interference between decay with and without mixing

Arg $|(q/p)(\bar{A}/A)|$ non-zero

Clearly CP violating

How is this T-violating?

Answer –it must be-- L is CPT invariant

Time dependant asymmetry

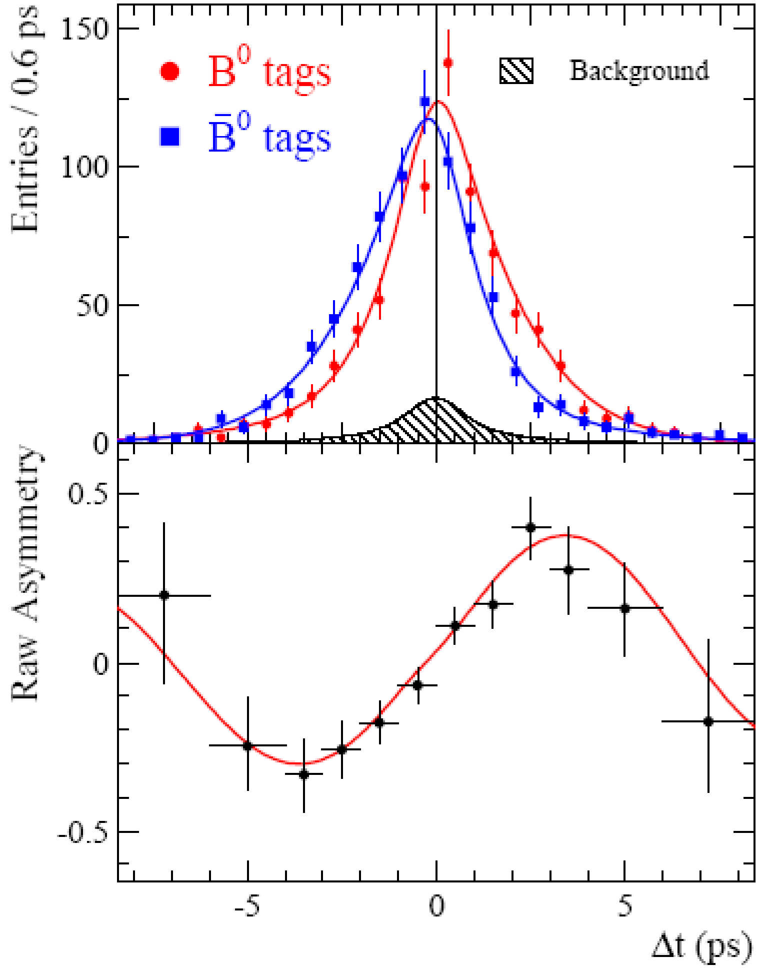
Data from BaBar

$$e^+e^- \rightarrow B^0 + \overline{B}^0$$

One B is 'tag'

Other B decays via

$$B(t) \rightarrow J/\psi K_S$$



Asymmetry in Δt

Is this T violation?

Not directly –no time reversed processes here

As in case of Direct CP violation

expected T violation for time reversed process

Effect indeed contains a T-violation

Alvarez and Szynkman Mod. Phys. Lett A 23, 25 2085 2008

Construct a demonstration using

$$|A(\ell^- X, J/\psi K_L)|^2 - |A(J/\psi K_S, \ell^+ X)|^2$$

order denotes which decay occurs first

And show this difference dominantly is a T-violating quantity

Up to small corrections

Trick of this

Use the coherent initial state

2 orthogonal neutral B's

Define a state

$$|B_\alpha\rangle = \frac{1}{N}\left(\langle J/\psi K_S|B^0\rangle|\bar{B}^0\rangle - \langle J/\psi K_S|\bar{B}^0\rangle|B^0\rangle\right)$$

And its orthogonal complement:

$$|B_{\alpha\perp}\rangle = \frac{1}{N}\left(\langle J/\psi K_S|B^0\rangle^* |B^0\rangle + \langle J/\psi K_S|\bar{B}^0\rangle^* |\bar{B}^0\rangle\right)$$

Then show

$$|A(\ell^- X, J/\psi K_L\rangle|^2 - |\langle A(J/\psi K_S, \ell^+ X\rangle|^2$$

is proportional to

$$|\langle B_\alpha | B^0\rangle|^2 - |\langle B_0 | B_\alpha\rangle|^2$$

Explicitly time reversal violating