B(eautiful) Physics I

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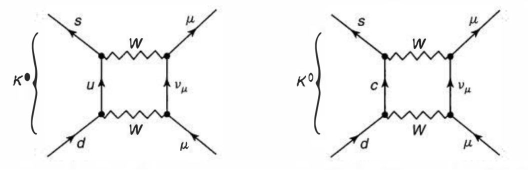
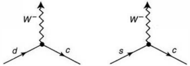
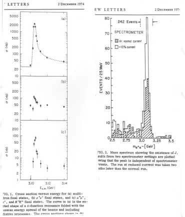
A lesson from history - GIM mechanism



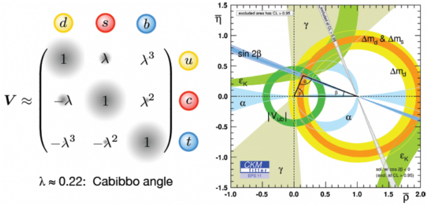


$\frac{-ig_w}{2\sqrt{2}}\gamma^\mu(1-\gamma^5)(-\sin\theta_C)$ $\frac{-ig_w}{2\sqrt{2}}\gamma^\mu(1-\gamma^5)\cos\theta_C$

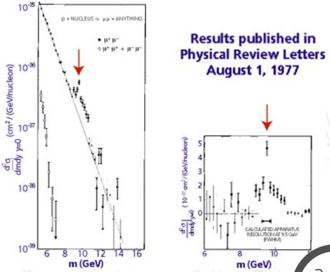


- Cabibbo angle was successful in explaining dozens of decay rates in the 1960s.
- There was, however, one that was not observed by experiments: $K^0 \to \mu^- \mu^+$.
- Glashow, Iliopoulos, Maiani (GIM) mechanism was proposed in the 1970 to fix this problem. The mechanism required the existence of a 4^{th} quark.
- At that point most of the people were skeptical about that. Fortunately in 1974 the discovery of the J/ψ meson silenced the skeptics.

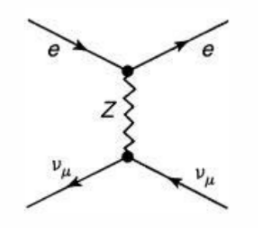
A lesson from history - CKM matrix

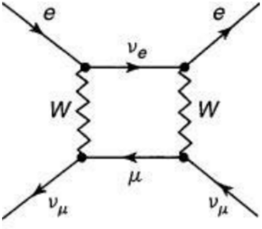


- Similarly, CP violation was discovered in 1960s in the neutral kaons decays.
- 2×2 Cabbibo matrix could not allow for any CP violation.
- For CP violation to be possible one needs at least a 3×3 unitary matrix
  ↬ Cabibbo-Kobayashi-Maskawa matrix (1973).
- It predicts existence of *b* (1977) and *t* (1995) quarks.

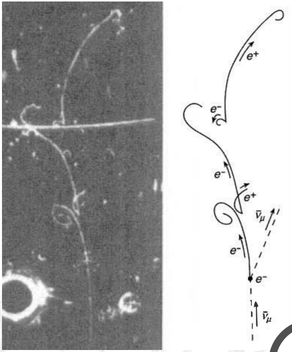


A lesson from history - Weak neutral current





- Weak neutral currents were first introduced in 1958 by Buldman.
- Later on they were naturally incorporated into unification of weak and electromagnetic interactions.
- 't Hooft proved that the GWS models was renormalizable.
- Everything was there on theory side, only missing piece was the experiment, till 1973.

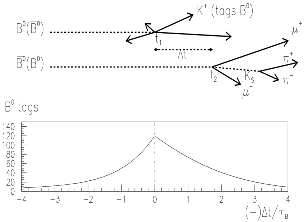


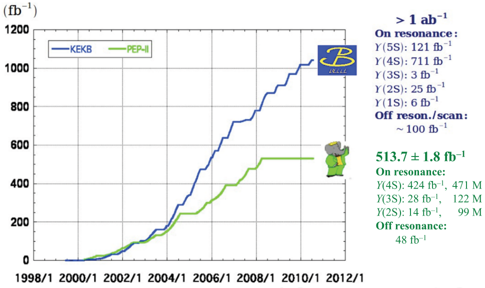
B-factories

⇛ There were many B factories: HERA-B, CLEO, ARGUS.

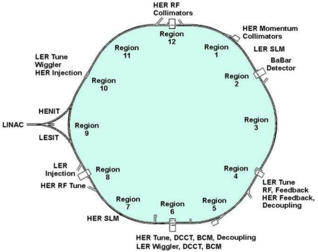
⇛ How ever in present when people talk about B-factories they mean BaBar and Belle experiments.

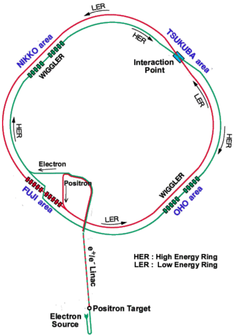
⇛ Both of them were asymmetric B-factories:





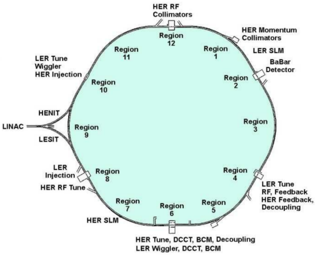
B-factories

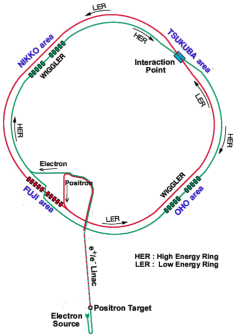




Parameters			PEP-II	KEKB
Beam energy		(GeV)	9.0 (e^-), 3.1 (e^+)	8.0 (e^-), 3.5 (e^+)
Beam current		(A)	1.8 (e^-), 2.7 (e^+)	1.2 (e^-), 1.6 (e^+)
Beam size at IP	x	(μm)	140	80
	y	(μm)	3	1
	z	(mm)	8.5	5
Luminosity		(cm^{-2} s^{-1})	1.2×10^{34}	2.1×10^{34}
Number of beam bunches			1732	1584
Bunch spacing		(m)	1.25	1.84
Beam crossing angle		(mrad)	0 (head-on)	± 11 (crab-crossing)

B-factories





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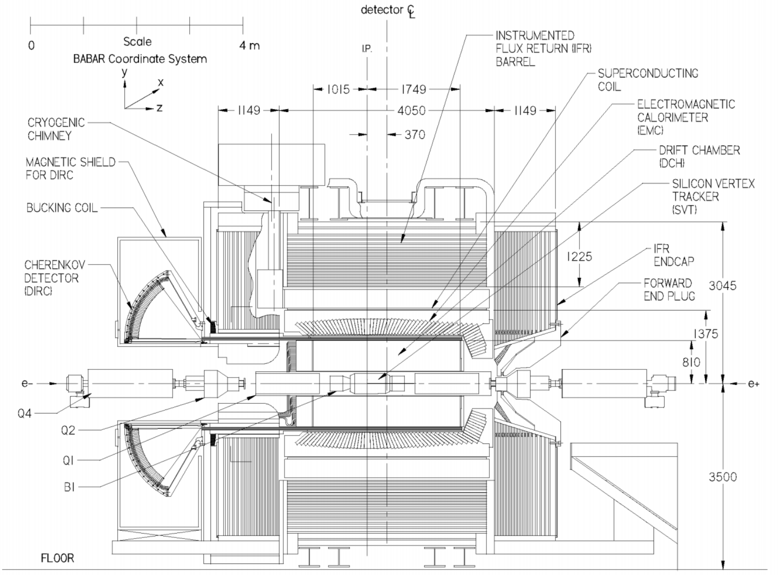
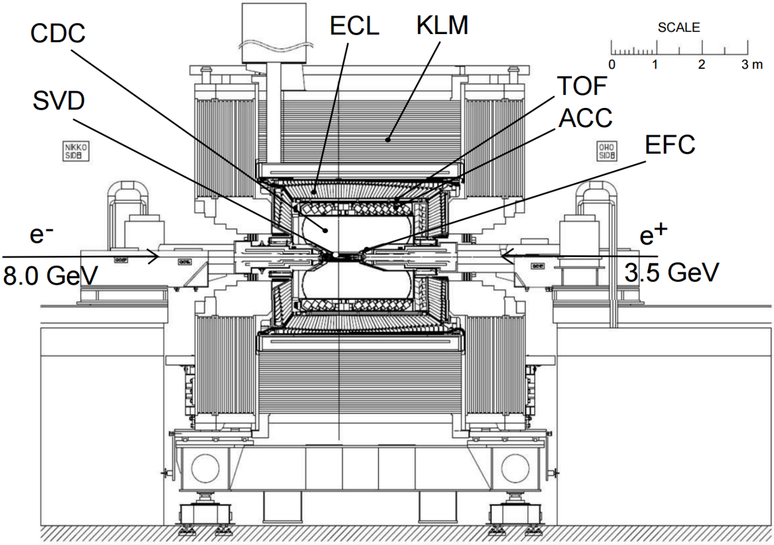
B-factories, detectors



B-factories, detectors



B-factories, Physics

⇛ The B-factories had enormous physics program:

- CKM matrix:
  - V_{ub} and V_{cb} from semi-leptonic be decays.
  - V_{td} and V_{ts} from $B_{s,d}$ mixing.
  - Charmless B decays.
  - B mixing.
  - Electro-weak penguin decays.
- Quarkonium physics
- Charm physics
- τ physics

B-factories, V_{ub}, V_{cb}

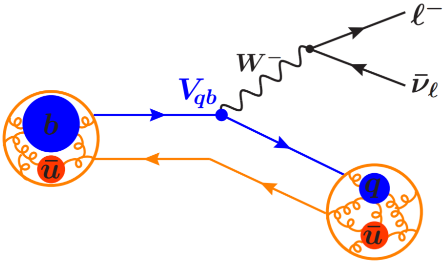
⇛ The decays of B^0 and B^+ that process via leading order tree decay involving a lepton in the final state $\ell = e, \mu$ are free from non SM contributions.

⇛ They can be used to probe the CKM-matrix elements: V_{cb} and V_{ub}.

⇛ In addition the measurement of $\frac{|V_{ub}|}{|V_{cb}|}$ determines the angle ϕ_1.

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2 |V_{qb}^2|}{192\pi^3 m_B^3} \mathcal{K}(m_B^2, m_M^2, q^2) \times \mathcal{F}^{(2)}(q^2)$$

⇛ From theory point of view the only thing that is not well known are the from factors: $\mathcal{F}^{(2)}(q^2)$. There are now many theoretical ideas to calculate them and reduce the errors.



B-factories, V_{ub}, V_{cb}

⇛ Measurement of semi-leptonic decays are very challenging, because of missing neutrino!

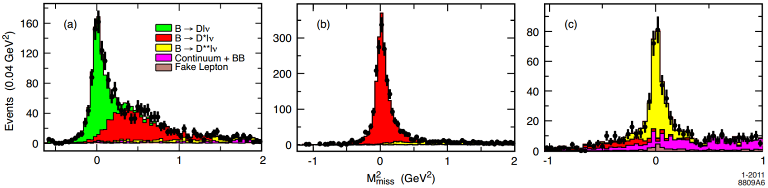
⇛ We start from calculating the missing 4-momentum:

$$(E_{miss}, p_{miss}) = (E_0, p_0) - \sum_i (E_i, p_i)$$

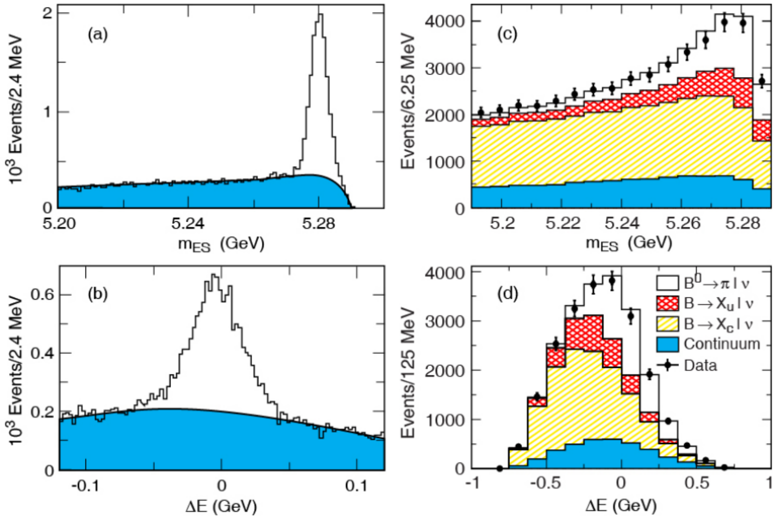
⇛ In case that the only missing particle in the detector is a neutrino the missing mass should be close to zero!

⇛ We also use the:

$$\Delta E = E_B^* - E_{beam}^*, \qquad M_{ES} = \sqrt{(E_{beam}^*)^2 - (p_B^*)^2}$$

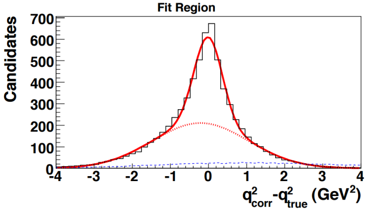


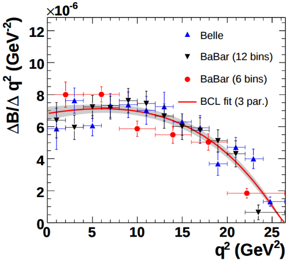
B-factories, V_{ub}, V_{cb}

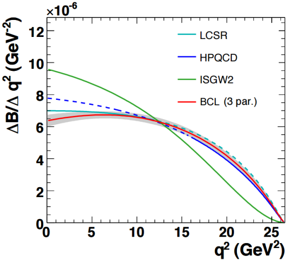


B-factories, V_{ub}, V_{cb}

$\Rrightarrow$ Also the $q^2 = [(E_\ell, p_\ell) + (E_{miss}, p_{miss})]^2$ distribution was measured.



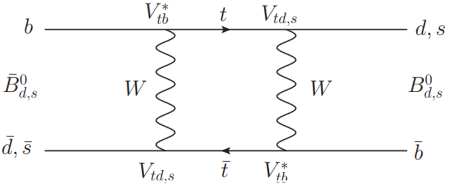




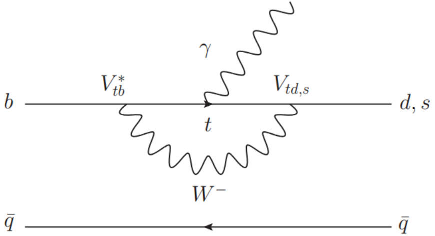
B-factories, V_{ts}, V_{tb}

$\Rrightarrow$ The CKM elements V_{ts}, V_{tb} are problematic to determine. One can use:

- Rare radiative K and B decays
- B^0 and B_s^0 oscilations:



$$\Delta m_d = \frac{G_F^2}{6\pi^2} f_B^2 m_B m_W^2 \eta_B S_0 |V_{tb}^* V_{td}|^2 \hat{B}_B$$



$\Rrightarrow$ Unfortunately the theory precision is limited by the QCD.

B-factories, V_{ts}, V_{tb}

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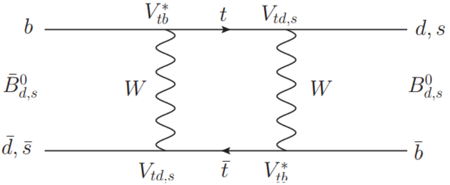

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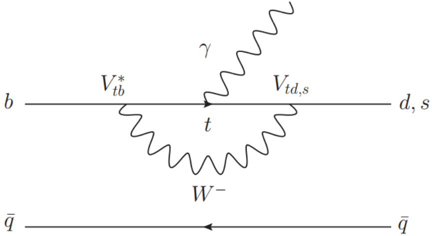
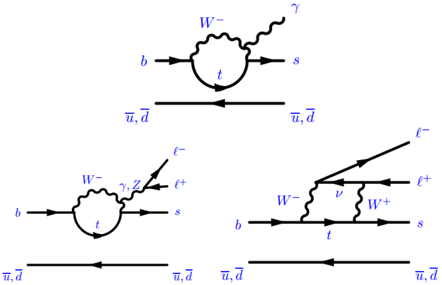


$\Rightarrow$ Unfortunately the theory precision is limited by the QCD.

Electroweak penguins

- Rare EWP decays are THE most sensitive probes of NP in flavour physics.
- They are described by the effective Hamiltonian (see next lecture for more details):

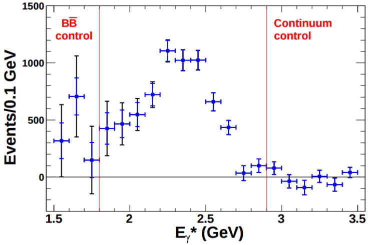
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\left[\lambda_q^t \sum_{i=1}^{10} C_i \mathcal{O}_i + \lambda_q^u \sum_{i=1}^{2} C_i (\mathcal{O}_i - \mathcal{O}_i^u)\right]$$

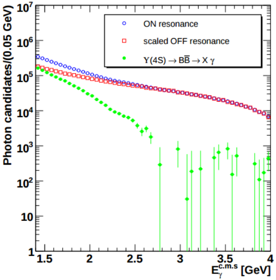


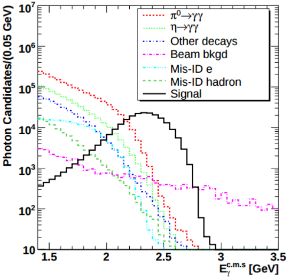
Inclusive/Exclusive $b \to s\gamma$

⇛ Measurement of inclusive modes is difficult. First attempt was done using sum of exclusive modes.

⇛ Latter one used the leptonic tag.







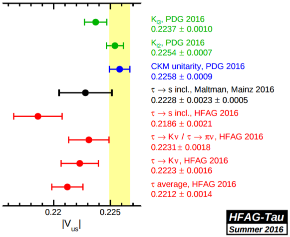
τ Physics

$\Rrightarrow$ *B*-factories are also τ factories!

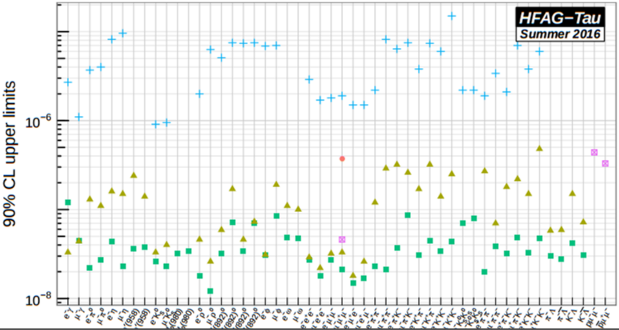
$\Rrightarrow$ τ leptons are very nice objects.

And allow 2 main things:

- Test of QCD in the harmonic decays.
- Search for NP ex. LFV.



$$B(\tau^- \to K^-\nu_\tau) = \frac{G_F^2 f_K^2 |V_{us}|^2 m_\tau^3 \tau_\tau}{16\pi\hbar}\left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{EW}$$



Warp up

$\Rrightarrow$ The Physics reach of B-factories was enormous.
$\Rrightarrow$ They robustness of their measurements because a text-book procedures when analysing the data.
$\Rrightarrow$ Fief anomalies remain (next lecture), which are beeing tackled by current B-factories.
$\Rrightarrow$ If you want to know more please read the ”Legacy” book: arxiv::1406.6311