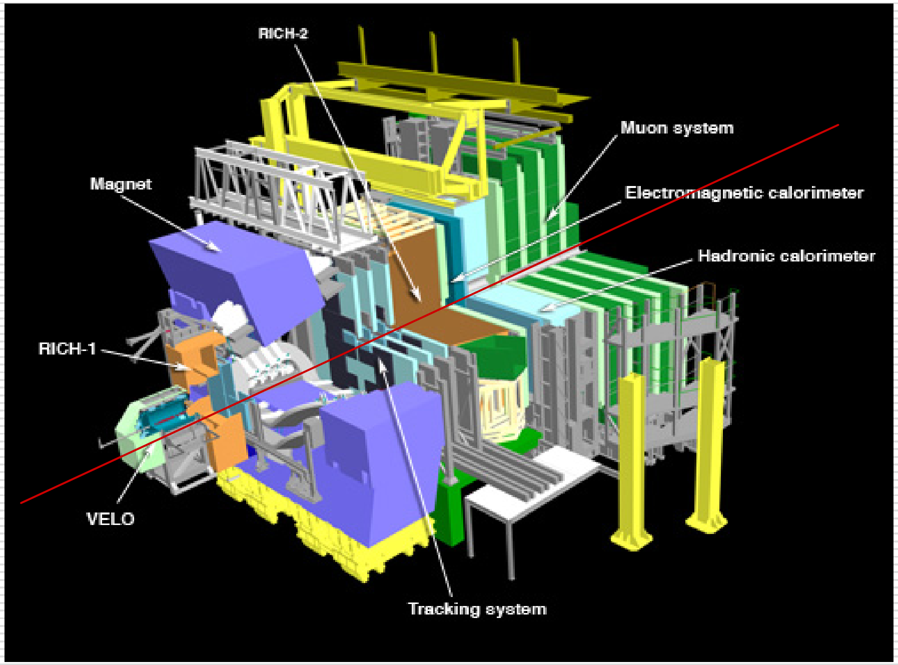
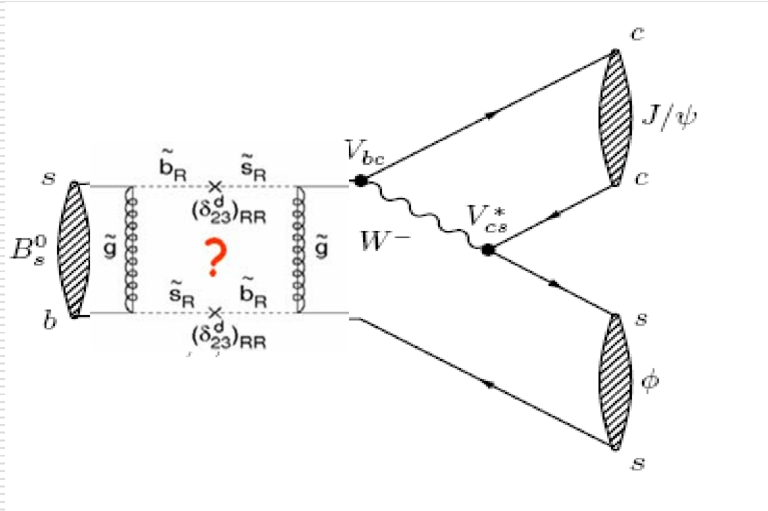
Search for New Physics in $B_s \to J/\psi\ \phi$ at LHCb

Or: "the asymmetry in $B_s \to J/\psi\ \varphi$ is easy to measure…"





Daan van Eijk

LHCb, Nikhef

BND school Rathen

22-09-'09

Excitement in 2008:

FIRST EVIDENCE OF NEW PHYSICS IN $b \leftrightarrow s$ TRANSITIONS

(UT*fit* Collaboration)

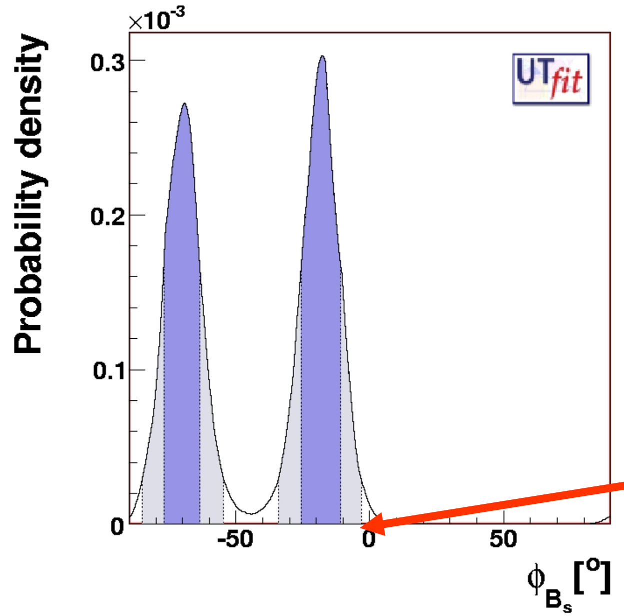
CDF+D0 (<10k events) measurement:

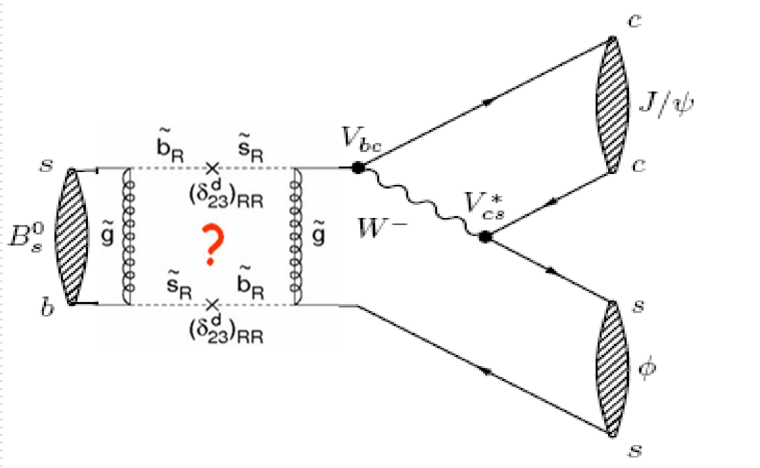
Φ_s = -19.9° ± 5.6°:

Φ_s poorly measured until now!

arXiv:

hep-ph/0803.0659





Prediction: Φ_s^{SM} = -2.11°± 0.10°

$B_s \to J/\psi\ \varphi$ is meson decay

$$
\begin{aligned}
B_s &= \bar{b}s \\
\overline{B}_s &= b\bar{s} \\
J/\psi &= \bar{c}c \\
\phi &= \bar{s}s
\end{aligned}
$$

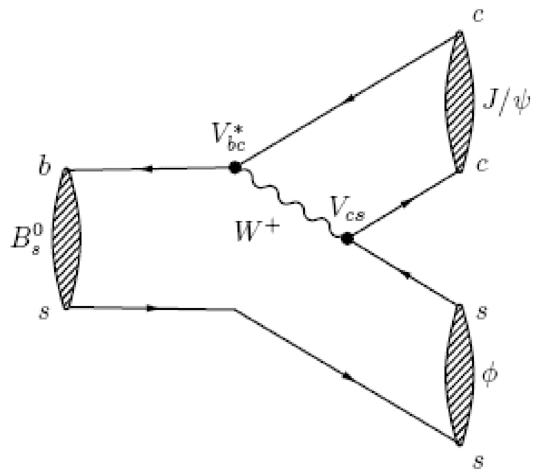
- $B_{(s)}$ particles have a long enough lifetime to fly a distance of ~1cm in the detector.

$B_s \to J/\psi\ \varphi$ is followed by subsequent decay:

- $J/\psi \to \mu^+\mu^-$
- $\Phi \to K^+K^-$

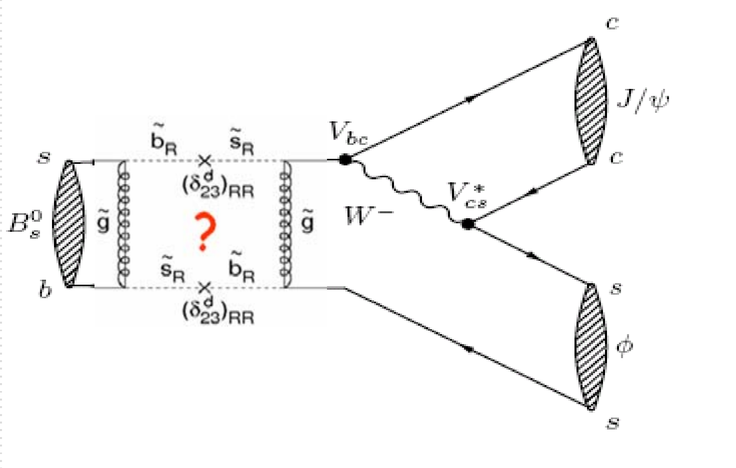
Muons and kaons are the particles that are seen in the detector, trigger on properties of those particles and their reconstructed tracks.

Tree diagram for $B_s \to J/\psi\ \varphi$:

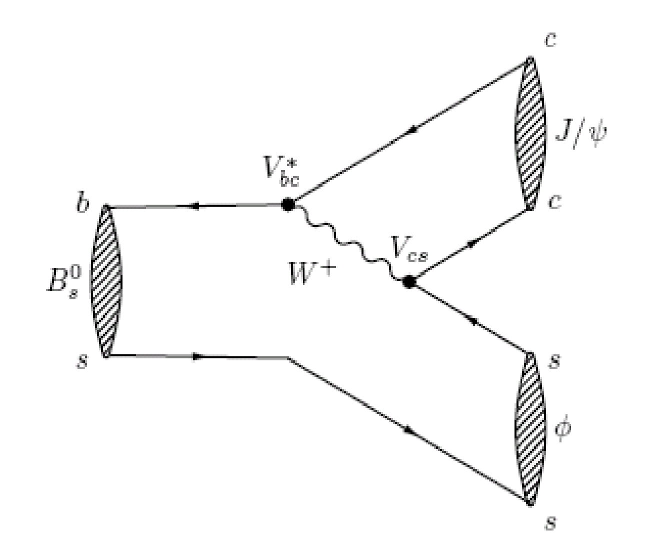


$B_s \to J/\psi\ \varphi$ in SM

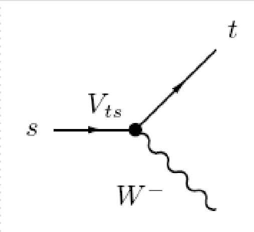
New Physics (NP):

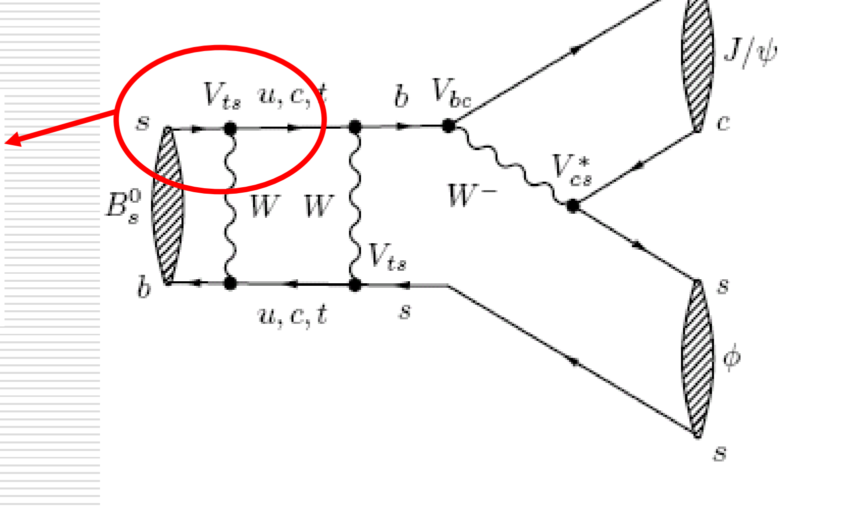


Tree diagram



$B_s \to \overline{B}_s$ mixing diagram





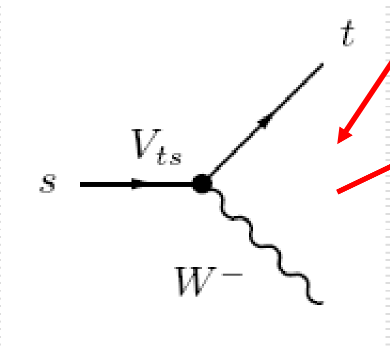
CKM-matrix in the SM Lagrangian

$$\mathcal{L}_{kinetic,cc}(Q_L) =$$

$$= \frac{g}{\sqrt{2}} \overline{u_{iL}} (V_L^u V_L^{d\dagger})_{ij} \gamma_\mu W^{-\mu} d_{iL} +$$

$$V_{CKM} = (V_L^d V_L^{u\dagger})_{ij}$$

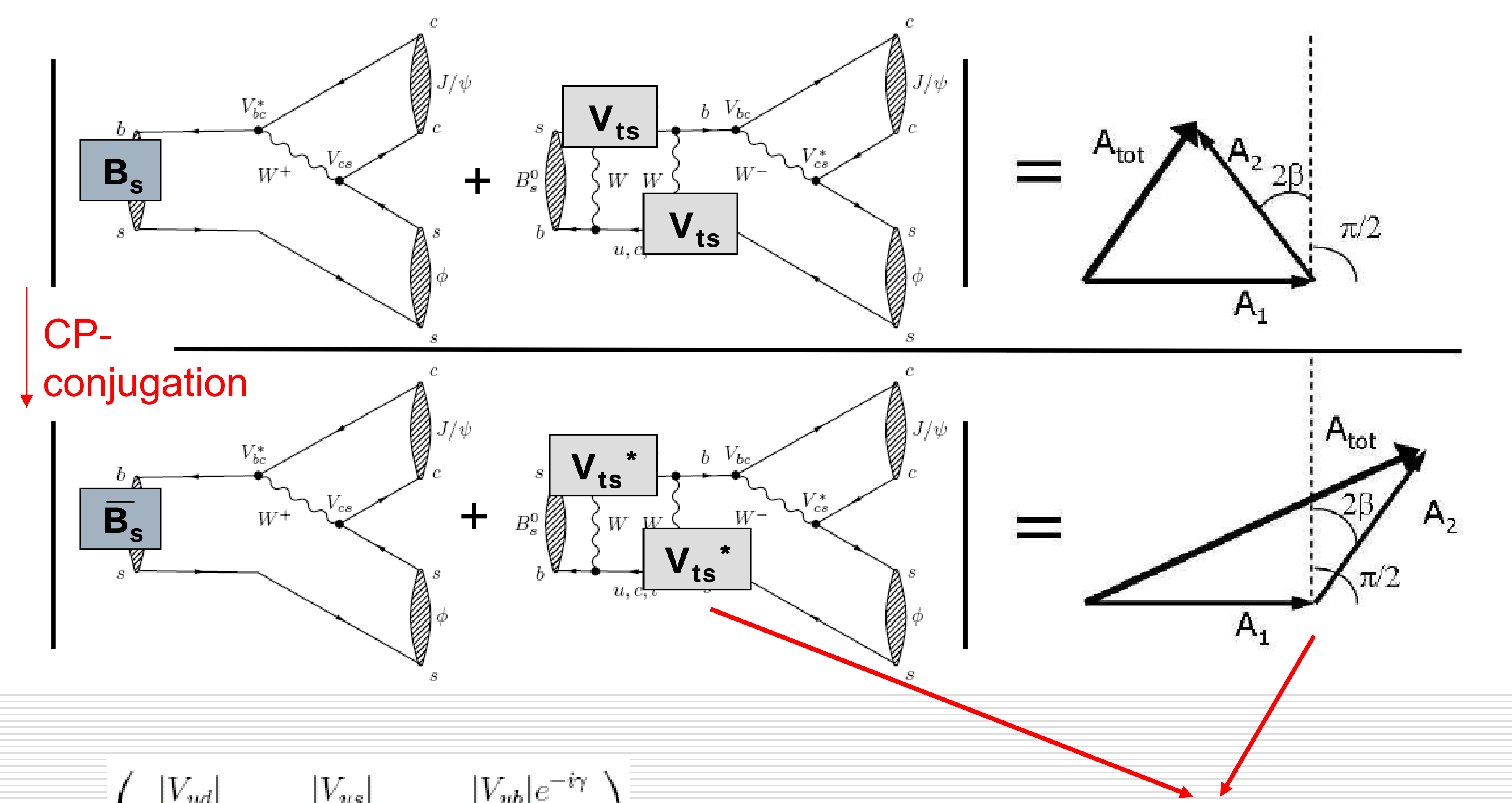
Vertex has amplitude V_{ts}



$$\mathbf{V_{CKM}} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} + \mathcal{O}(\lambda^5)$$

$\Phi_s = -2\beta_s + \Phi_{NP}$

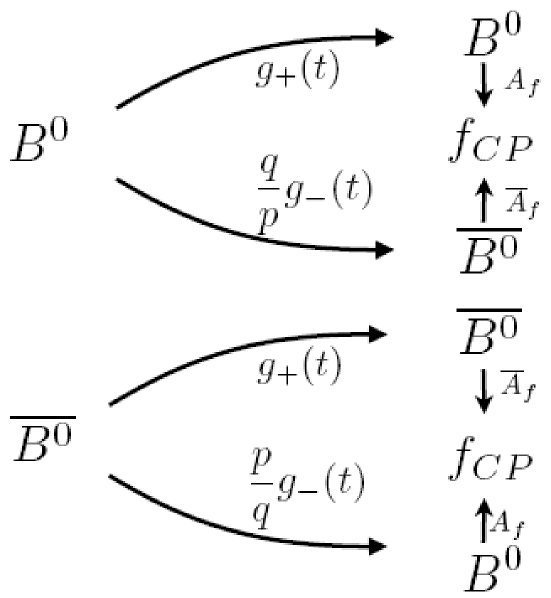
At LHCb: Measure complex phases



$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix}$$

Weak phase flips sign under CP-conjugation!

CP-violation: what is it?



$$g_+(t)A_{f_{CP}} + \frac{q}{p}g_-(t)\overline{A}_{f_{CP}}$$

$$g_+(t)\overline{A}_{f_{CP}} + \frac{p}{q}g_-(t)A_{f_{CP}}$$

$$\Gamma \propto |A_{+-}|^2 \left[|g_+(t)|^2 + |\lambda_{+-}|^2 |g_-(t)|^2 + 2\mathcal{R}\left(\lambda_{+-} g_+^*(t) g_-(t)\right)\right]$$

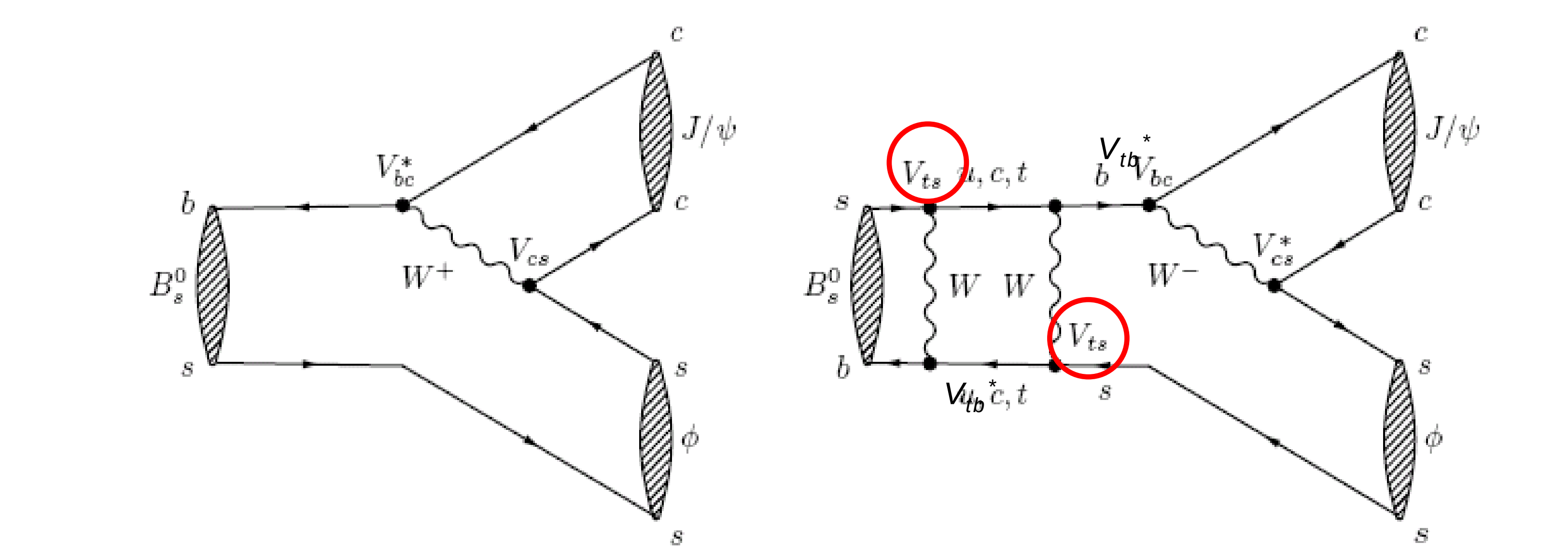
$$\propto |\overline{A}_{+-}|^2 \left[|g_+(t)|^2 + \frac{1}{|\lambda_{+-}|^2} |g_-(t)|^2 + \frac{2}{|\lambda_{+-}|^2}\mathcal{R}\left(\lambda_{+-}^* g_+^*(t) g_-(t)\right)\right]$$

$$\lambda = \frac{q}{p}\frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} = e^{2i\beta_s}$$

$$A_{CP}(t) = \frac{\Gamma_{P^0(t)\to f} - \Gamma_{\bar{P}^0(t)\to f}}{\Gamma_{P^0(t)\to f} + \Gamma_{\bar{P}^0(t)\to f}}$$

$$\sim \sin\Phi_s \sin \Delta m_s t$$

Recap: $B_s \to J/\psi\ \varphi$ and sensitivity to Φ_s



$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix}$$

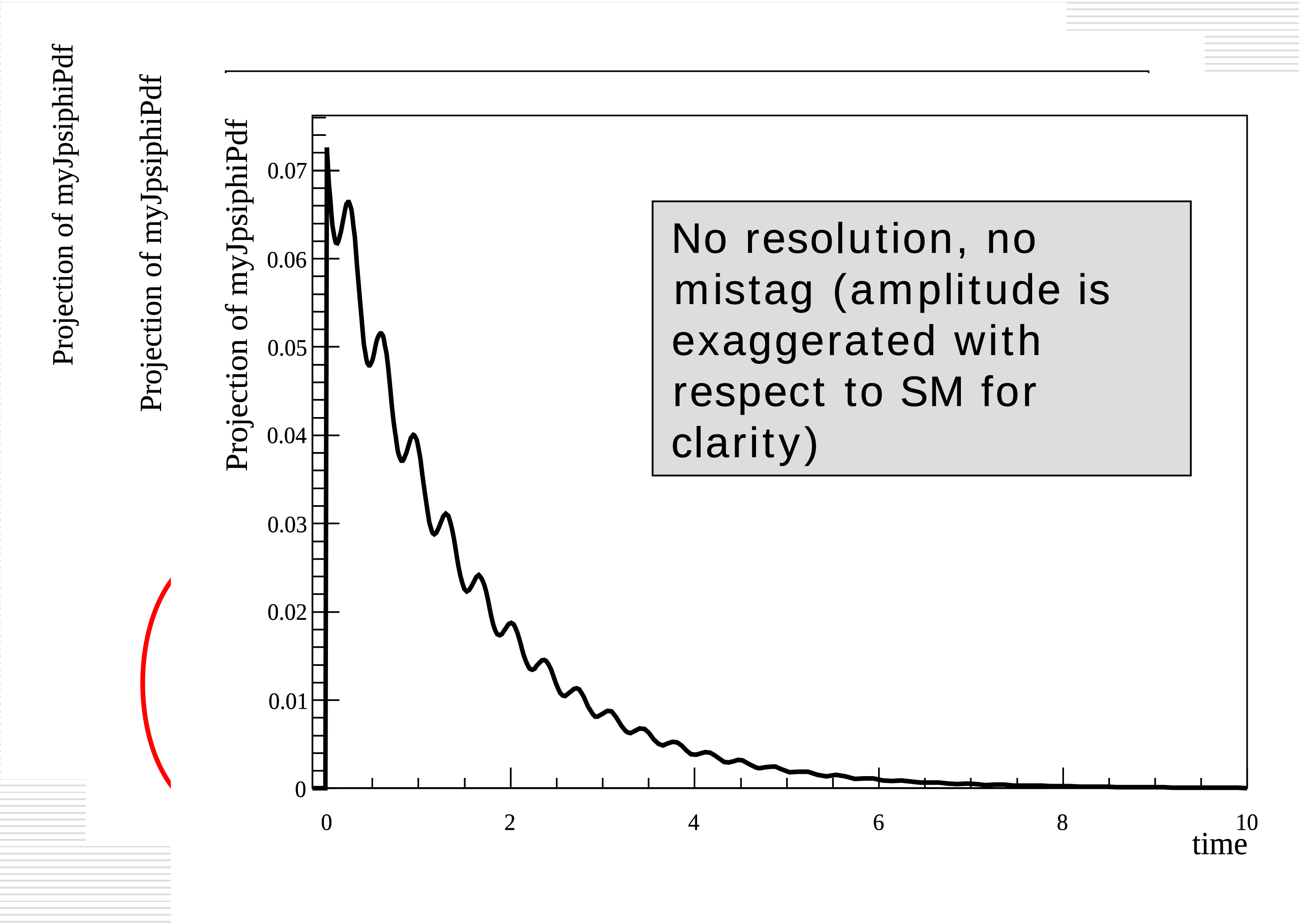
$$\Phi_s = -2\beta_s + \Phi_{NP}$$

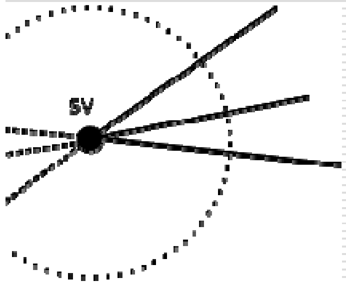
$$A_{CP}(t) = \frac{\Gamma_{P^0(t)\to f} - \Gamma_{\bar{P}^0(t)\to f}}{\Gamma_{P^0(t)\to f} + \Gamma_{\bar{P}^0(t)\to f}}$$

$$\sim \sin\Phi_s \sin\Delta m_s t$$

B_s proper time: $A_{CP} \sim \sin\Phi_s \sin\Delta m_s t$

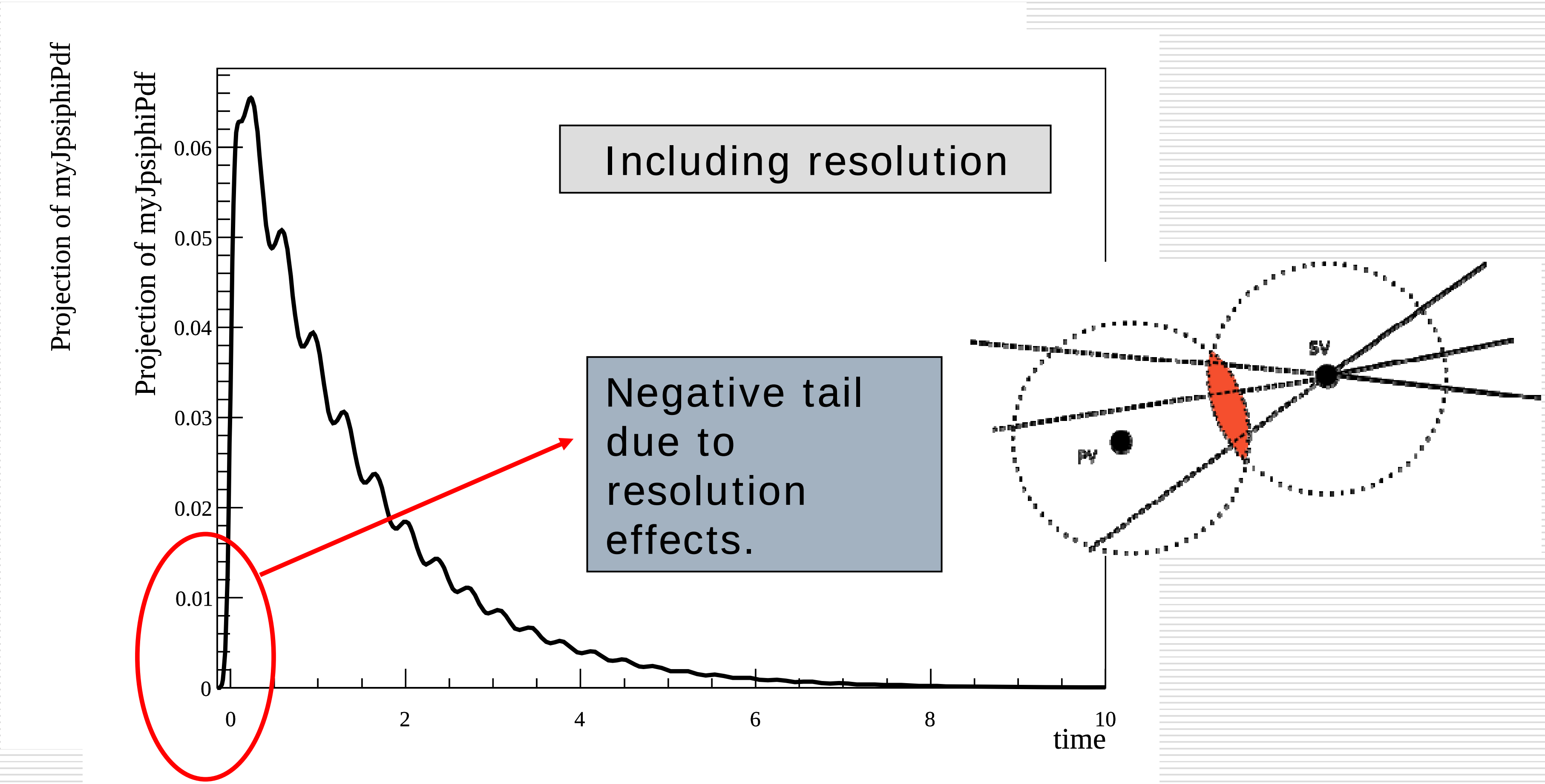
- Amplitude of oscillations is measure for Φ_s





B_s proper time: $A_{CP} \sim \sin\Phi_s \sin\Delta m_s t$

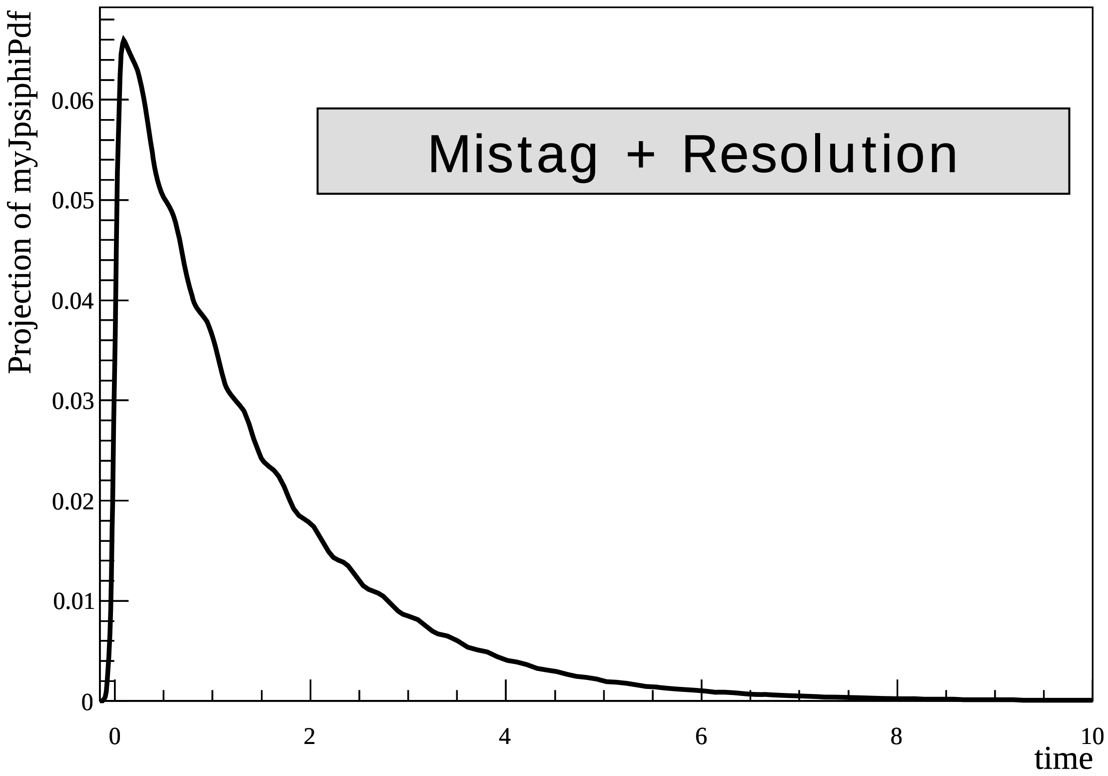
- Amplitude of oscillations is measure for Φ_s



B_s proper time: $A_{CP} \sim \sin\Phi_s \sin\Delta m_s t$

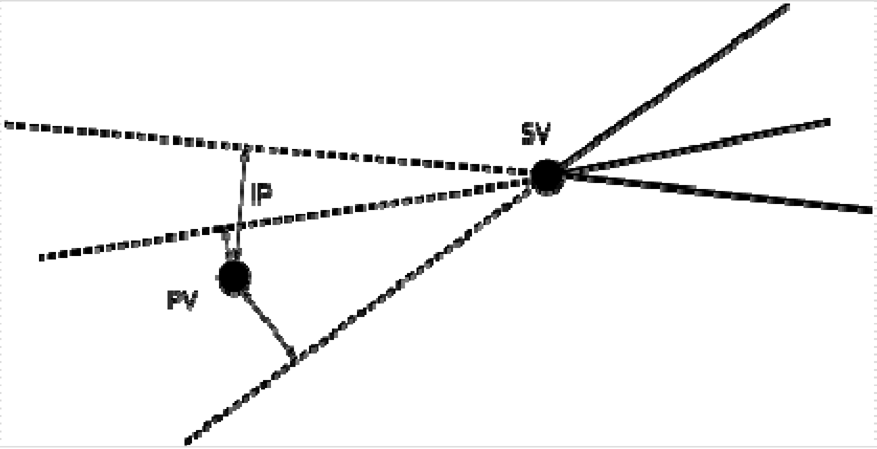
- Amplitude of oscillations is measure for Φ_s

$$A_{CP}(t) = \frac{\Gamma_{P^0(t)\to f} - \Gamma_{\bar{P}^0(t)\to f}}{\Gamma_{P^0(t)\to f} + \Gamma_{\bar{P}^0(t)\to f}}$$



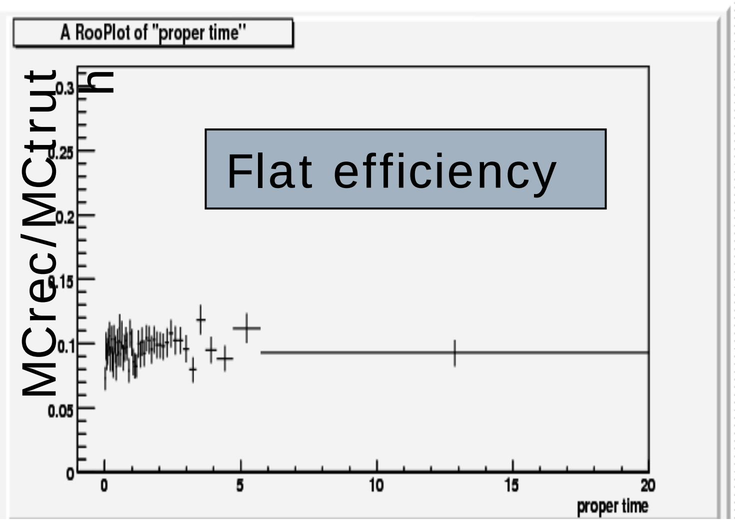
Flavor tagging is determining the flavor of the initially produced B meson, mistag is the fraction of the B's tagged wrong.

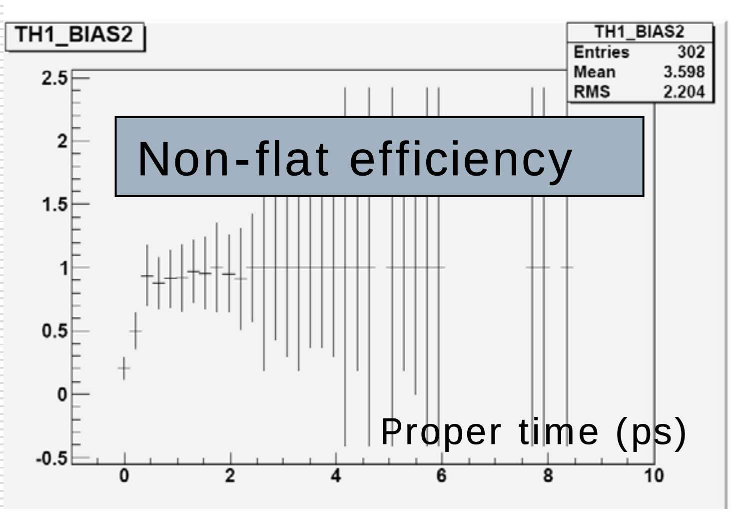
Proper time efficiency + resolution



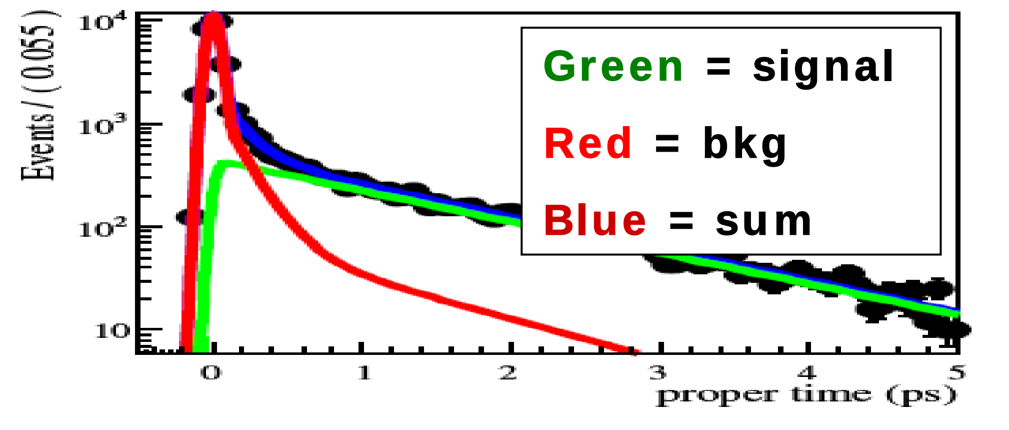
In the ideal case, without background:

- Determine resolution from negative tail, need events at small t for this
- This means making a selection such that efficiency is flat, meaning without IP cut.





Including background



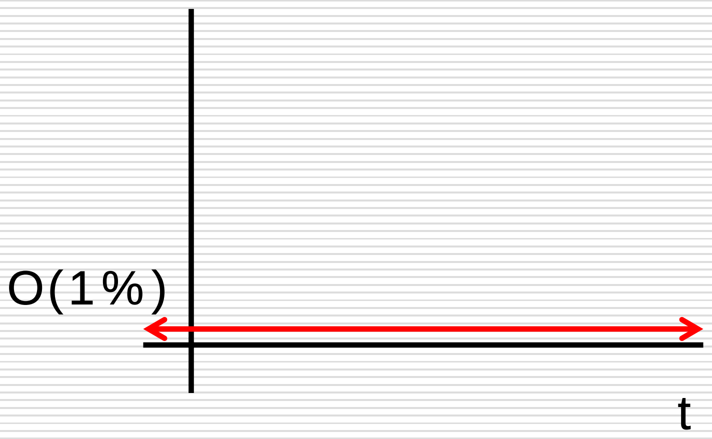
- Need events around t=0 for resolution
- Main background is prompt background (created around t=0)
- Problem: trigger rates too high
- And: These events do not contribute much to sensitivity of Φ_s

Two possible solutions:

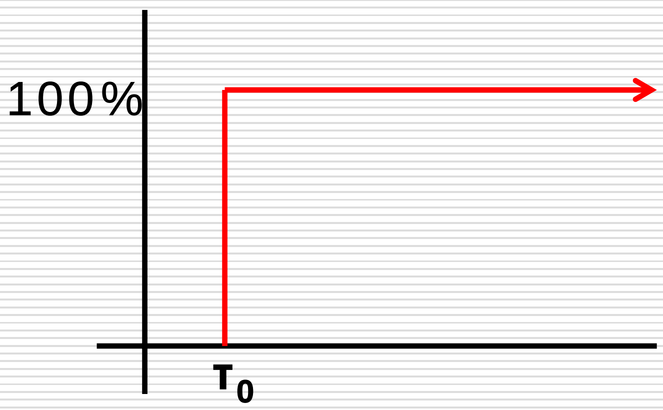
1. (currently used in LHCb)
   - Prevent IP cuts to keep events around t=0
   - Make other smart (but possibly complicated) cuts to remove background, without affecting efficiency.
2. New idea: prescaled and displaced selection

Solution 2: Prescaled and displaced selection

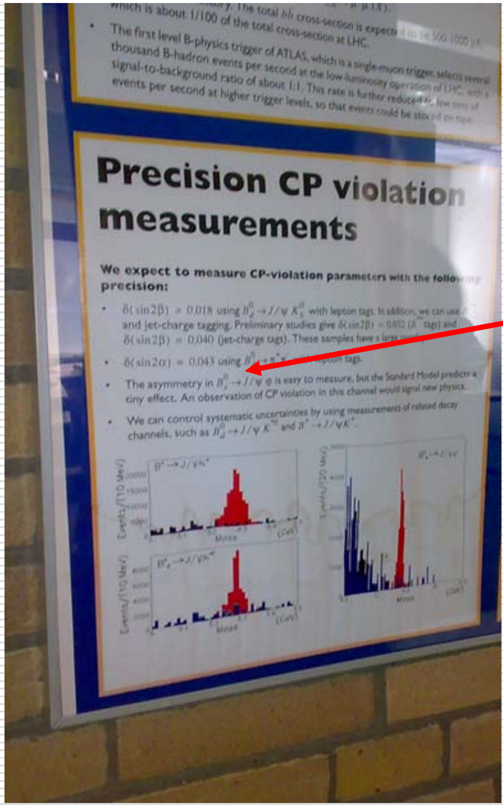
- Prescaled unbiased selection
- Flat efficiency, low rate
- Keep enough background events to determine resolution
- Use as reference to determine proper time efficiency of other samples

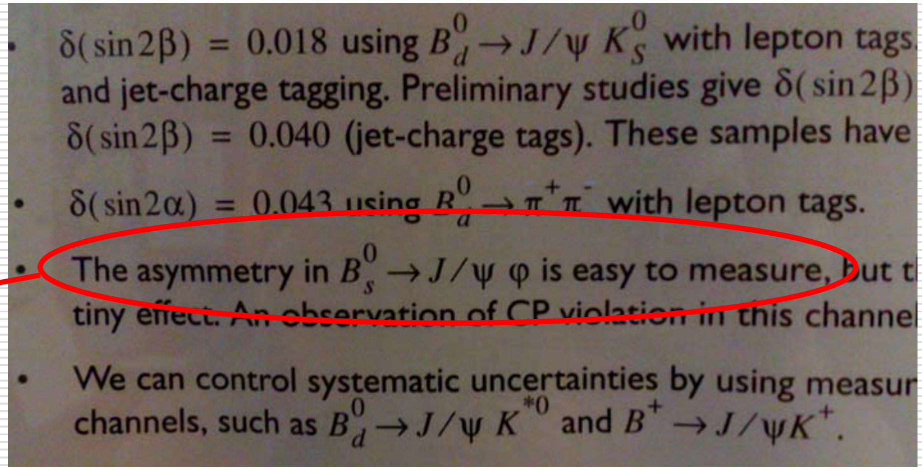


- Displaced selection
- Lifetime cut: cut away prompt background
- Understandable efficiency
- Optimized for sensitivity to Φ_s



Nikhef ATLAS hallway: $B_s \to J/\psi\ \phi$ is easy...



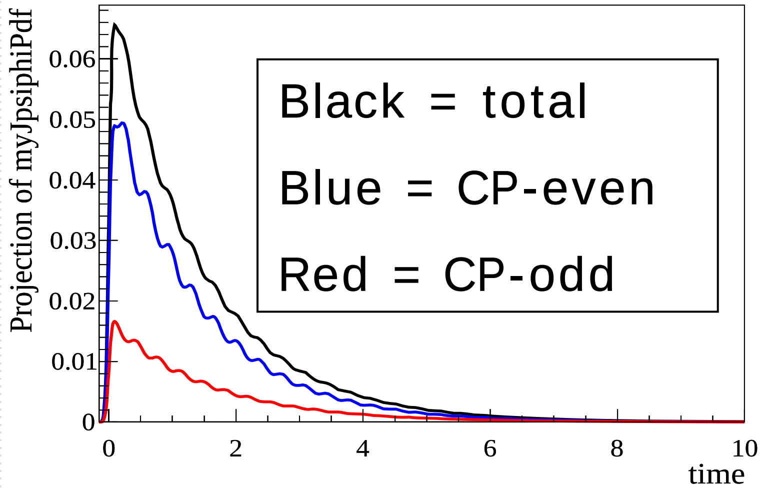


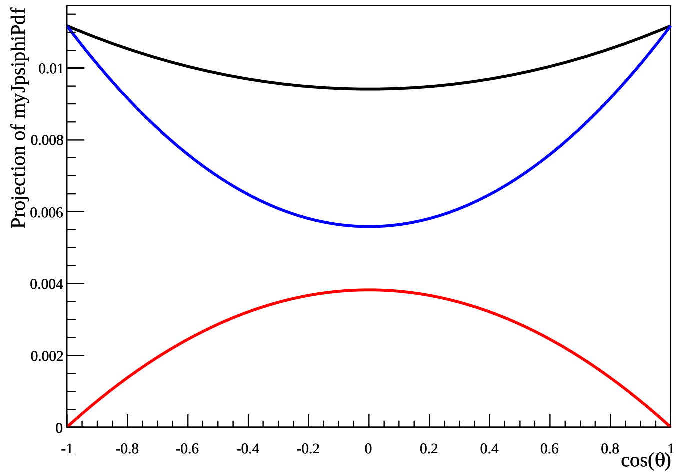
J/ψ	ϕ	
↑ $S_z = 1$	↑ $S_z = 1$	$L_z = -2 \quad L = 2$
← $S_z = 0$	→ $S_z = 0$	$L_z = 0$
← $S_z = 0$	↓ $S_z = -1$	$L_z = 1$

Is it? Extra complication: $B_s \to J/\psi\ \varphi$ has final state that is an admixture of CP-even and CP-odd components due to vector nature of J/ψ and φ.

$J=L+S=0$ (B_s) is conserved!

Angular analysis in $B_s \rightarrow J/\psi\ \varphi$

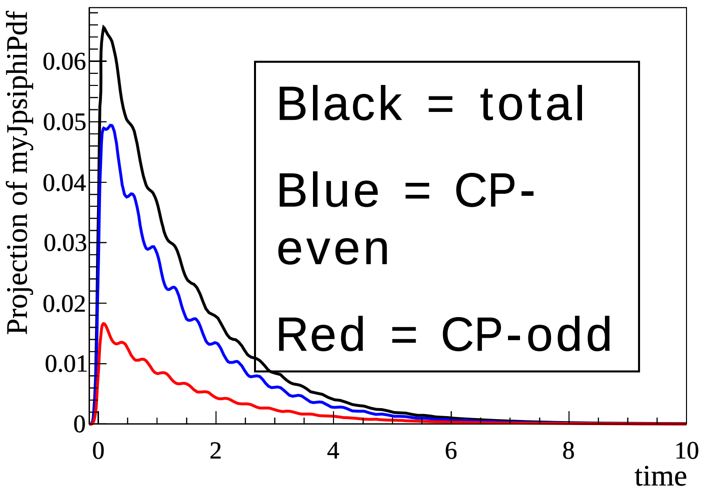


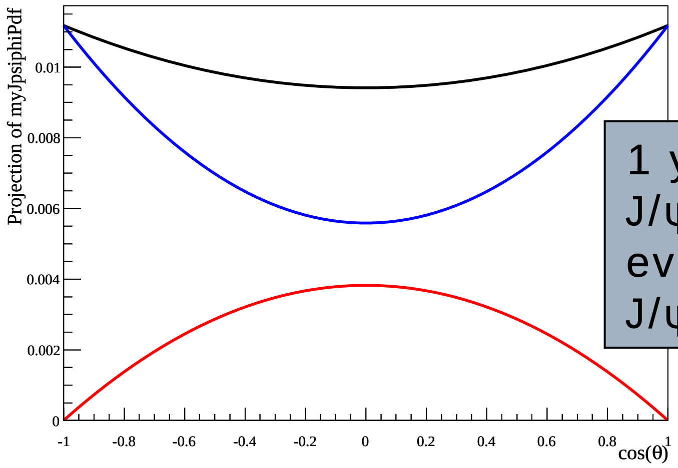


- $B_s \rightarrow J/\psi\ \varphi$ is admixture of CP-even and CP-odd components
- CP-even and CP-odd amplitudes have different sign.
- Need the separate components to determine Φ_s!

Possible to separate the CP-even and CP-odd components in $B_s \rightarrow J/\psi\ \varphi$ using angular distributions.

$B_d \rightarrow J/\psi\ K^*$ requires similar time dependent, angular, tagged analysis as $B_s \rightarrow J/\psi\ \varphi$.





1 year LHCb: 0.2 fb^{-1}
$J/\psi\ K^*$: O(100k) events
$J/\psi\ \varphi$: O(10k) events

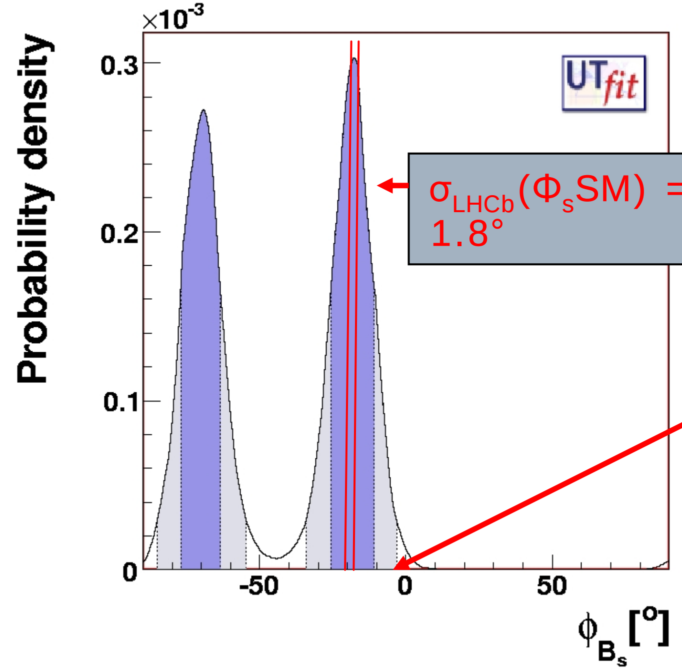
- Angular distributions for $B_d \rightarrow J/\psi\ K^*$ known from BaBar and Belle (B_s not accesible yet there)
- Check the angular efficiencies at LHCb
- Use these angular efficiencies for $B_s \rightarrow J/\psi\ \varphi$
- Only possible if we use the same cuts for both channels!
- Implementing and checking the discussed (trigger) selections for $B_d \rightarrow J/\psi\ K^*$ will be my work the coming months

Prospects for LHCb

FIRST EVIDENCE OF NEW PHYSICS IN $b \leftrightarrow s$ TRANSITIONS

(UT*fit* Collaboration)

Lot of discussion, now fixed to 2 sigma effect. LHCb will greatly improve uncertainty.



$\sigma_{LHCb}(\Phi_s SM)$ = 1.8°

Φ_s^{SM} = -2.11°± 0.10°

Expected sensitivity LHCb after one year (2.0 fb^{-1}):
$\sigma(\Phi_s^{SM})$ = 1.8°

So if $\Phi_{TeVatron} = \Phi_{true}$:

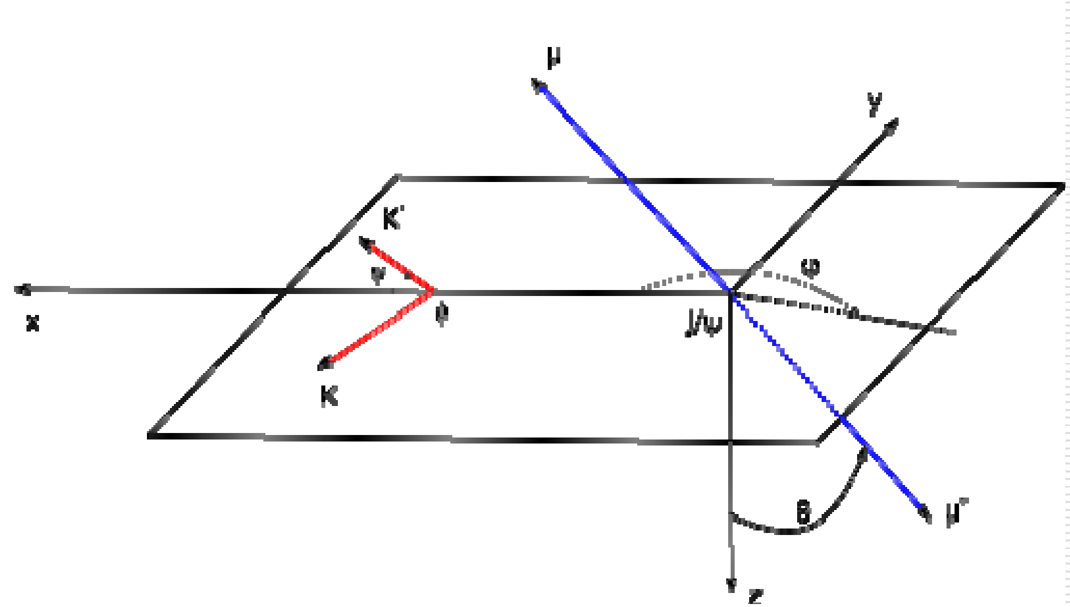
LHCb 5σ discovery!

UTfit: Φ_s = -19.9° ± 5.6°

Φ_s poorly measured until now!

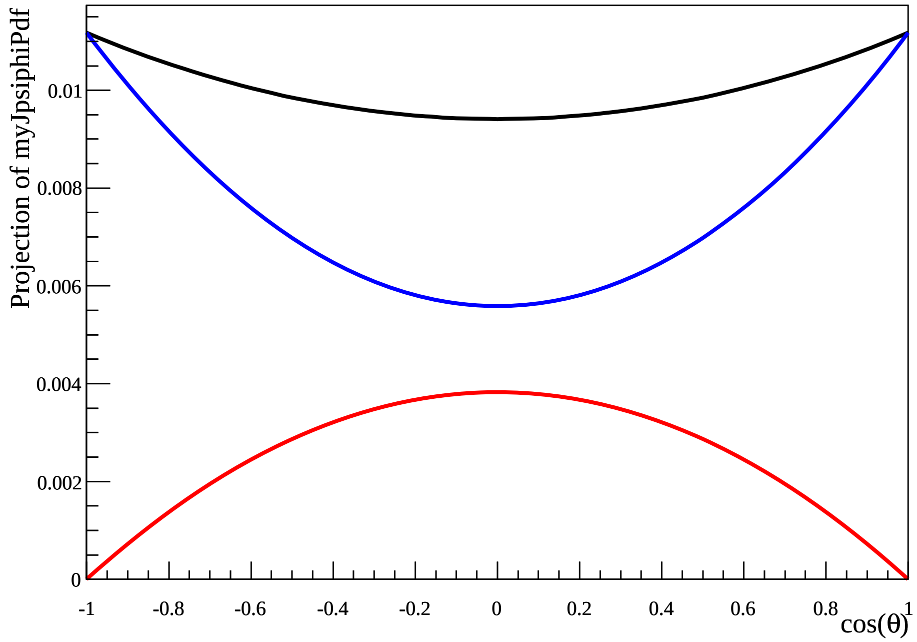
Backup

Topology and time-dependent angular distributions



One-angle distribution

Decay distributions simplify a lot if we integrate over ψ and φ



Possible to separate the CP-even and CP-odd components!

$$d^2\Gamma/(dt\, d\cos\theta) \sim A_{even}\,(1+\sin 2\beta_s)\sin\Delta m_s t\,(1+\cos^2\theta)$$

$$+\,A_{odd}\,(1-\sin 2\beta_s)\sin\Delta m_s t\,(1-\cos^2\theta)$$

S-wave contributions

In $B_s \to J/\psi(\to \mu^+ \mu^-) \varphi(\to K^+ K^-)$ the KK system is in L=1 (P-wave) configuration, since φ is a vector meson with J=1, and the K's have S=0.

J = L + S is conserved

L=0	S-wave
L=1	P-wave

Two S-wave contributions:

- In $B_s \to J/\psi K^+K^-$ the KK system can have any partial wave configuration, so need to take into account the S-wave contribution if the KK invariant mass is around the φ mass!
- Resonant contribution from $B_s \to J/\psi f_0(\to K^+K^-)$, since f_0 is J=0 and also here KK system is in S-wave

(CP-odd) S-wave component of 10%

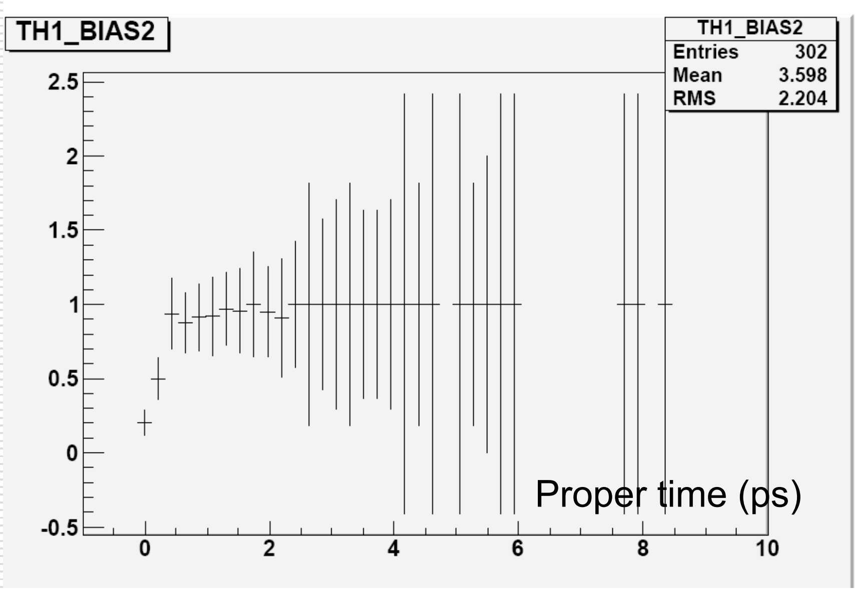
expected under φ(1020)-mass

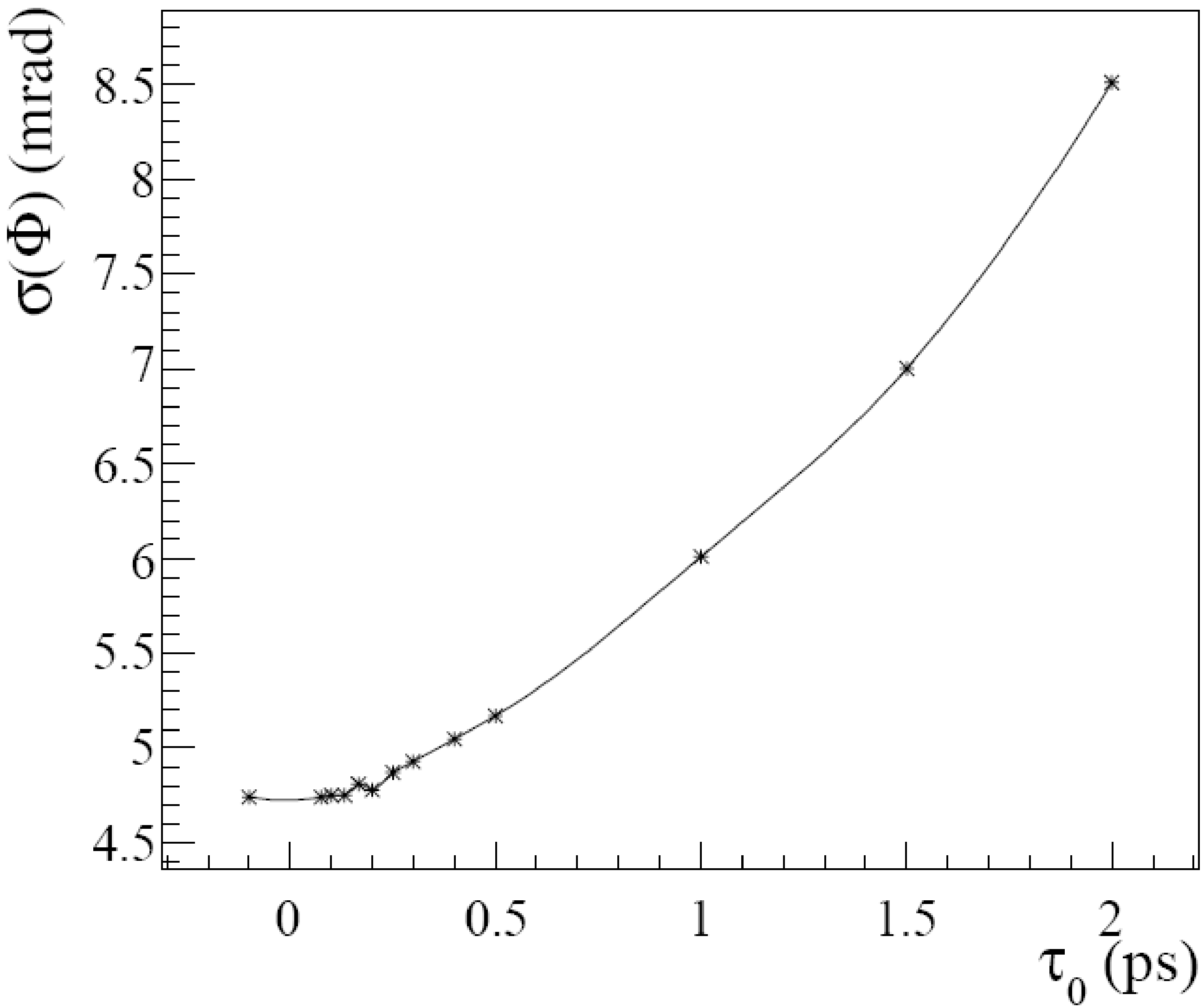
Penguin contributions

Complication: some trigger lines are biased

- Want to include also these lines to obtain more events

- IP-cuts remove background
- Biased samples due to IP-cuts
- Nontrivial efficiency, determine with respect to prescaled sample

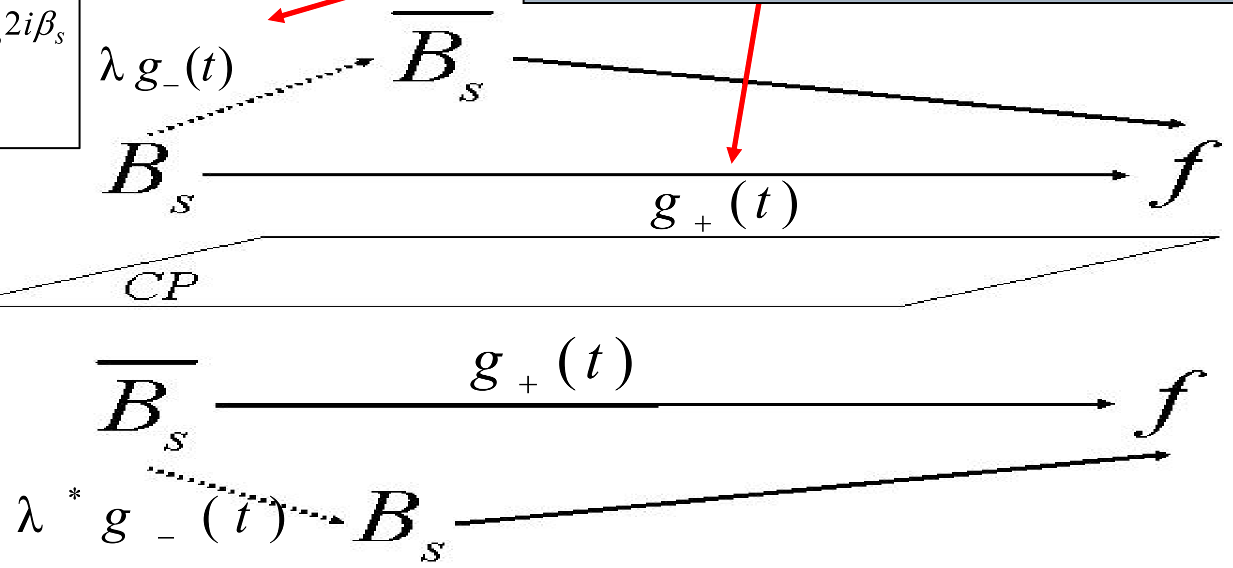



σ(Φ) (mrad)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
0
0.5
1
1.5
2
τ0 (ps)

CP-violation: time-dependent

$$\lambda = \frac{q}{p}\frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} = e^{2i\beta_s}$$

Decay path is time-dependent!



Sum of 2 amplitudes, direct and oscillated

$$A_{CP}(t) = \frac{\Gamma_{P^0(t)\to f} - \Gamma_{\bar{P}^0(t)\to f}}{\Gamma_{P^0(t)\to f} + \Gamma_{\bar{P}^0(t)\to f}}$$

$$\sim \sin\Phi_s \sin\Delta m_s t$$

(Strictly speaking only if $\Delta\Gamma = 0$)