

# The 'Other' Unitarity Triangles

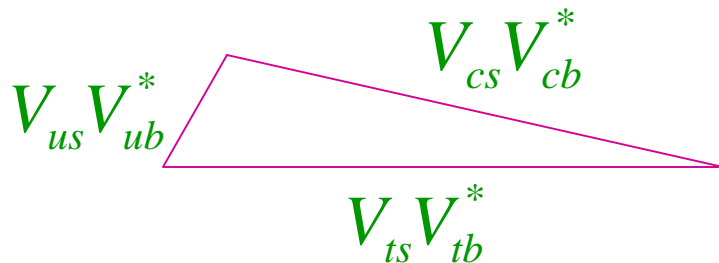
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$V_{\text{CKM}}$  is a unitary matrix  $\Rightarrow$  12 equations

$$V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 0 \text{ the unitarity triangle: sides } O(\lambda^3)$$

The 'other' unitarity triangles are:

$$(1) \quad V_{us} V_{ub}^* + V_{cs} V_{cb}^* + V_{ts} V_{tb}^* = 0 \text{ 'squashed' triangle:}$$



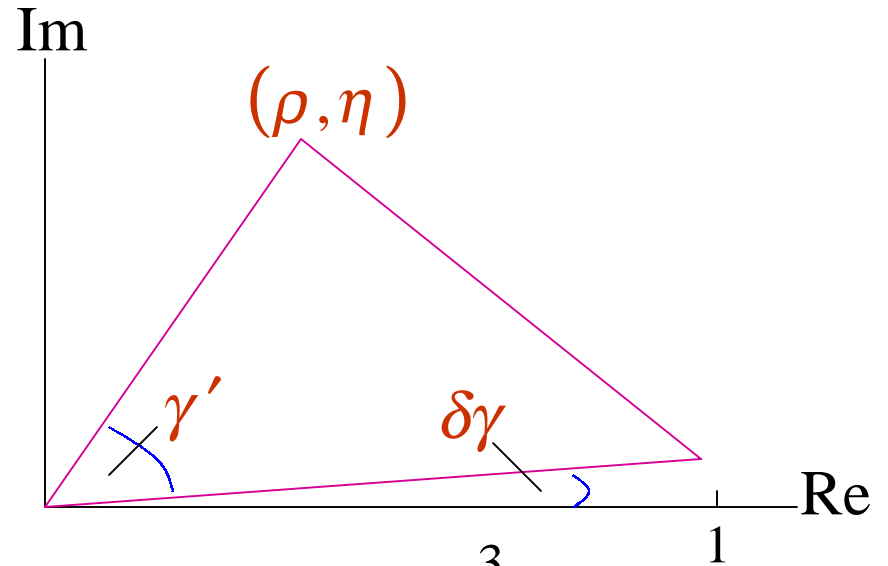
$$\beta_s \equiv \arg \left[ -\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right] = \lambda^2 \eta + O(\lambda^4)$$

very small;

# The 'other non-squashed' triangle

(2) 'non-squashed' triangle:

$$V_{ud}^* V_{td} + V_{us}^* V_{ts} + V_{ub}^* V_{tb} = 0$$



Agrees with 'the' unitarity triangle at leading order ( $\alpha(\lambda^3)$ ).

Different when next-to-leading order terms are taken into account.

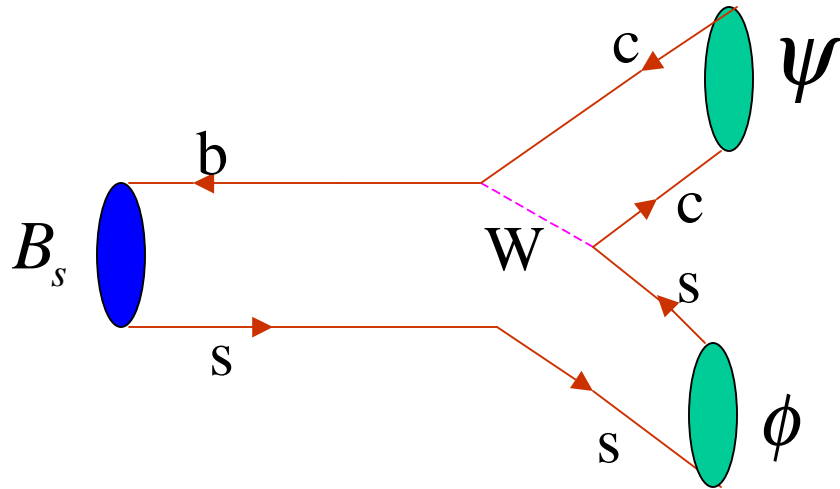
Angle  $\delta\gamma = \lambda^2 \eta$  measures CP violating weak  $B_s^0 - \overline{B_s^0}$  phase  $\phi_s$

$$\phi_s = -2\delta\gamma = -2\lambda^2 \eta$$

Ref: B Decays at the LHC (hep-ph/003238)

$$B_s \rightarrow J / \psi \phi$$

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Gold-plated decay:

Rich physics potential:

- Extract  $\Delta\Gamma_s$  and  $\Delta m_s$
- Probe  $\phi_s$  and measure  $\eta$

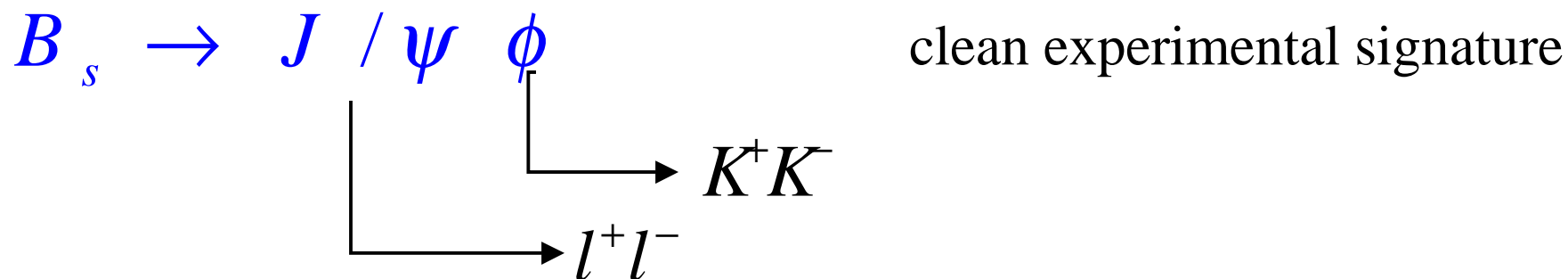
Most interesting feature:

Tiny CP violating asymmetry in the SM  $O(0.03)$

$\Rightarrow$  new physics contribution is a correction to essentially zero!

# Angular analyses

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But final state is an admixture of different CP eigenstates

$\Rightarrow$  ‘angular’ analysis needs to be performed

Dighe, Dunietz, Lipkin & Rosner (hep-ph/9511363) suggest  
‘simple(!!!) angular distribution based on a transversity variable’ .

This allows one to directly separate the summed contribution of the even partial waves (S,D) from the odd one (P) by means of their opposite parities.

CDF (F.Abe et al., Phys. Rev.Lett. 75 (1995) 3068) reported the first angular distribution analysis of the decay  $B_s \rightarrow J / \psi \phi$

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CDF obtained a separation into longitudinal & transverse helicity amplitudes and longitudinal polarization fraction  $\Gamma_L/\Gamma$

$$\Gamma_L / \Gamma = 0.56 \pm 0.21(\text{stat})_{-0.04}^{+0.02}(\text{sys})$$

But no statement about the CP-even & CP-odd contribution

Dighe, Dunietz, Fleischer (hep-ph/9804253) suggest using appropriate weighting functions for the angular distributions of the decay products (**moment analysis**) to extract  $(\Gamma_H, \Gamma_L, \Delta m)_{B_s}$

$$\phi_s = -2\lambda^2\eta = -2\lambda^2 R_b \sin \gamma \quad \text{where}$$

$$R_b \equiv \frac{1}{\lambda} \frac{|V_{ub}|}{|V_{cb}|}; \quad R_b = 0.36 \pm 0.08$$

$\Rightarrow \phi_s$  allows determination of  $\gamma$   $\rightarrow$  comparison of  $\gamma$  obtained from  $B_s$  &  $B_d$   
 $\Rightarrow$  Test whether the  $B_s$  &  $B_d$  mixing phases are described by SM or NP

## Experimental issues:

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▪ **Untagged analyses** (no distinction b/w initially present  $B_s$  or  $\bar{B}_s$  meson

⇒  $|\cos \phi_s|$   
Require large  $|\Delta\Gamma_s|$

▪ **Tagged analyses**

⇒  $\sin \phi_s$   
Require  $\Delta m_s$

Expected SM asymmetry is not within CDF/DØ experimental reach.

⇒ Any asymmetry seen would be a sure sign of new physics!

# Future prospects

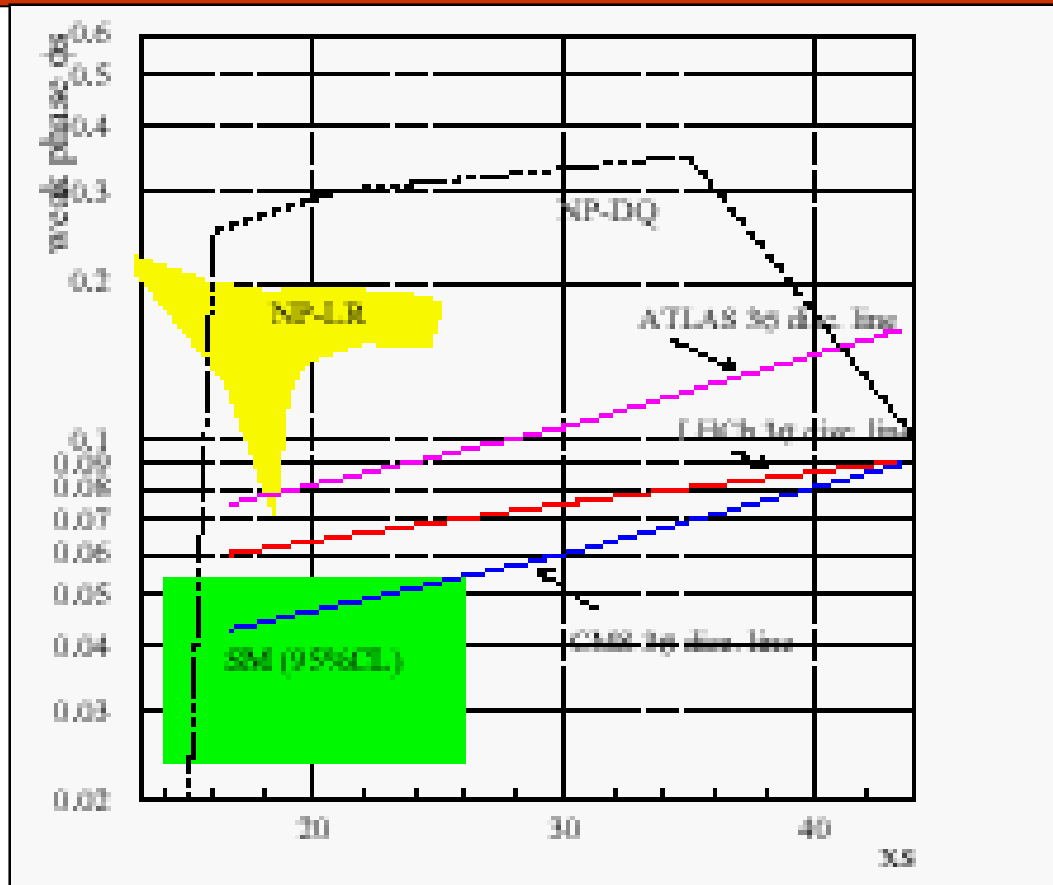
	ATLAS	CMS	LHCb
Event yields	300,000 (3yrs)	600,000 (3yrs)	370,000 (5yrs)
Proper time resolution	0.063 ps	0.063 ps	0.031 ps
Background	~15%	~ 10%	~3%
	dominated by $B_d^0 \rightarrow J/\psi K^*, J/\psi K^+ \pi^-$	dominated by $B_d^0 \rightarrow J/\psi K^*, J/\psi K^+ \pi^-$	combinatorial

Stat. uncertainty on

$\phi_s(x_s = 20)$	0.03	0.014	0.02
$\phi_s(x_s = 40)$	0.05	0.03	0.03

**BTeV: 0.025 ( $x_s = 20$ ) to 0.035 ( $x_s = 40$ )** Very preliminary!!

# New physics effects



New physics predicts  
CP asymmetries  
as large as  $O(40\%)$

The left-right symmetrical model with spontaneous CP violation(NP-LR)

Ref: P. Ball and R. Fleischer, Phys. Lett. **B475**, 111 (2000).

The isosinglet down quark (NP-DQ)

Ref: D. Silverman, Phys. Rev. **D58**, 095006 (1998).