Points for discussion on

- Semileptonic B decays
- CP violation

Abi Soffer

Tel Aviv University

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From Sébastien's talk:

CEPC and other flavour factories

Machine	CEPC (10^{12} Z)	Belle II (50 ab^{-1} + 5 ab^{-1} at $\Upsilon(5S)$)	LHCb (50 fb^{-1})	FCC-ee (150 ab^{-1})
Data taking	2030-2040	$\to$ 2025	$\to$ 2030	2035-2045
B^+	6×10^{10}	3×10^{10}	3×10^{13}	3×10^{11}
B^0	6×10^{10}	3×10^{10}	3×10^{13}	3×10^{11}
B_s	2×10^{10}	3×10^{8}	8×10^{12}	1×10^{11}
B_c	1×10^{8}	–	6×10^{10}	6×10^{8}
b baryons	10^{10}	–	10^{13}	10^{11}

- Approximate numbers (not indicated: LHCb 300 fb^{-1} for 2035 ?)
- Similar number of $B_{u,d,s}$ as Belle II, allowing similar programme (rare decays, CKM determination. . .)
- But try to focus on differences/complementarities
  - $b\bar{b}$ production incoherent and boosted compared to Belle II
  - different environment (e^+e^- vs pp) compared to LHCb
  - interesting prospects for τ reconstruction ?

$\Longrightarrow$CEPC: Particular focus on B_s, B_c,b-baryon and τ modes ?

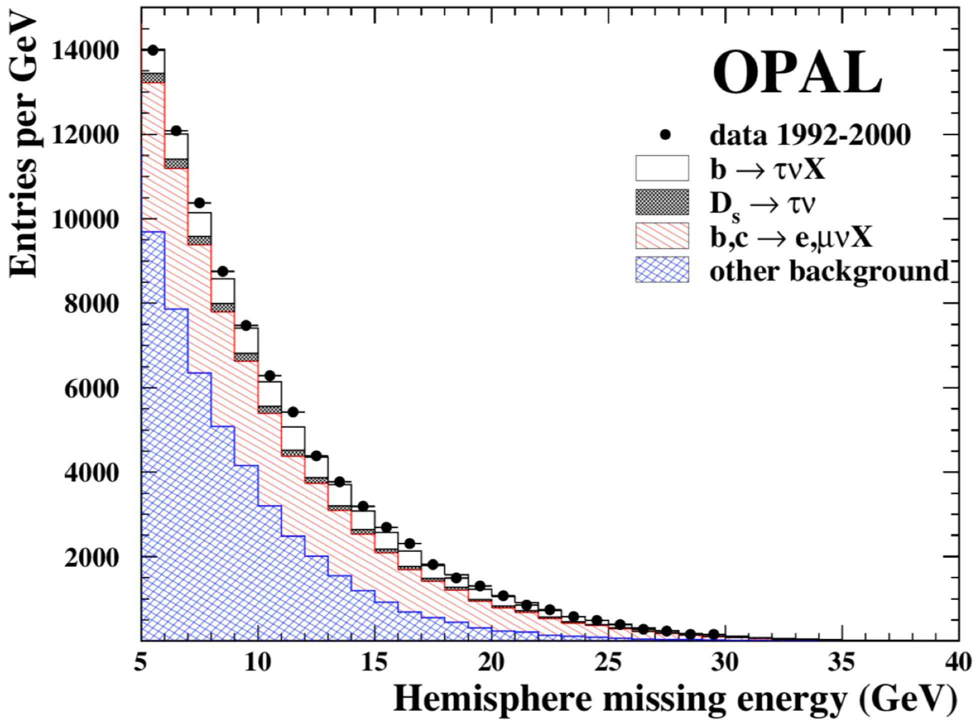
But note that:

- Belle II may also have an upgrade by the 2030s.
- In $ee \to B\bar{B}$, the initial state is exactly known.
- At the Z we have $ee \to b\bar{b}X$, more similar to LHCb!
- So can't base CEPC sensitivity on that of Belle II times $\sqrt{L_{\text{CEPC}}/L_{\text{Belle II}}}$.
- In some cases can use LEP sensitivity times $\sqrt{L_{\text{CEPC}}/L_{\text{LEP}}}$.
- Flavor-physics measurements are discussed in many publications. In our report, I think only a very short summary with citations is sufficient, avoid repetition.
- More useful to focus on placed where 10^{12} Z's give a significant advantage

(Semi)Tauonic b-hadron decays

LEP demonstrated the capability. E.g., in the OPAL (hep-ex/0108031):

- Divide the event into 2 hemispheres
- b tag one hemisphere using vertexing: eff=47%, purity=92%
- Fit the missing energy in the other hemisphere
- Obtain a BR of (2.78 ± 0.18 ± 0.51)%
- With ~4M Z→hadron events
- Gives an idea of the precision possible with 10^{12} Z's
- Similar precision by the other LEP experiments



(Semi)Tauonic b-hadron decays

- ALEPH (hep-ex/0010022) also measured $\mathrm{Br}(b \to D^{*-}\tau^{+}\nu X) = (0.88 \pm 0.31 \pm 0.28)\%$
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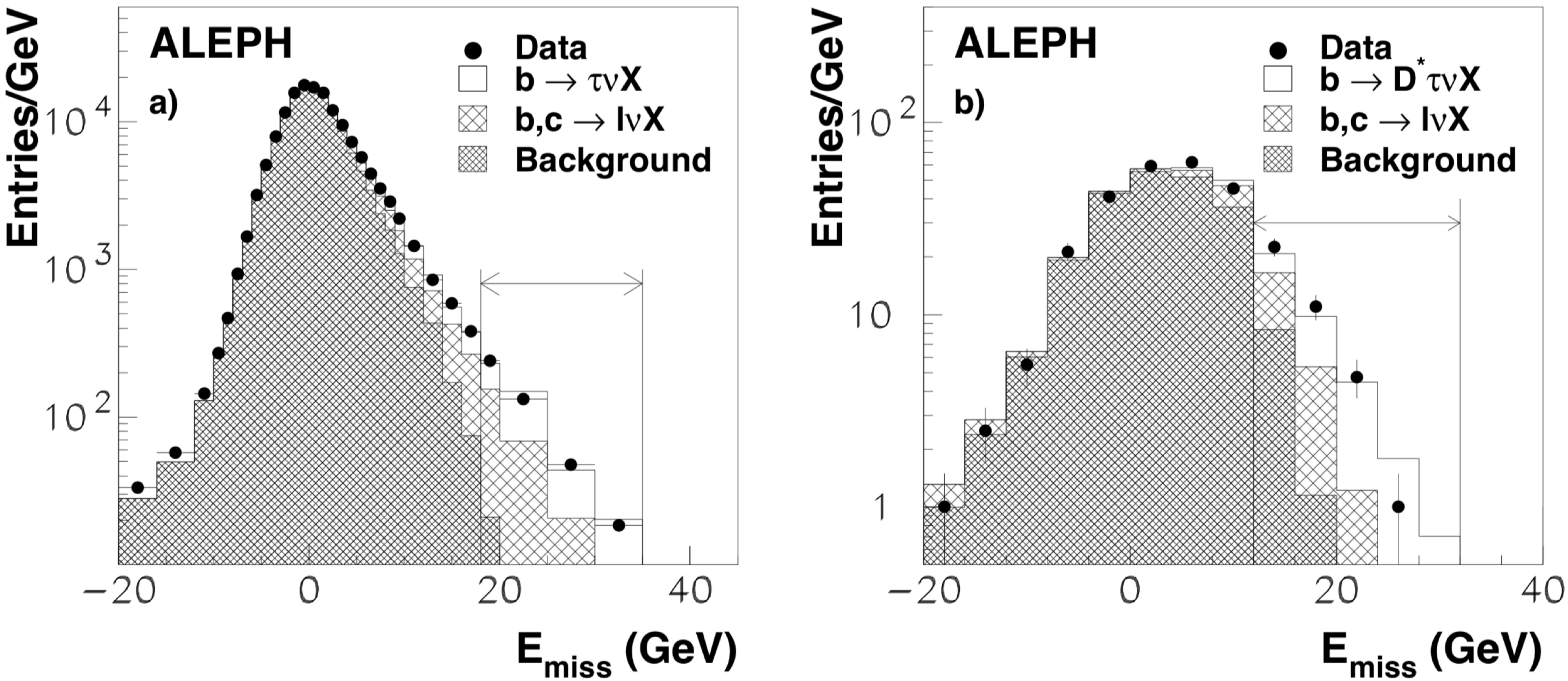

The competition to CEPC

- At the Upsilon(4S), the 2 B's are not separated kinematically
  - B factories fully or partially reconstruct the other B in the event to reduce background and measure missing mass (called "Recoil B tagging")
  - Effective B-tagging efficiency is ~1%, compared with ~50% at LEP
- LHCb:
  - sensitivity to $(b \to D^{*-}\tau^{+}\nu)$ with 1-3 fb^{-1} is similar to those of BABAR and Belle (from published results)
  - With 25-50, expect sensitivity similar to that of Belle II with 50 ab^{-1}
  - With 300 fb^{-1}, sensitivity probably less than that of CEPC
- Improvements at CEPC wrt. LEP:
  - Better vertexing:
    - higher b-tag purity (other hemisphere)
    - higher signal purity from displaced B and tau vertex (used by LHCb)
  - Better calorimetry:
    - Better missing mass resolution

More discussion

- There is a whole set of measurements:
  - Inclusive $b \to \tau\nu X$
  - $B \to D^{(*)}\tau\nu,\ B \to D^{**}\tau\nu,$
    $B \to \pi/\rho\tau\nu,$
    $B_s \to K^{(*)}\tau\nu$ (requires some kaon ID),
    $B_c \to \psi\tau\nu$ (J/ψ done by LHCb)
- Measure not only BRs, but q^2 distribution, polarizations
  - (Belle has already measured the tau polarization, with a 50% error)
- Interpretation ambiguity between exclusive and semi-exclusive
  - e.g., hard to differentiate betwen $B \to D^{(*)}\tau\nu$ and $B \to D^{(*)}\tau\nu X$
  - Similar problem at LHCb
  - Resolving requires performing many exclusive modes
  - E.g., Belle II can measure exclusive $B^- \to \tau^-\bar{\nu}$.
    CEPC cannot, but might be able to use $b \to \pi^+\tau\nu X$ + isospin to estimate contribution of $B^- \to \pi^0\tau^-\bar{\nu}$

What can we learn from these decays?

- If a large deviation from the SM is found by Belle II and LHCb:
  - CEPC could add more detailed information
  - The tension is currently 3.1 sigma
- Otherwise
  - The increased sensitivity offered by CEPC might be hard to interpret
  - What are the theoretical limitations?

Basic CP violation @ CEPC

- As an example, look at the CP parameter $\sin 2\beta$:
  - $0.687 \pm 0.028 \pm 0.012$ at BABAR with 450 M BB events
  - $0.84 \pm 1.0 \pm 0.16$ at ALEPH with 4M Z events
  - Naïve lumi scaling gives stat errors of 0.003 at Belle II and 0.002 at CEPC.
- So CEPC could have similar sensitivity to Belle II
  - But significantly later

More interesting

- Can introduce sensitive CPV studies of semi-tauonic B decays
  - Aloni, Grossman, AS, 1806.04146
  - Duraisamy, Datta, 1302.7031
  - Hagiwara, Nojiri, Sakaki, 1403.5892
- These are difficult measurement
  - phase-space-dependent
  - require exclusive reconstruction

Perhaps also interesting

- Take advantage of the fact that in the SM, b quarks produced in Z decays are more left-handed ($c_L = -0.42, c_R = 0.08$), so they are polarized
- This could be useful for studying T-violating triple products in 3-body Λ_b decays, using the polarization direction (the b-jet direction) as one of the axes.
  - (The idea was conveyed to me by Yuval Grossman)
- Λ_c from $Z \to c\bar{c}$ could also be used, although the polarization is smaller for charm ($c_L = 0.35$ $c_R = -0.15$) and one has to beware of Λ_c produced in b-hadron decays
- I don't have much more to say about it at this point, except to encourage theoretical work on measurement options and how they could be used to improve SM parameters or search for new physics.
- 1505.02771 discusses how to use Λ_b decays to study polarization