On the Magic of *T odd* Moments

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I Basics & a Caveat

O_T *T odd*:

$$O_T \xrightarrow{T} -O_T$$
$$(\mathbf{p},\mathbf{s}) \xrightarrow{T} -(\mathbf{p},\mathbf{s})$$

$\langle \mathbf{p}_1 \cdot (\mathbf{p}_2 \times \mathbf{p}_3)\rangle$	4-body final state	P odd
$\langle \mathbf{s} \cdot (\mathbf{p}_1 \times \mathbf{p}_2)\rangle$	3-body final state	P even
$\langle \mathbf{s}_1 \cdot (\mathbf{s}_2 \times \mathbf{p})\rangle$	2-body final state	P odd

Caveat:

- non-zero P odd moment establishes ~~P~~
- yet a non-zero T odd moment does not establish ~~T~~

why?

- T *anti*-unitary $\qquad\qquad [X,P] = i$
- FSI can fake T: $\exp(i\int dt\, H_I) - 1 = i\int dt\, H_I - (\int dt\, H_I)^2 + \ldots$

yet

- can undertake to evaluate FSI effect
- can disentangle it by comparing CP conjugate moments

CP unitary -- FSI cannot fake ~~CP~~!

II Historical Precedent

$K_L \rightarrow \pi^+\pi^- e^+e^-$

Φ angle between $\pi^+\pi^-$ & e^+e^- planes

- $d\Gamma/d\Phi = \Gamma_1\cos^2\Phi + \Gamma_2\sin^2\Phi + \Gamma_3\sin\Phi\cos\Phi$
- $A = 2\Gamma_3/\pi(\Gamma_1+\Gamma_2)$ -- a *T odd* correlation
  - $A \sim 13\%$ KTeV, NA48
- fully consistent with $\cancel{C}P$ through ε_K
- for a while (arguably) largest observed $\cancel{C}P$

III $Pol_\perp(\mu)$ in $K_{\mu 3}$ Decays

$K \to \mu^+ \nu \pi$ $Pol_\perp(\mu) = \langle \mathbf{s}_\mu \cdot (\mathbf{p}_\mu \times \mathbf{p}_\pi) / |\mathbf{p}_\mu \times \mathbf{p}_\pi| \rangle$ -- T odd moment

$K_L \to \mu^+ \nu \pi^-$

$Pol_\perp^{SM}(\mu) \sim 10^{-3}$ ($\sim \alpha/\pi$) -- Coulomb FSI!

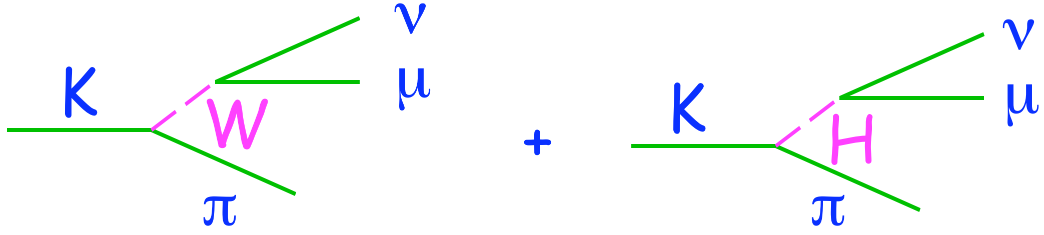
$K^+ \to \mu^+ \nu \pi^0$

$Pol_\perp(\mu) = (-1.7 \pm 2.3 \pm 1.1) \times 10^{-3}$ vs. $Pol_\perp^{SM}(\mu) < 10^{-6}$

$Pol_\perp(\mu) \propto \mathrm{Im}\,\xi$, $\xi = f_-/f_+$,

$f_{-[+]}$ helicity violating[conserving] amplitude

➥ a clean search for ~~CP~~ via Higgs dyn.



generic guestimate:

direct ~~CP~~ presumably unsuppressed by $\Delta I = 1/2$ rule:

$$5 \times 10^{-6} \times 20 \sim 10^{-4}$$

-- unless enhanced couplings to leptons!

$K^+ \to \mu^+ \nu \gamma$

$BR(K^+ \to \mu^+ \nu \gamma) \approx 5.5 \times 10^{-3}$

but: $Pol_\perp^{FSI}(\mu) \sim (1\text{-}2) \times 10^{-4}$ Isidori & Hiller '99

IV D & B Decays

Pilot sudy of $D^0/D^+/D_s \to KK\pi\pi$ by FOCUS

Table 1
D^0 ($\overline{D^0}$) yields split by $C_T(\overline{C_T})$ sign.

Decay mode	Request	Events
$D^0 \to K^-K^+\pi^-\pi^+$	$C_T > 0$	174 ± 21
$D^0 \to K^-K^+\pi^-\pi^+$	$C_T < 0$	190 ± 24
$\overline{D^0} \to K^-K^+\pi^-\pi^+$	$\overline{C_T} > 0$	255 ± 24
$\overline{D^0} \to K^-K^+\pi^-\pi^+$	$\overline{C_T} < 0$	220 ± 25

Table 2
$D^+_{(s)}$ ($D^-_{(s)}$) yields split by $C_T(\overline{C_T})$ sign.

Final State	Request	D^+ Events	D_s^+ Events
$K_S^0K^+\pi^-\pi^+$	$C_T > 0$	122 ± 16	126 ± 17
$K_S^0K^+\pi^-\pi^+$	$C_T < 0$	118 ± 16	147 ± 18
$K_S^0K^-\pi^-\pi^+$	$\overline{C_T} > 0$	145 ± 16	120 ± 17
$K_S^0K^-\pi^-\pi^+$	$\overline{C_T} < 0$	137 ± 16	119 ± 16

V τ Decays

$\cancel{CP}$ in τ decays

most promising channels: $\tau \to \nu K \pi$

- most sensitive to Higgs dynamics
- CP asymmetries possible also in final state distributions rather than integrated rates
- unique opportunity for $e^+e^- \to \tau^+\tau^-$
  pair produced with spins aligned:
  1 τ decays can `tag' the spin of the other
  ➥ can probe spin-dependent $\cancel{CP}$ with unpolarized beams!

$\tau \to \nu h$, $\boxed{\nu h_1 h_2}$, $\nu h_1 h_2 h_3$

$\tau^- \to \nu\, K^- \pi^0 \,/\, \overline{K}^0 \pi^-$

☺ 3-body final state

➥ $\cancel{CP}$ in distributions in general   Kuehn & Mirkes '96,'97

☺ quite possibly larger than integrated ones

☺ yield info on underlying transition operator

☺ allows consistency checks

☺ presumably higher sensitivity to non-minimal Higgs dynamics

➼ energy distributions, angular correlations …

➼ *T odd* moments: $\langle \mathbf{s}_\tau . (\mathbf{p}_K \times \mathbf{p}_\pi) \rangle$

✍ can extract info on $\mathbf{s}_\tau$ from τ pair spin alignment C.Nelson

✍ can compare τ^+ with τ^-

VI Summary

- $\not{C}\not{P}$ uncovered almost exclusively in partial rates
- we are just at the beginning of exploring unknown & novel territories of $\not{C}\not{P}$ in final state distributions
- those could provide specific info on the chirality of New Physics operators
- $K^+ \to \mu^+ \nu \pi^0$ -- search window of 3 orders of magnitude in $P_\perp(\mu)$
  - ✍ natural place for non-minimal scalar dynamics to surface
- $D, B \to 4\ P$
- $\tau \to \nu\ K\pi\ /\ K\pi\pi$ -- there is fame within your grasp!