Is B_s Production by Neutrinos Interesting?

(revised)

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Outline:

1. CKM matrix
2. B_s mixing and CP violation
3. B_s production and tagging
4. B_s production by neutrinos
5. Further issues

CKM Matrix

- Quark mixing described in SM by unitary matrix V:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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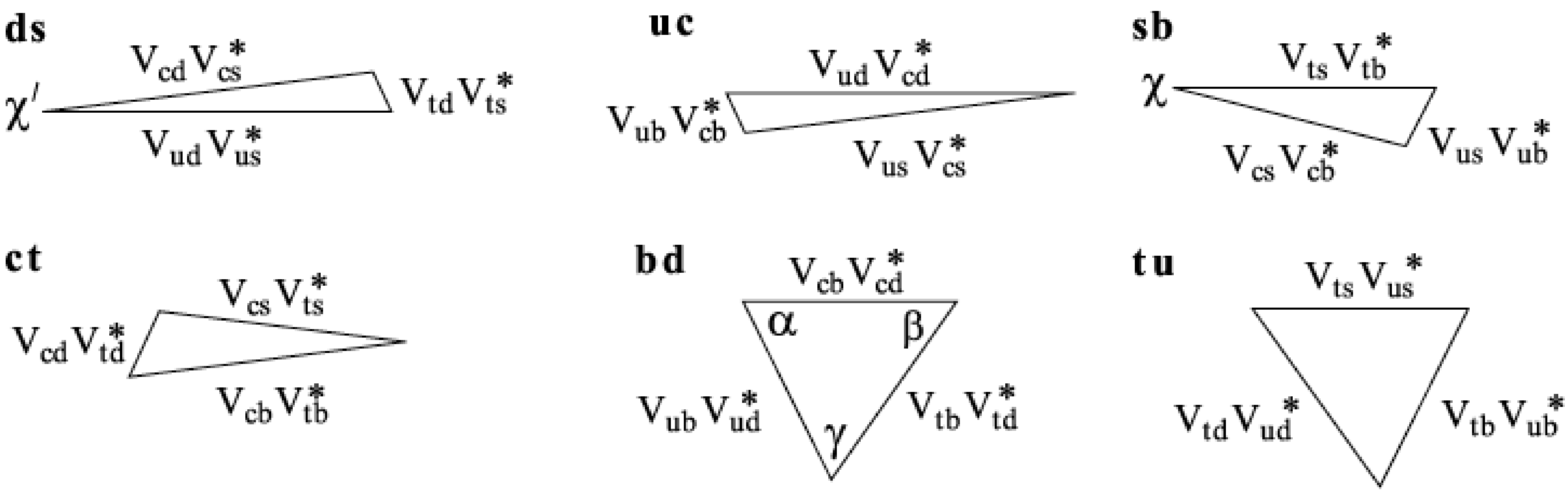
- Unitarity of *V* implies triangle relations, e.g., $V_{ub}V_{ud}^* + V_{cb}V_{cd}^* + V_{tb}V_{td}^* = 0$:



* Note: not scale drawings – all triangles in fact have equal areas

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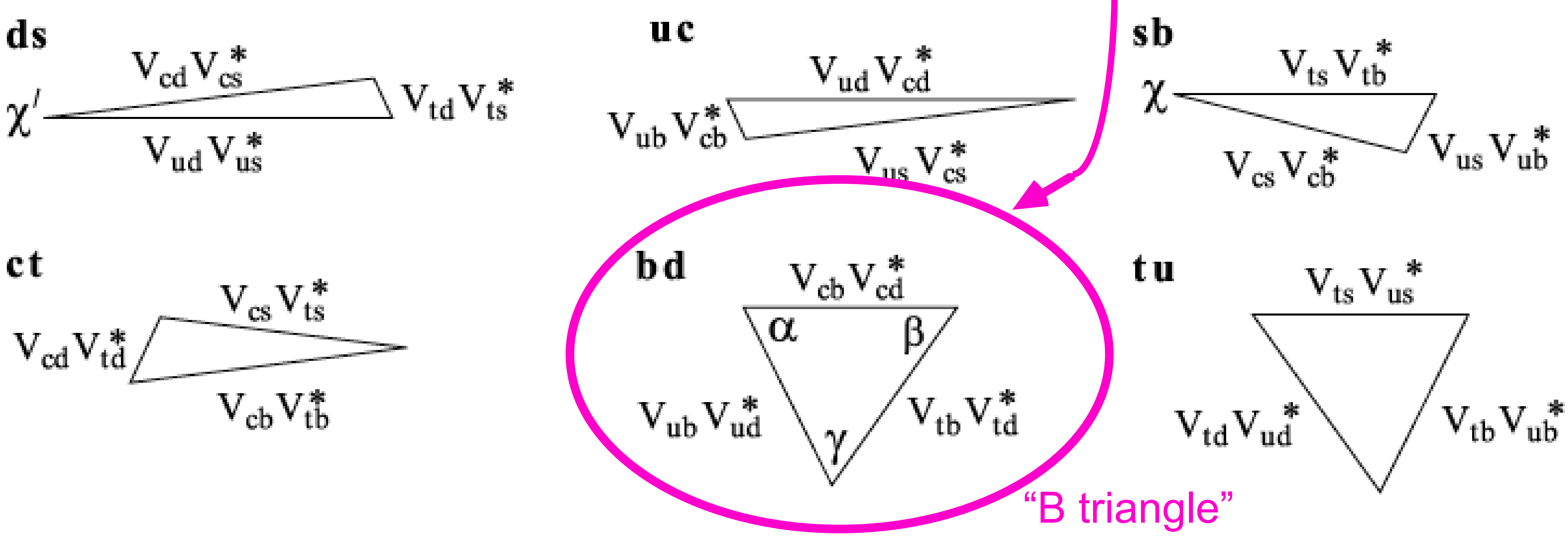

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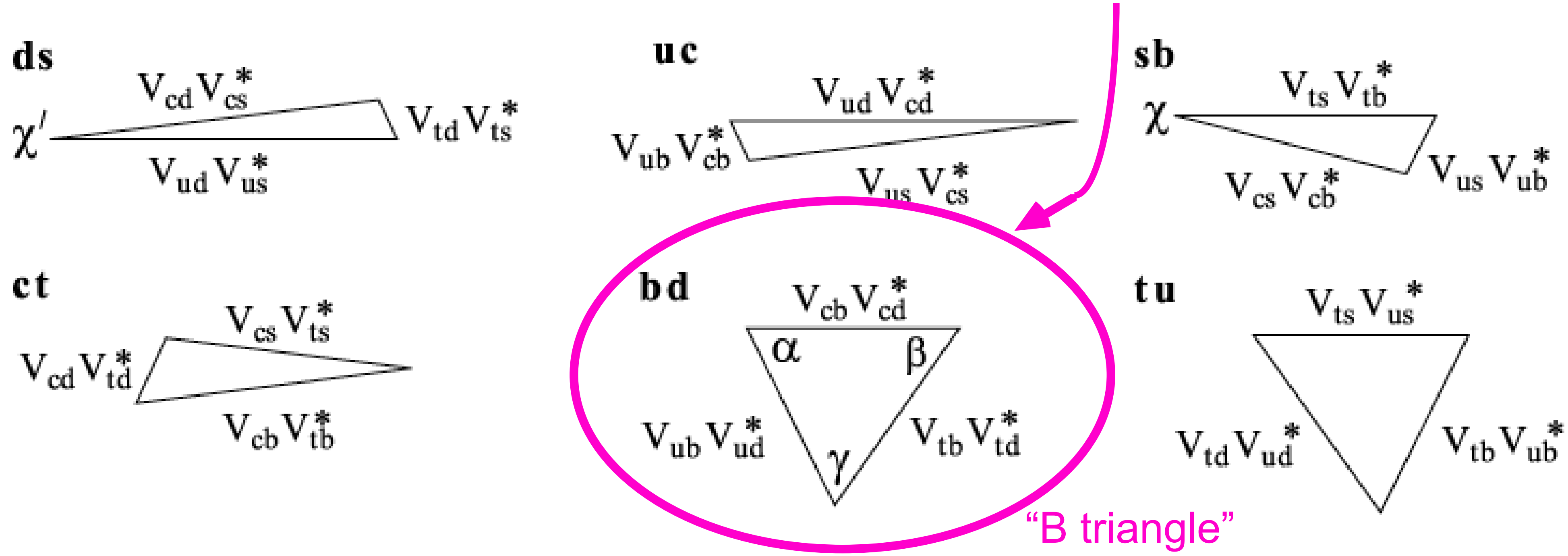

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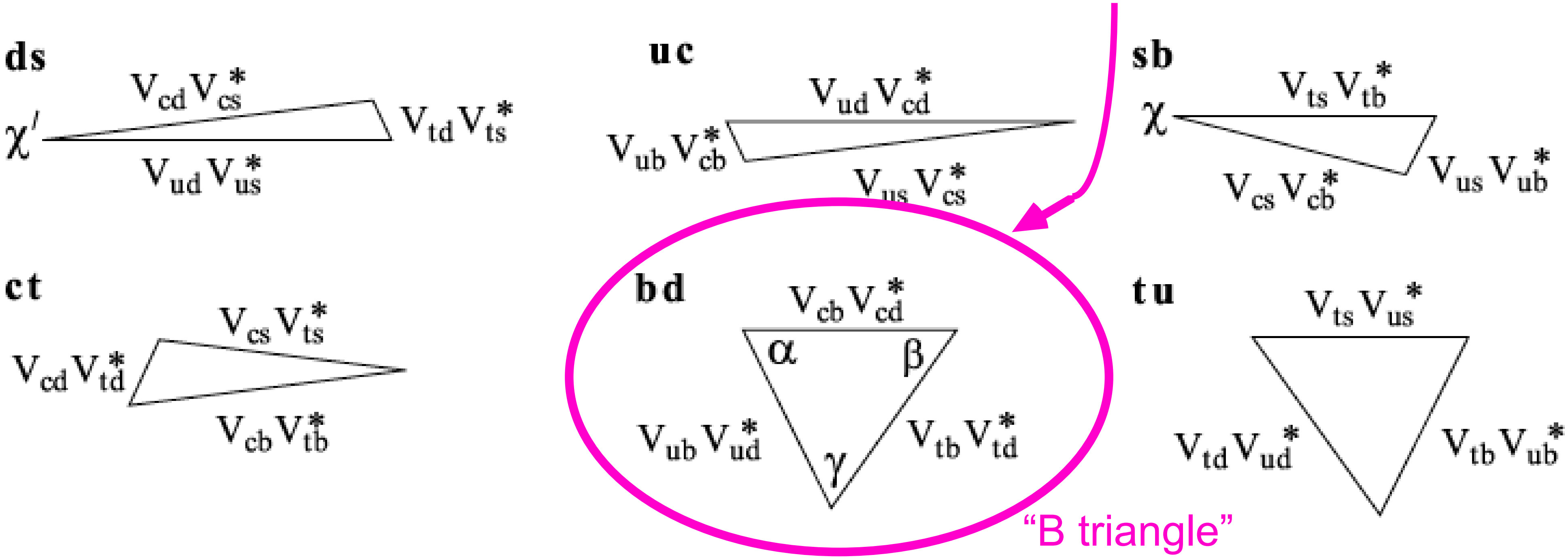
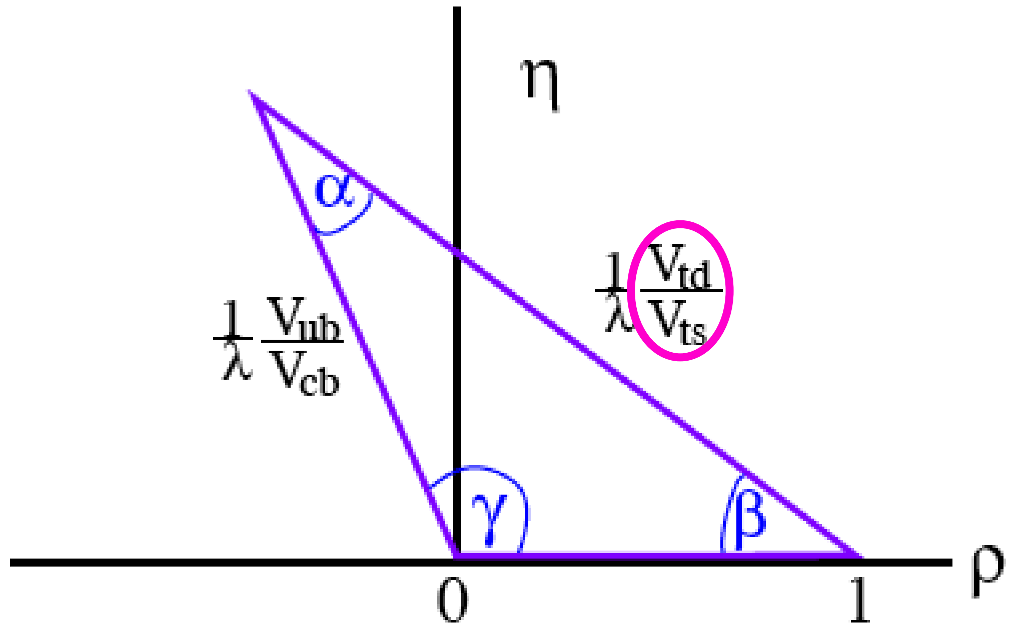


- Sides determine B decays and mixing, angles determine B CP violation

⇒ If CKM phase is origin of CP violation, angles & sides will be consistent, and angles measured in different processes will have the same values

Testing SM Mixing and ~~CP~~

- Note angle γ and its opposite side are challenging to measure:



Normalized unitarity triangle on Wolfenstein-parameter (ρ–η) plane

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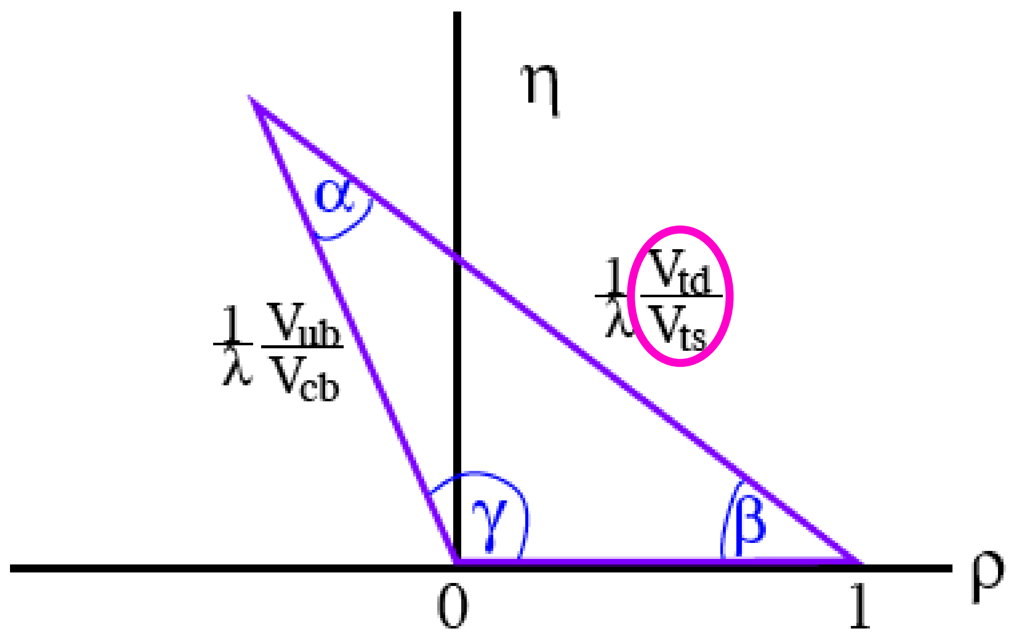

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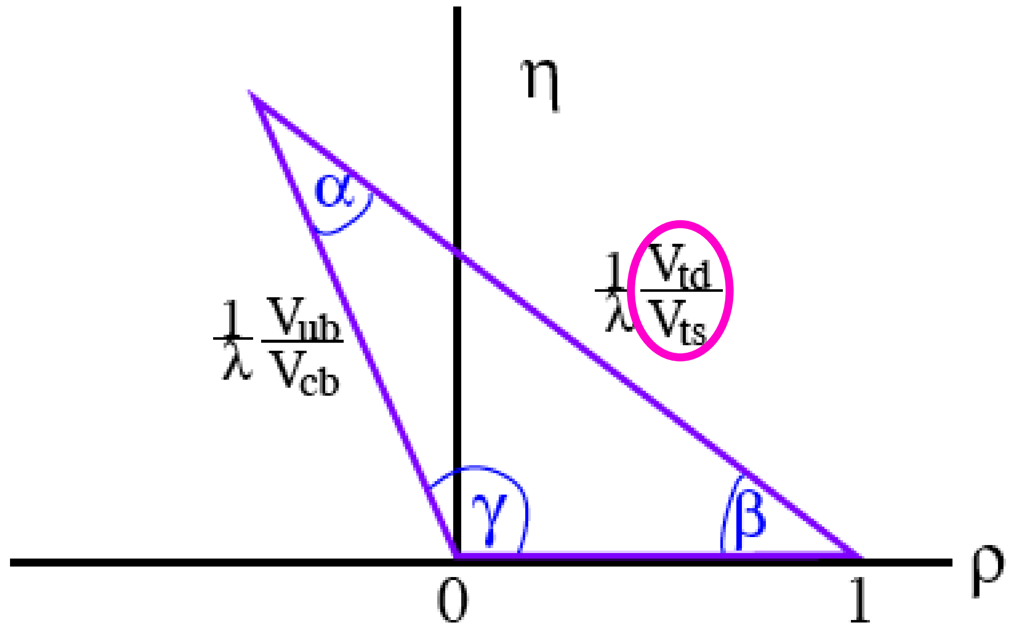

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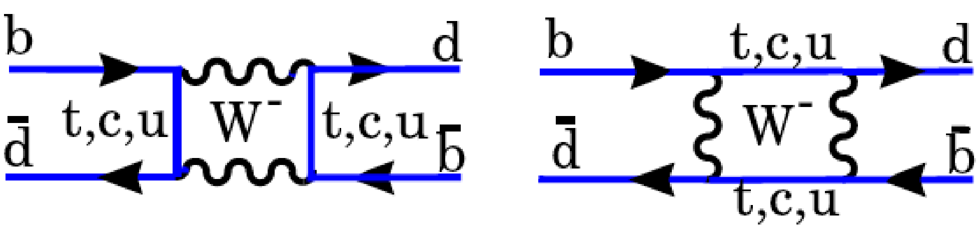
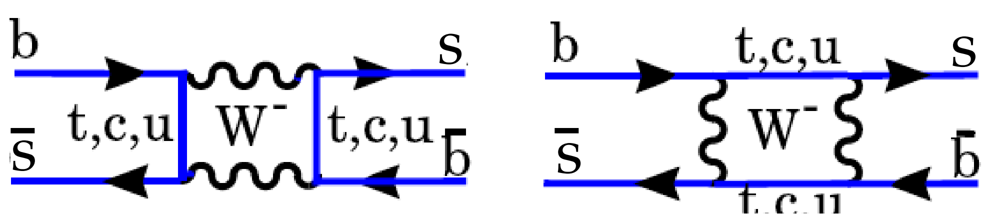


vs



→ various theoretical uncertainties cancel in the ratio $\Delta m_d/\Delta m_s$

Testing SM Mixing and ~~CP~~

- Angle γ measurable using CP asymmetry of tagged $B_s \to D_s^{\pm} K^{\mp}$ events:

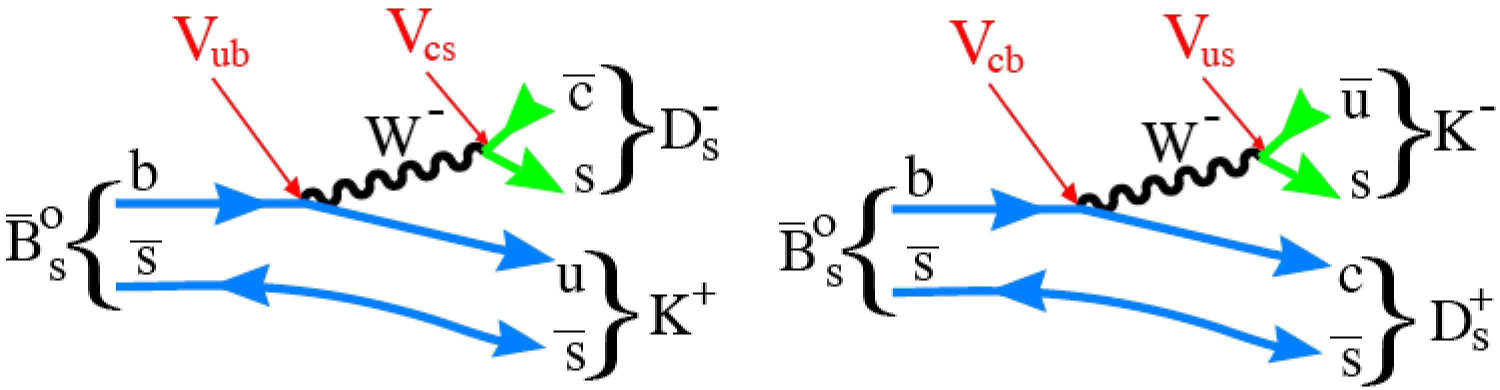
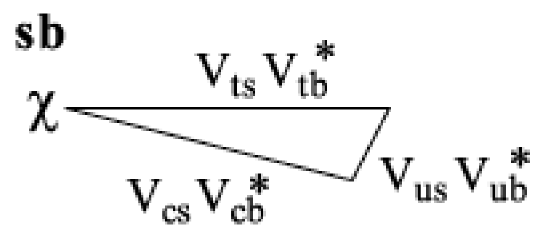


Figure 1.13: Two diagrams for $\overline{B}_s^o \to D_s^{\pm} K^{\mp}$.

Note BTeV Proposal Update (2002) → Δ(sin γ) = ±11.5° by this method

- Angle χ measurable in $B_s \to J/\psi\ \eta,\ J/\psi\ \eta'$



- Various other B_s decays also important: $B_s \to K^+ K^-$, $B_s \to D_s^+ \pi^-$...

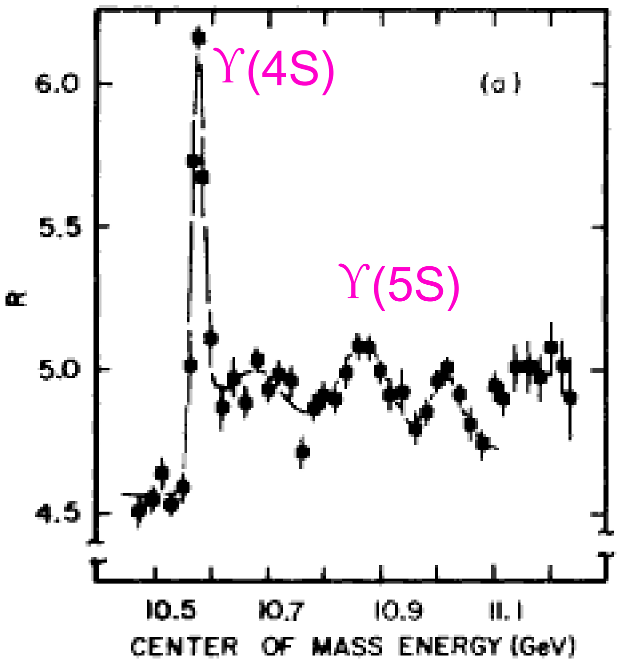
How to Study B_s?

- Impractical in e^+e^- B factory

→ would need $J^{PC} = 1^{--}$ resonance with large BR into B_s

– $\Upsilon(4S)$ too low in mass
⇒ would need to use $\Upsilon(5S)$

but $\Upsilon(5S)$ cross section is small:



and

– $BR(\Upsilon(5S) \to B_s)$ unknown,

but,

from CLEO [Chul Hi Park, PhD thesis UMI-91-21403-mc, Oct 1990]:

"We extract an upper limit of 30% on the B_s fraction in $\Upsilon(5S)$ decays using the measured D_s^+."

How to Study B_s?

- Might be done in hadron collider (CDF, D0, LHCb)
  - but tagging efficiency $\ll 1$

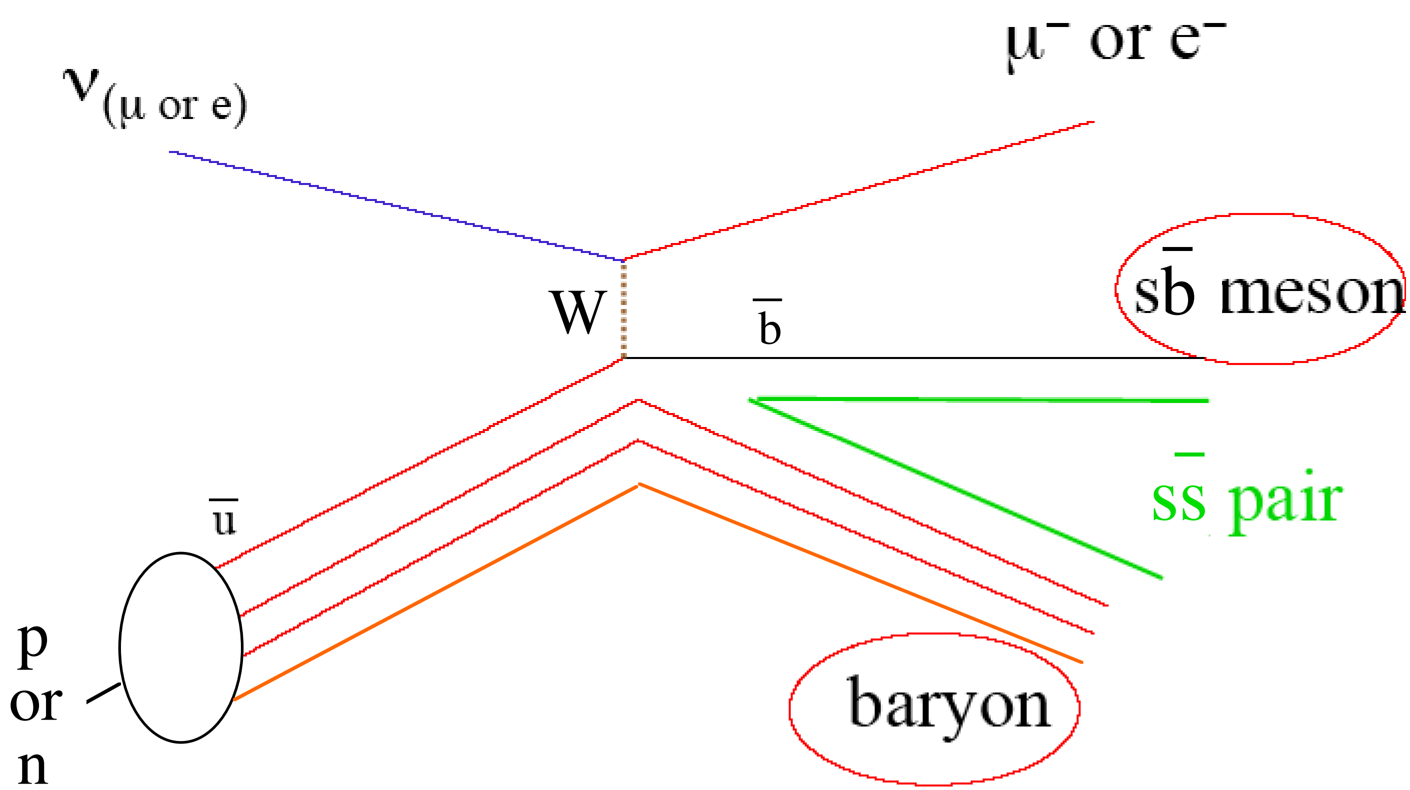
    e.g. BTeV study (BTeV Proposal Update, 2002) $\rightarrow \varepsilon D^2 = 13\%$

    [sum of εD^2 for
    • Same Side Tagging (Kaon for B_s and Pion for B^0)
    • Away Side Kaon Tagging
    • Away Side Lepton Tagging
    • Jet Charge Tag]
- Remains to be seen how well this works in practice
- Nevertheless, e.g. LHC*b* hope to measure Δm_s to ~ 0.01 ps^{-1} if $\Delta m_s \lesssim 70$ ps^{-1}

Neutrino Production of B_s

- Neutrino production of B_s has unique advantage...

"Perfect" flavor tagging via flavor-specific production mechanism:



$\Rightarrow$ ν beam makes B_s and $\bar{\nu}$ beam makes $\bar{B}_s$

$\rightarrow$ A high-energy Neutrino Factory makes pure B_s and $\bar{B}_s$ tagged by $\mu^{\mp}/e^{\mp}$

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  ... but at what cost in rate???

Neutrino Production of B_s

- Need neutrino energy well above threshold: $\sqrt{s} \gg 6$ GeV

$\Rightarrow E_\nu > 20\,\text{GeV}$ – say $E_\nu \sim 50\,\text{GeV}$

- Cross-section guestimate: $\sigma(\nu N \to B_s X) \sim 10^{-40}\,\text{cm}^2$?

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- But $b \to u$ production CKM-suppressed $\sim 10^{-2}$ w.r.t. Cabibbo-suppressed $u \to c$

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→ Is a Neutrino Factory also a B_s Factory?

Further issues

- To do the *b* physics, need
  - superb vertex resolution throughout assumed-$10^3\ \mathrm{m}^3$ near-detector volume!

    (but maybe $10^{10}\ B_s$/y is more events than necessary $\Rightarrow$ detector can be smaller?)
- What energy is best?
  - note $\sigma \propto E_\nu$
- How (im)perfect will the tagging be?
- All things considered, how well can the *b* physics be done?
  - Monte Carlo study is called for
- What else...?

Summary

- B_s production by high-energy Neutrino Factory potentially very interesting
- Simulation work needed to quantify *b*-physics reach