Hunting Penguins with $B_s^0 \to J/\psi K_S^0$

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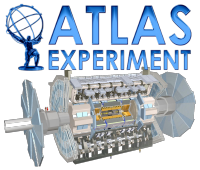
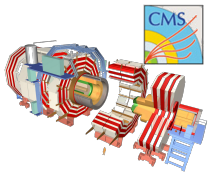
Two Complementary Strategies:

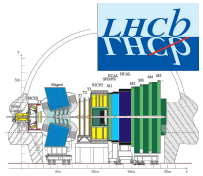
Direct Observation
Search for new particles





$\Leftrightarrow$

Indirect Evidence
Search for quantum loop effects



Rely on interplay between

$\swarrow$ $\searrow$

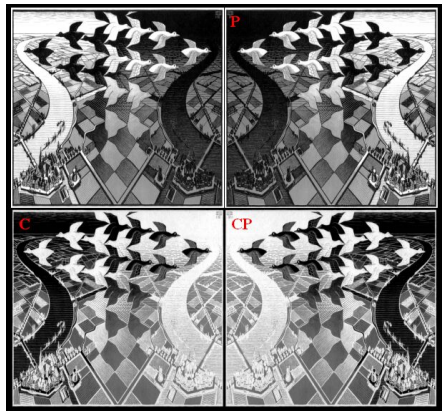
High precision measurements $\Leftrightarrow$ Accurate Standard Model predictions

Indirect searches focus on:

- Violation of Charge + Parity symmetry
- Rare decays

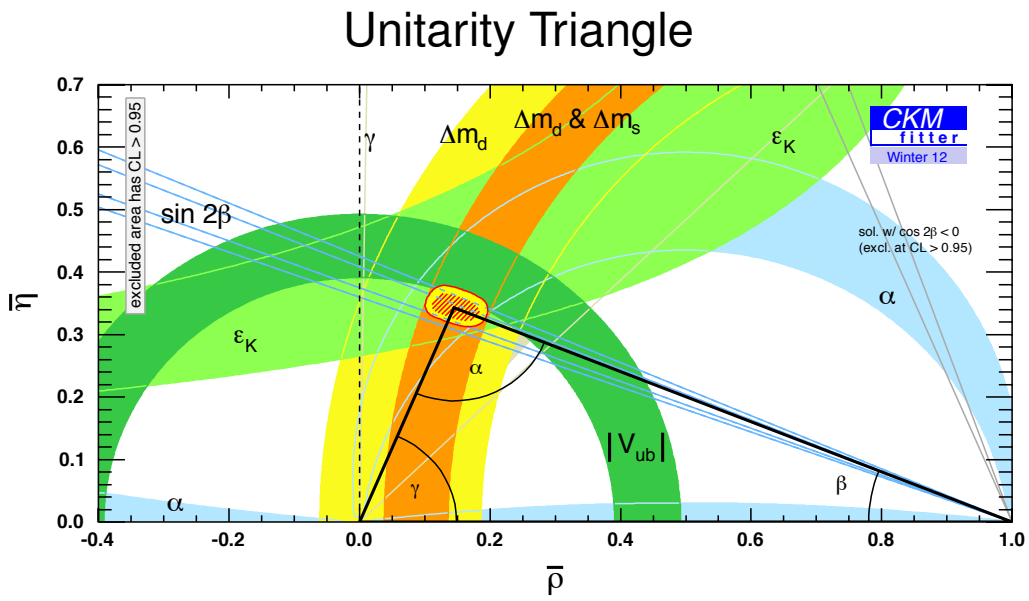
$\Downarrow$

CKM Mechanism



[Escher, *Day and Night*]

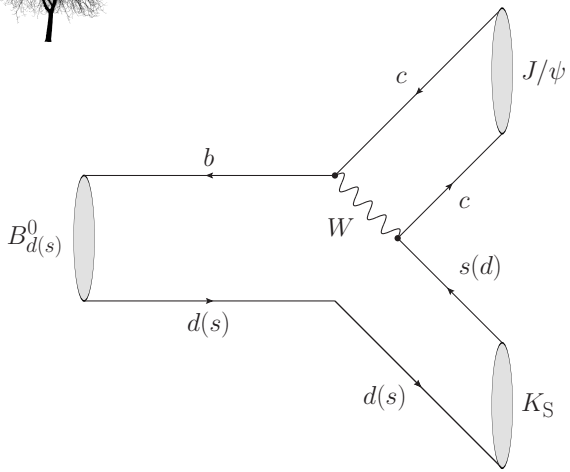
Current constraints on CKM mechanism:

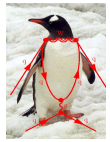


Shows small tension between $\sin(2\beta)$ and $|V_{ub}|$.

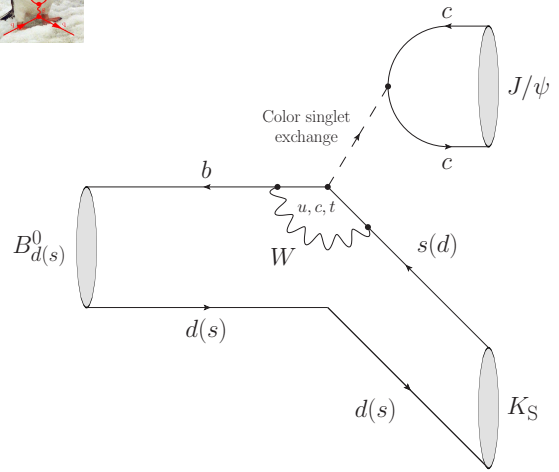
- Is this a hint of New Physics?
- . . . or can it be explaind by the Standard Model?

Tree Topology





Penguin Topology



Decay Amplitude:

$$A(B_d^0 \to J/\psi K_S^0) = V_{cs} V_{cb}^* \left(A'^{c}_{\text{tree}} + A'^{c}_{\text{pen}}\right) + V_{us} V_{ub}^* \, A'^{u}_{\text{pen}} + V_{ts} V_{tb}^* \, A'^{t}_{\text{pen}} \qquad (1)$$

Assuming Unitarity of CKM Matrix

$$A(B_d^0 \to J/\psi K_S^0) = \left(1 - \frac{\lambda^2}{2}\right) \mathcal{A}' \left[1 + \epsilon \, a' \, e^{i\theta'} \, e^{i\gamma}\right] \qquad (2)$$

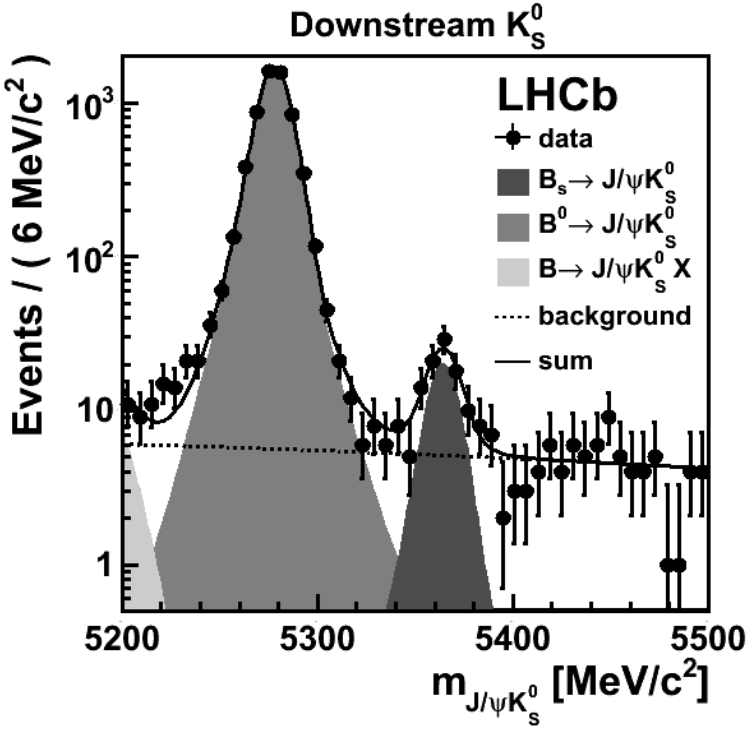
where a' is the size, θ' the strong phase and γ the weak phase of penguin contributions and

$$\epsilon \equiv \frac{\lambda^2}{1 - \lambda^2} \approx 0.053 \qquad (3)$$

$\Rightarrow$ Penguin corrections are doubly Cabibbo-suppressed

Roadmap:

1. Branching ratio measurement ✓
2. Analyse decay time distribution and acceptance
3. Measure the CP observables and determine the penguin contributions



arXiv 1205.0934 [hep-ex]

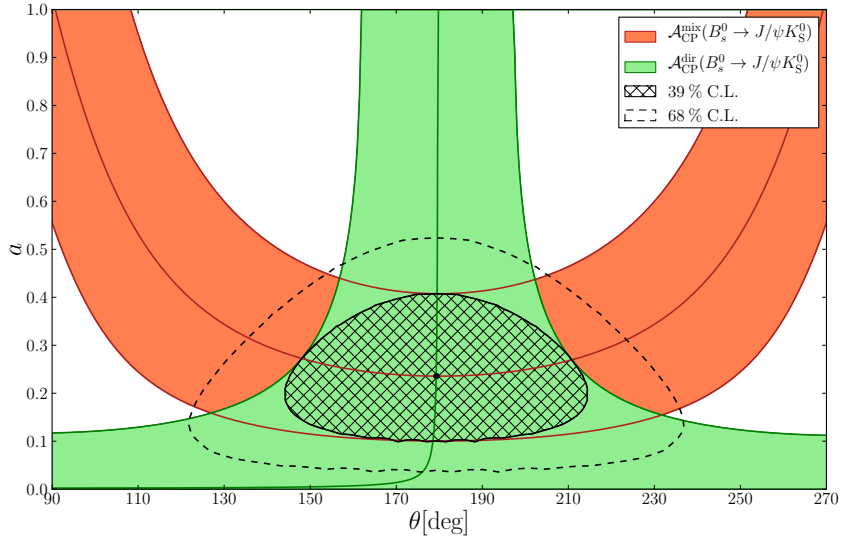
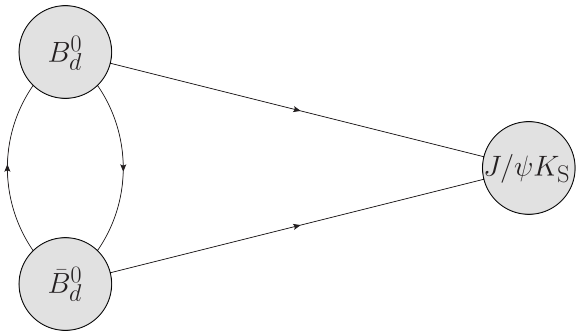


Illustration: Penguin parameter determination with the full LHCb data sample (2018)

Back Up

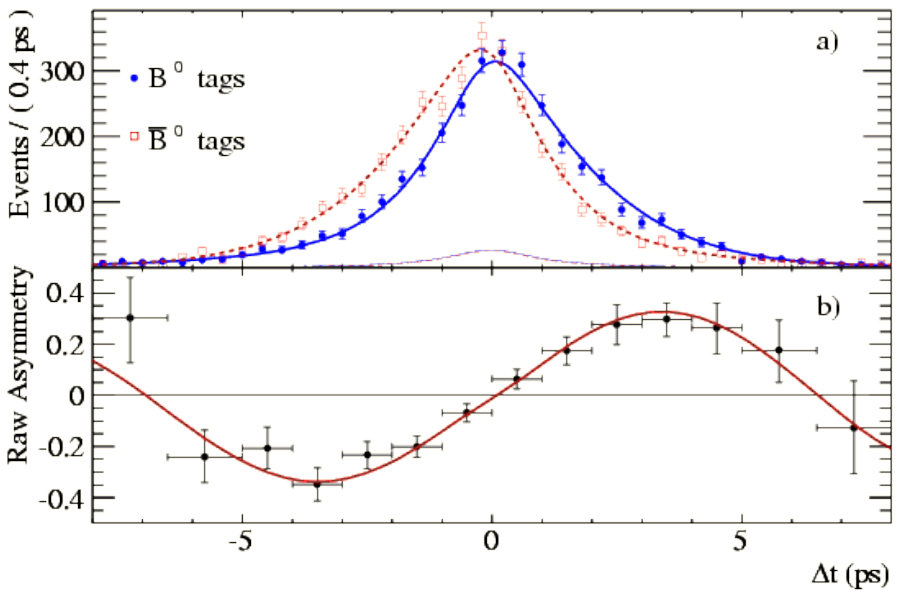
The CKM constraint on β:

- Well measured by B-factories
- Uses $B^0_d \to J/\psi K^0_S$ channel
- Interference between the direct decay and the decay after mixing



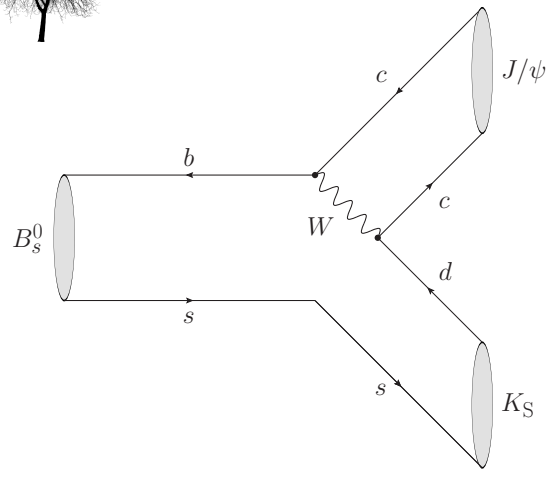
This leads to time-dependent CP asymmetry:

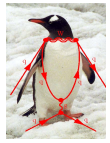
$$a_{CP}(t) = -\mathcal{A}^{mix}_{CP} \sin(\Delta m_d t) = \sin(2\beta) \sin(\Delta m_d t) \quad (4)$$



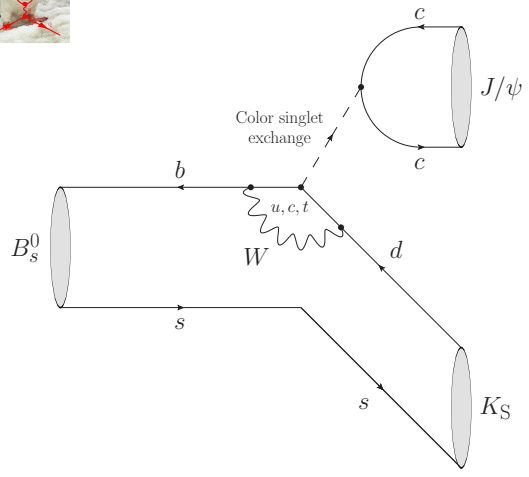
[BaBar, 2008]

Tree Topology





Penguin Topology



Decay Amplitude:

$$A(B_s \to J/\psi K_S) = V_{cd} V_{cb}^* \left(A_{\text{tree}}^c + A_{\text{pen}}^c\right) + V_{ud} V_{ub}^* A_{\text{pen}}^u + V_{td} V_{tb}^* A_{\text{pen}}^t \qquad (5)$$

Assuming Unitarity of CKM Matrix

$$A(B_s^0 \to J/\psi K_S) = -\lambda \mathcal{A}\left[1 - a\, e^{i\theta} e^{i\gamma}\right] \qquad (6)$$

again, a, θ and γ are the size, stong phase and weak phase of penguin contributions

$\Rightarrow$ Penguin corrections enter in Cabibbo-allowed way