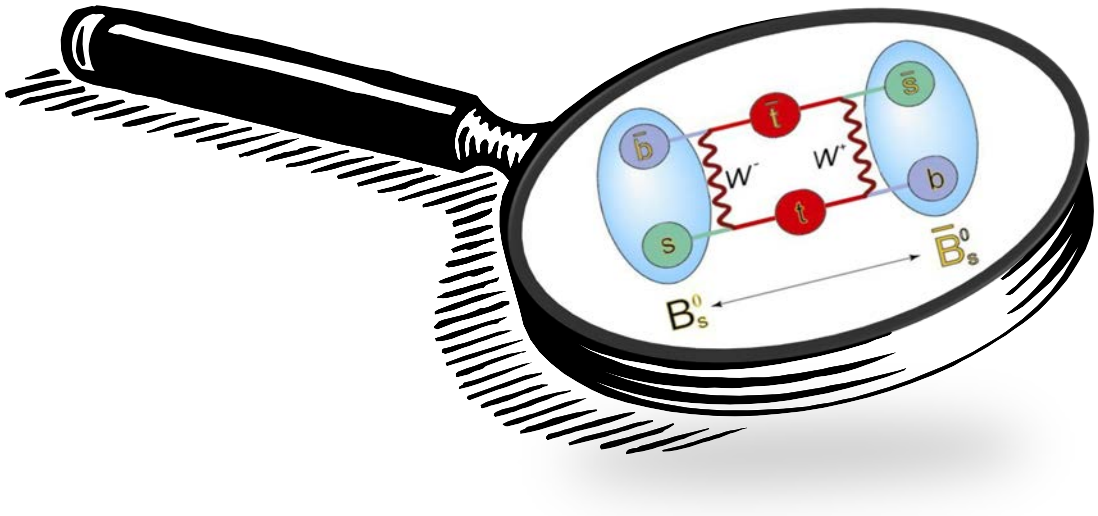
Precision Measurements in the Bottom Quark Sector:

Probing New Physics in Quantum Loops

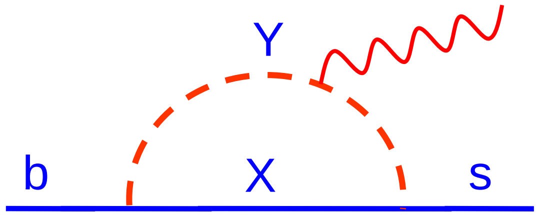


Ulrich Uwer • Physikalisches Institut • Universität Heidelberg

Probing New Physics

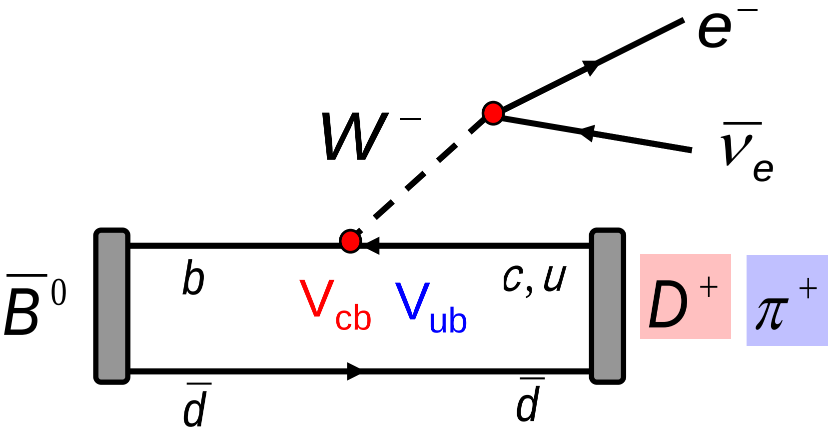
- **Energy frontier:**
  If energy is high enough we can discover NP detecting the production of "real" new heavy particles

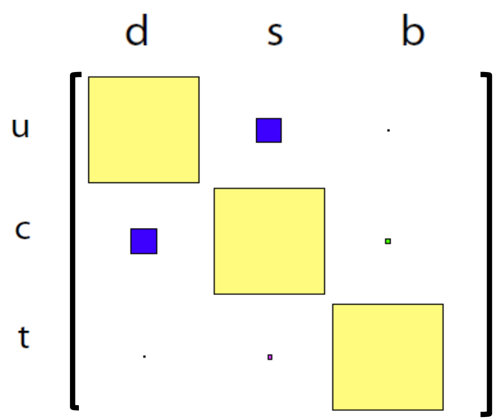
- **Precision (Intensity) frontier:**
  If the precision of the measurements is high enough we can discover NP due to effect of "virtual" new particles in loops also at low scales. However this also requires precise theoretical calculation.



Advantage of b hadrons: rich phenomenology of different loop effects such as mixing, CP violation, rare decays….

Weak b hadron hecays



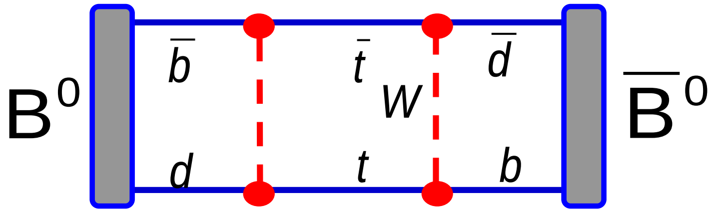


b cannot decay into top quark

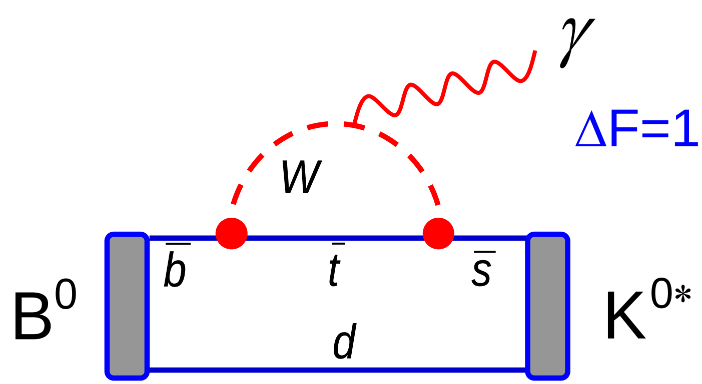
Tree decays “CKM” suppressed:
→ Loop corrections important.

Flavor Changing Neutral Current (FCNC) Processes:

$\Delta F=2$



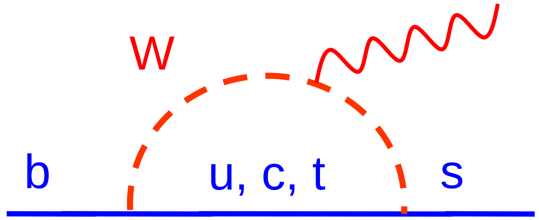
$\Delta F=1$



New Physics in Quantum Loops

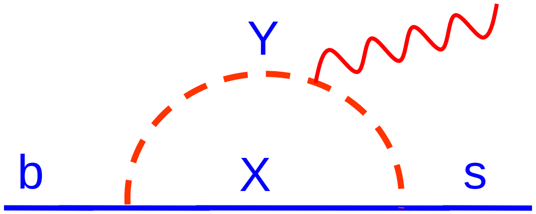
New Physics are corrections to Standard Model processes:

Standard Model



+

New Physics



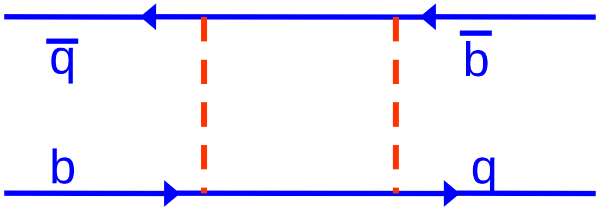
$$\mathcal{A}_{SM} \quad + \quad \mathcal{A}_{NP}$$

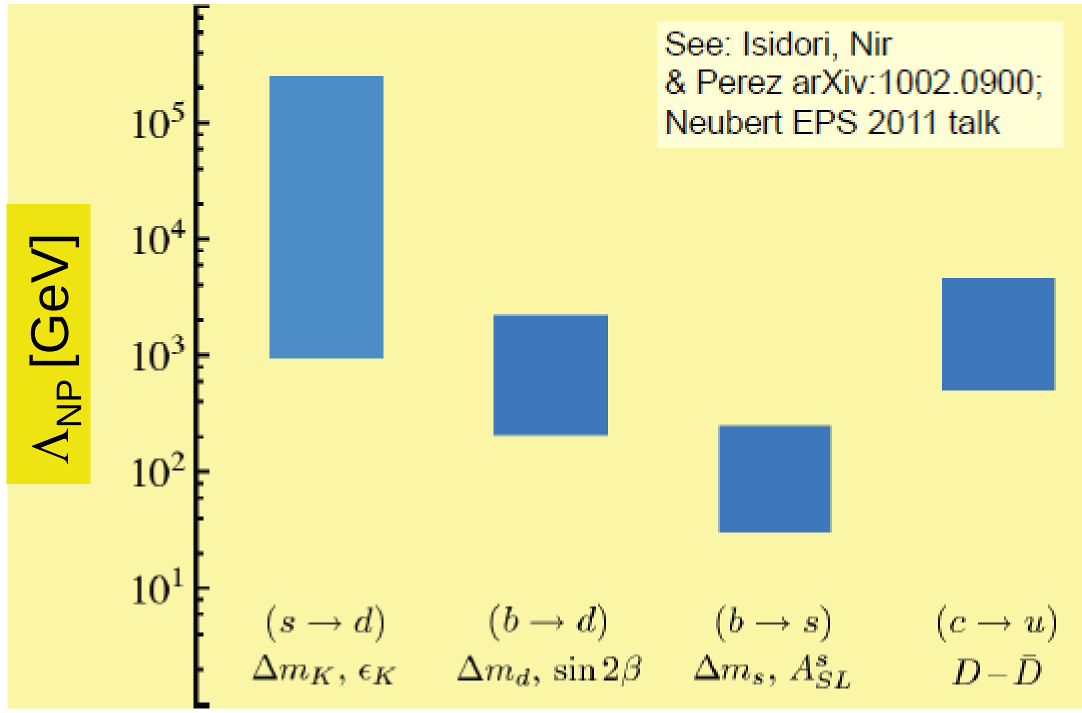
$$\mathcal{A}_{BSM} = \mathcal{A}_0 \left(\frac{c_{SM}}{m_W^2} + \boxed{\frac{c_{NP}}{\Lambda_{NP}^2}} \right)$$

What is the scale of Λ_{NP} ? Size of C_{NP} and alignment w/r to C_{SM} ?

The Flavor Problem

excluded NP scales
for generic flavor
models C_{NP}=1





Possible scenarios:
- new particles indeed have very large masses.
- new particles have degenerated masses
- mixing angles in new flavor sector are small, similar to SM

Flavor Problem: Absence of NP effects in flavor physics implies non-natural "fine tuning" if NP at TeV scale exists: Minimal flavor violation (MFV)

Neutral Meson Mixing

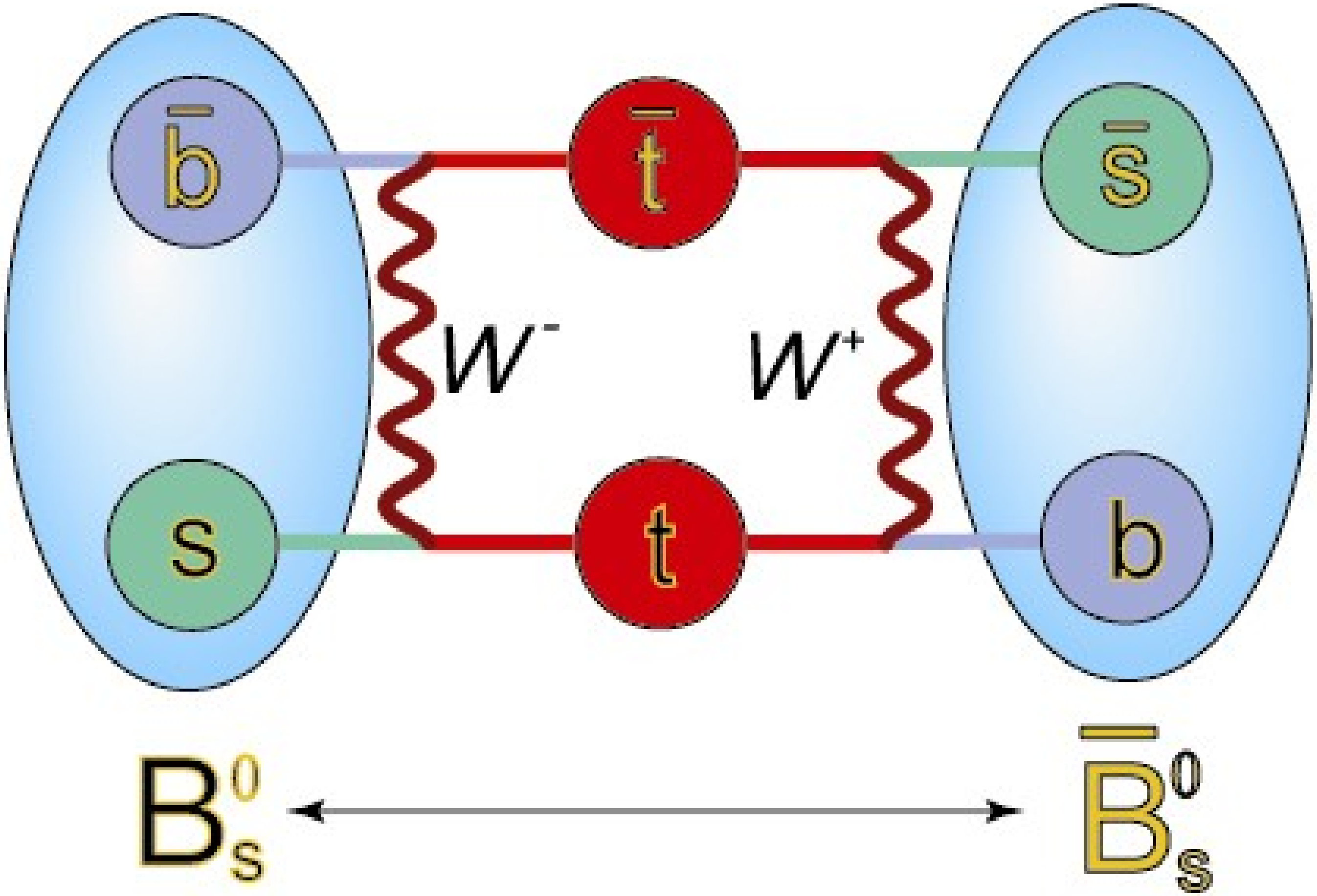
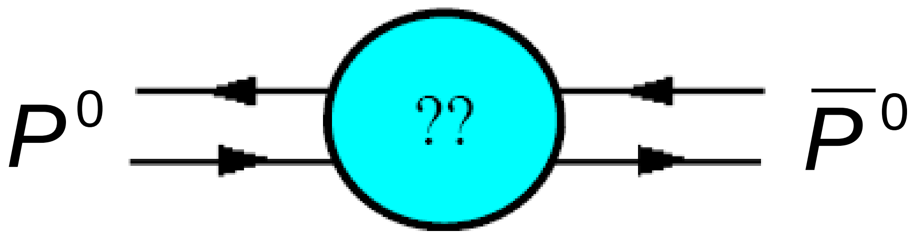


Figure from http://www.gridpp.ac.uk/news/?p=205

Mixing Phenomenology



$$i\frac{d}{dt}\begin{pmatrix} |B_q^0(t)\rangle \\ |\overline{B}_q^0(t)\rangle \end{pmatrix} = \underbrace{\left(\mathbf{M_q} - \frac{i}{2}\mathbf{\Gamma}_q\right)}_{\begin{pmatrix} M - \frac{i}{2}\Gamma & M_{12} - \frac{i}{2}\Gamma_{12} \\ M_{12}^* - \frac{i}{2}\Gamma_{12}^* & M - \frac{i}{2}\Gamma \end{pmatrix}}\begin{pmatrix} |B_q^0(t)\rangle \\ |\overline{B}_q^0(t)\rangle \end{pmatrix}$$

No mass eigenstates

CPT

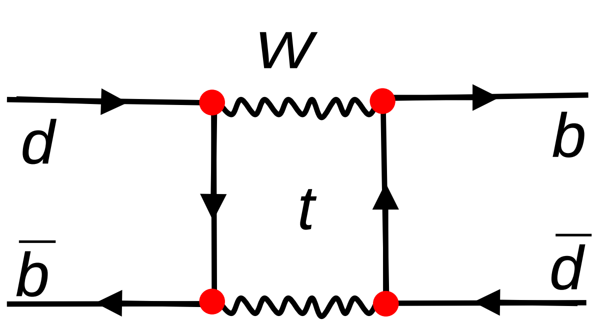
$$m_{11} = m_{22} = m$$
$$\Gamma_{11} = \Gamma_{22} = \Gamma$$

M and **Γ** hermitian:

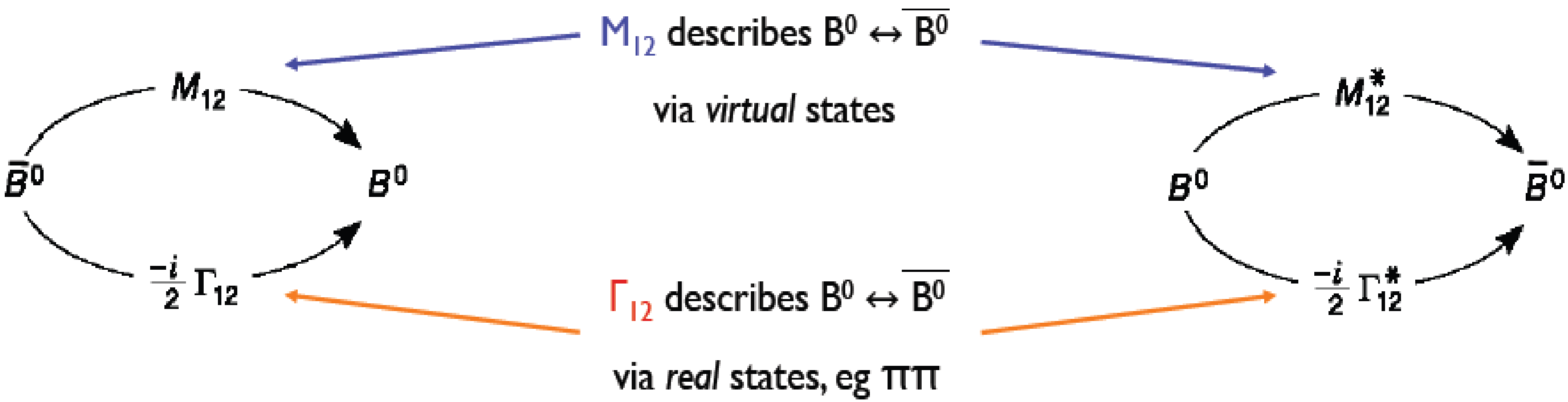
$$m_{21} = m_{12}^*$$
$$\Gamma_{21} = \Gamma_{12}^*$$

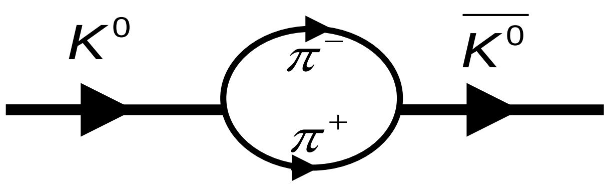
Off – diagonal elements describe the mixing.

Different Mixing Mechansim



„off-shelll virtual states“





„on-shell real states“

Theory parameter for mixing

$$|M_{12}^q|, \quad |\Gamma_{12}^q|, \quad \phi_q^{M/\Gamma} \equiv \arg\left(-\frac{M_{12}^q}{\Gamma_{12}^q}\right)$$

Mass Eigenstates

Diagonalization: Mass eigenstates:

$$|B_L\rangle = p|B^0\rangle + q|\overline{B^0}\rangle \quad \text{with } m_L, \Gamma_L$$

$$|B_H\rangle = p|B^0\rangle - q|\overline{B^0}\rangle \quad \text{with } m_H, \Gamma_H$$

Time evolution:

$$|B_{H,L}(t)\rangle = |B_{H,L}(0)\rangle \cdot e^{-im_{H,L}t} \cdot e^{-\frac{1}{2}\Gamma_{H,L}t}$$

complex coefficients $|p|^2 + |q|^2 = 1$

If there is no CP-violation |p/q|=1: B_L CP=+1, B_H CP=-1

From eigenvector and eigenvalue calculation:

$$\frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$

$$m_{H,L} = m \pm \frac{1}{2}\Delta m \quad \Gamma_{H,L} = \Gamma \mp \frac{1}{2}\Delta\Gamma$$

$$\Delta m + \frac{i}{2}\Delta\Gamma = 2\sqrt{\left(M_{12} - \frac{i}{2}\Gamma_{12}\right)\left(M_{12}^* - \frac{i}{2}\Gamma_{12}^*\right)}$$

Observable Mixing Parameter

$$m = \frac{M_H + M_L}{2}, \qquad \Gamma = \frac{\Gamma_H + \Gamma_L}{2}$$

$$\Delta m = M_H - M_L, \quad \Delta\Gamma = \Gamma_L - \Gamma_H$$

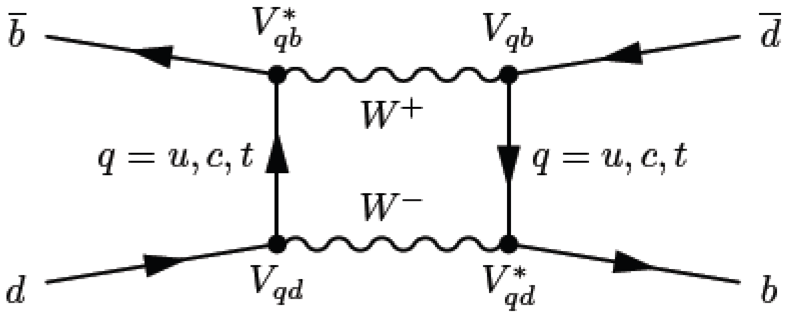
$$\boxed{\begin{aligned} \Delta m &= M_H - M_L \simeq 2|M_{12}^q|, \\ \Delta\Gamma &= \Gamma_L - \Gamma_H \simeq 2|\Gamma_{12}^q| \cos\phi_{M/\Gamma} \end{aligned}}$$

Mixing parameters are calculable (see U.Nierste et al.)

Often a difference phase is used
(because experimental accessible)

$$\phi_M = \arg(-M_{12})$$

Theoretical predictions



$t-\bar{t}:$ $\propto m_t^2 \left|V_{tb}V_{td}^*\right|^2$ $\propto m_t^2\lambda^6$

$c-\bar{c}:$ $\propto m_c^2 \left|V_{cb}V_{cd}^*\right|^2$ $\propto m_c^2\lambda^6$

$c-\bar{t}, \bar{c}-t:$ $\propto m_c m_t V_{tb} V_{td}^* V_{cb} V_{cd}^*$ $\propto m_c m_t \lambda^6$

u quark can be replaced using unitarity V_{CKM}

$$M_{12,q} = \frac{G_F^2}{12\pi^2}(V_{tq}^* V_{tb})^2 M_W^2 S_0(x_t) \boxed{B_{B_q} f_{B_q}^2} M_{B_q} \hat{\eta}_B$$

$$\Delta m \approx 2\left|M_{12}\right|$$

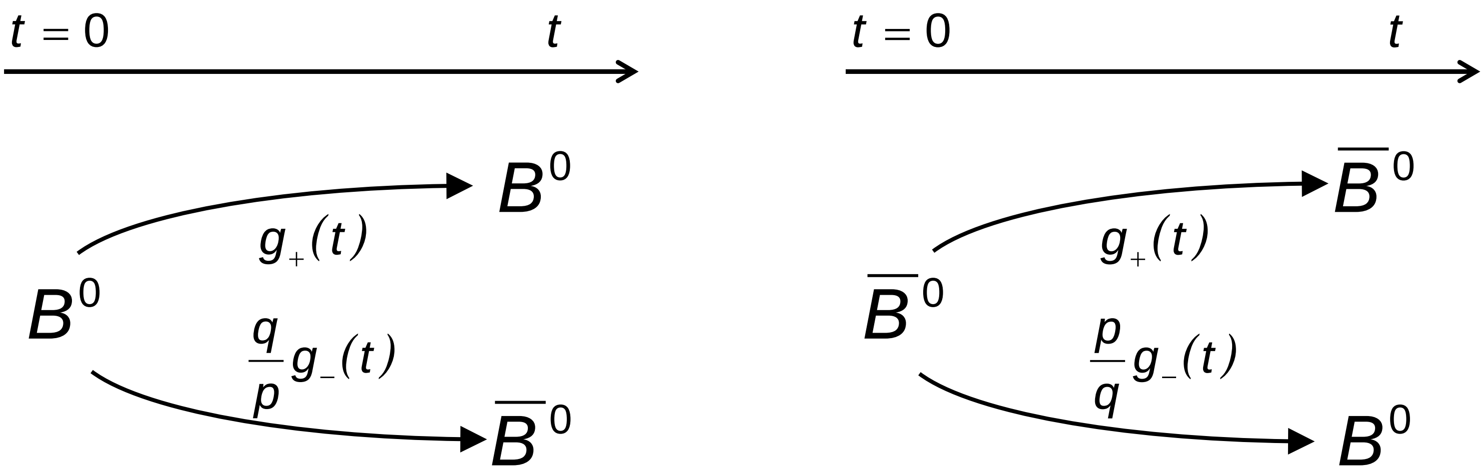
here: q=d

$S_0\left(m_t^2/m_W^2\right)$ = Inami-Lim funct. = result of box diagramm.

B_B = bag factor, f_B = decay constant: non-perturbative effects

η_B = *perturbative QCD corrections*

Mixing phenomenology



$$|B^0(t)\rangle = g_+(t)|B^0\rangle + \frac{q}{p}g_-(t)|\overline{B}^0\rangle \qquad |\overline{B}^0(t)\rangle = g_-(t)\frac{p}{q}|B^0\rangle + g_+(t)|\overline{B}^0\rangle$$

$$g_+(t) = e^{-i(m-i\frac{\Gamma}{2})t}\left[+\overset{1}{\cancel{\cosh\frac{\Delta\Gamma t}{4}}}\cos\frac{\Delta m t}{2} - i\cancel{\sinh\frac{\Delta\Gamma t}{4}}\sin\frac{\Delta m t}{2}\right]$$

$$g_-(t) = e^{-i(m-i\frac{\Gamma}{2})t}\left[-\cancel{\sinh\frac{\Delta\Gamma t}{4}}\cos\frac{\Delta m t}{2} + i\underset{1}{\cancel{\cosh\frac{\Delta\Gamma t}{4}}}\sin\frac{\Delta m t}{2}\right]$$

$\Delta\Gamma \approx 0$

Mixing phenomenology

Mixed/ unmixed probability: $\Delta\Gamma \approx 0$

$$\mathcal{P}(B^0 \to B^0, t) = \left|\left\langle B^0 | B^0(t) \right\rangle\right|^2 = \frac{e^{-\Gamma t}}{2}(1 + \cos(\Delta m t))$$

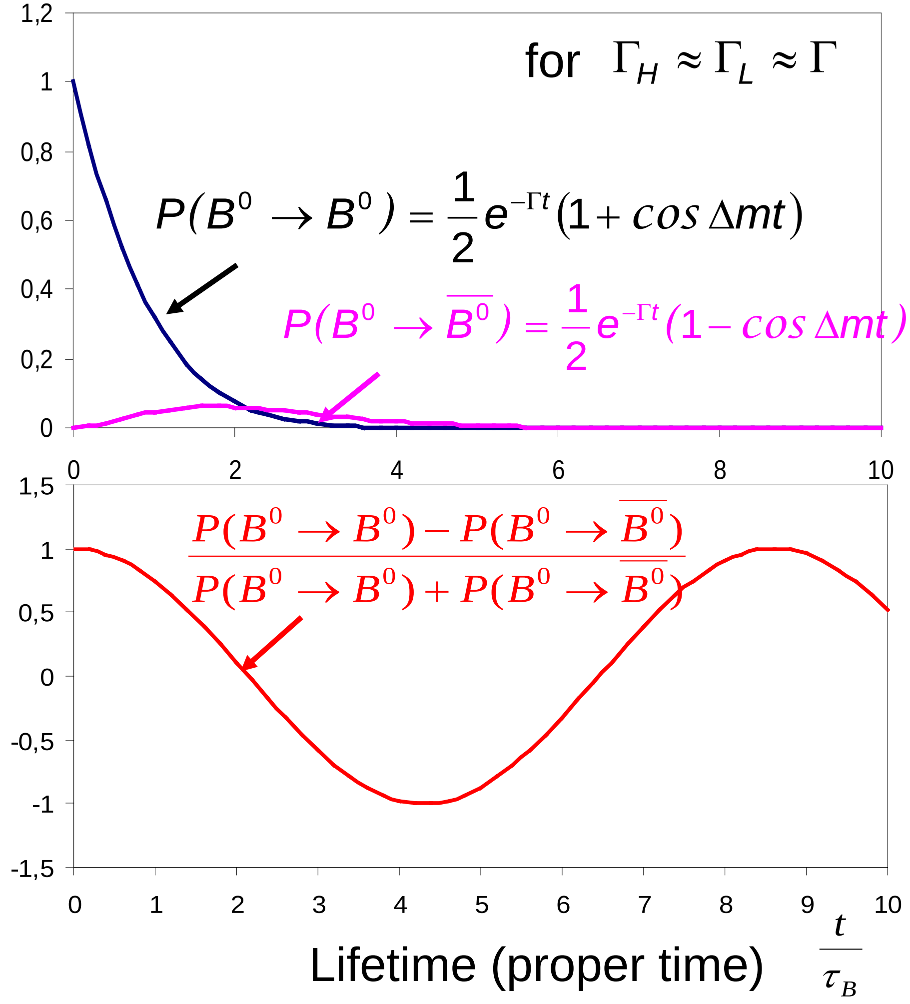
$$\mathcal{P}(B^0 \to \bar{B}^0, t) = \left|\left\langle B^0 | \bar{B}^0(t) \right\rangle\right|^2 = \frac{e^{-\Gamma t}}{2}\left|\frac{q}{p}\right|^2 (1 - \cos(\Delta m t))$$

Mixing asymmetry:

$$A(t) = \frac{unmixed(t) - mixed(t)}{unmixed(t) + mixed(t)} = \cos(\Delta m t)$$

If |q/p| =1

Time dependent mixing asymmetry



$\cos(\Delta m t)$

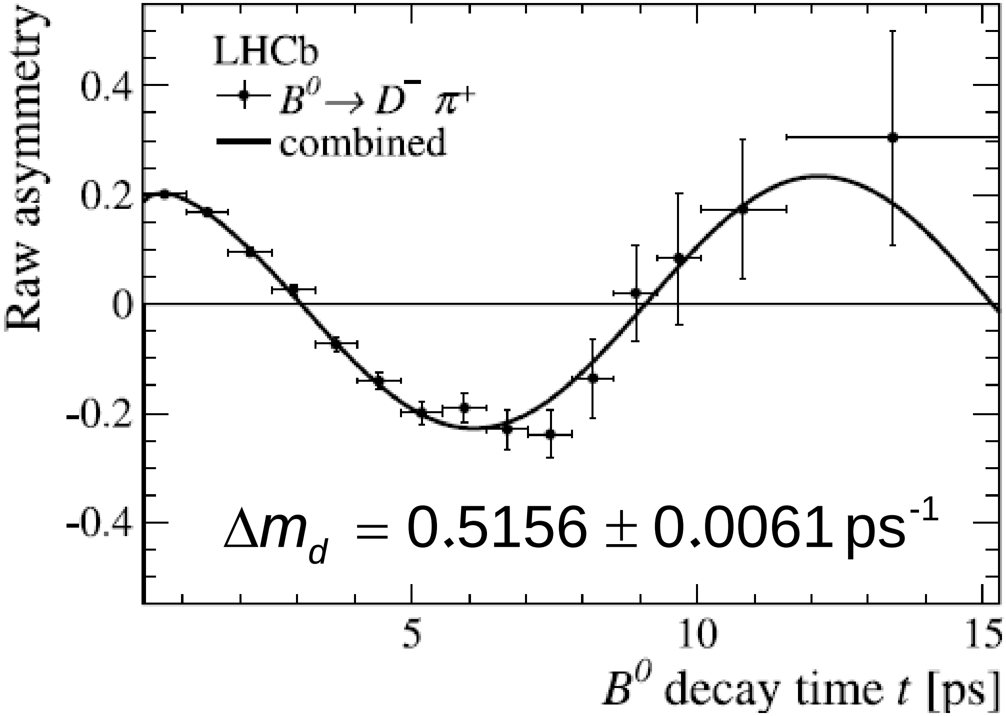
B^0 Mixing *)

B^0

$\updownarrow$

$\overline{B}^0$

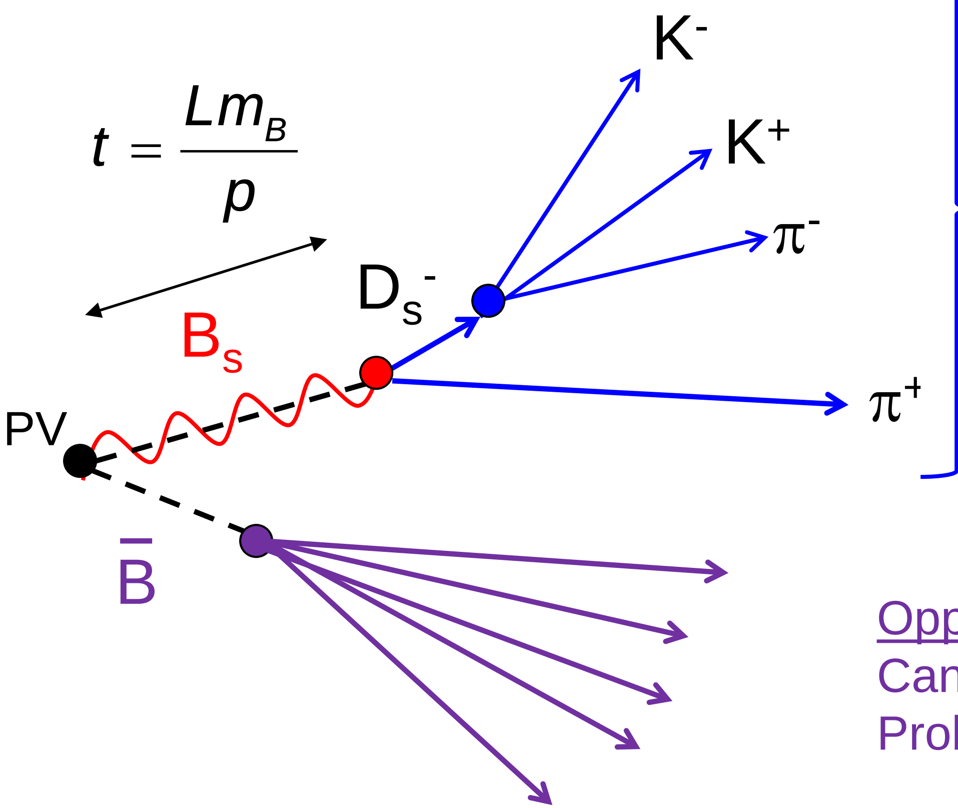
Phys. Lett. B 719 (2013) 318.



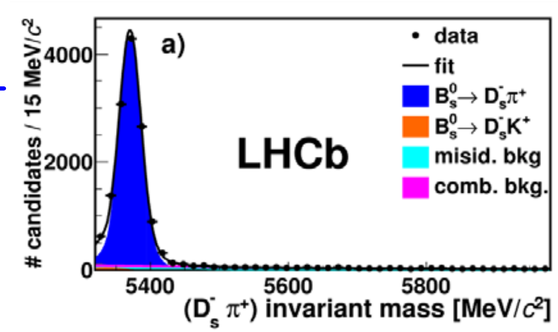
*) ARGUS (DESY) in 1987: $m_{top} > 50$ GeV, PL B 192 (1987) 245.

B_s Mixing Measurement

$$t = \frac{L m_B}{p}$$



Signal B
(flavor specific decay)



Need production flavor

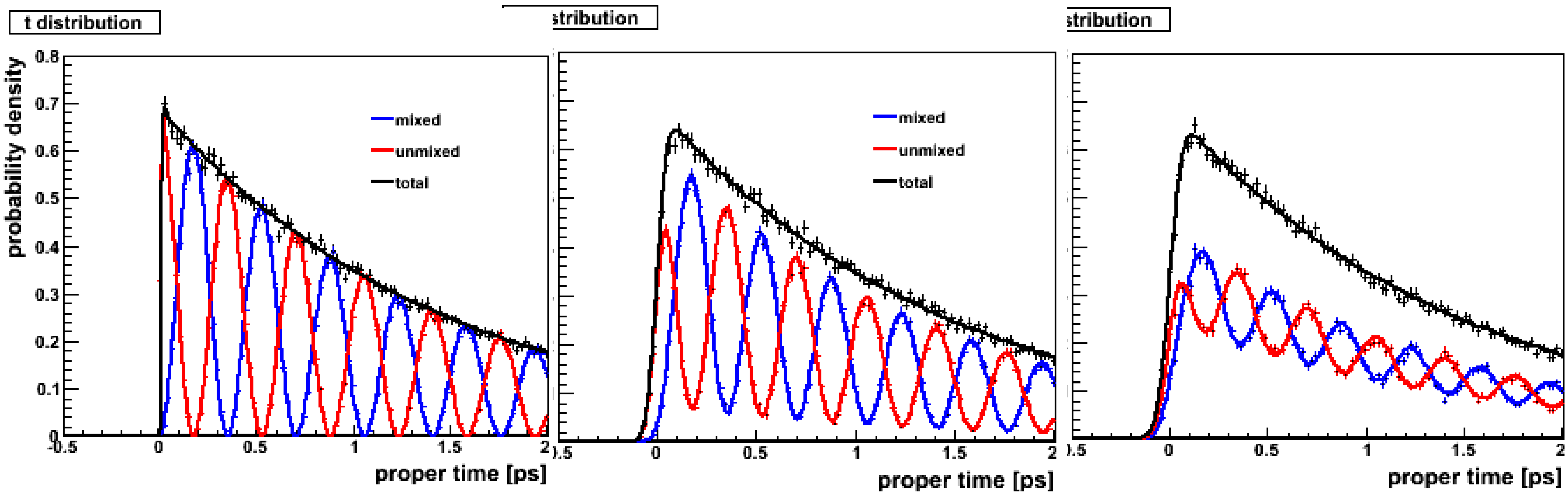
<u>Opposite B</u>
Can be used for flavor tagging
Problem w/ neutral B's (→mixing)

$$PDF \propto \left[e^{-\Gamma t} \cdot \left(\cosh\left(\frac{\Delta\Gamma}{2} t \right) \pm D \cdot \cos(\Delta m \cdot t) \right) \right] \otimes R(\sigma_t)$$

Production flavour from tagging algorithms

resolution

Detector effects on B_s oscillation



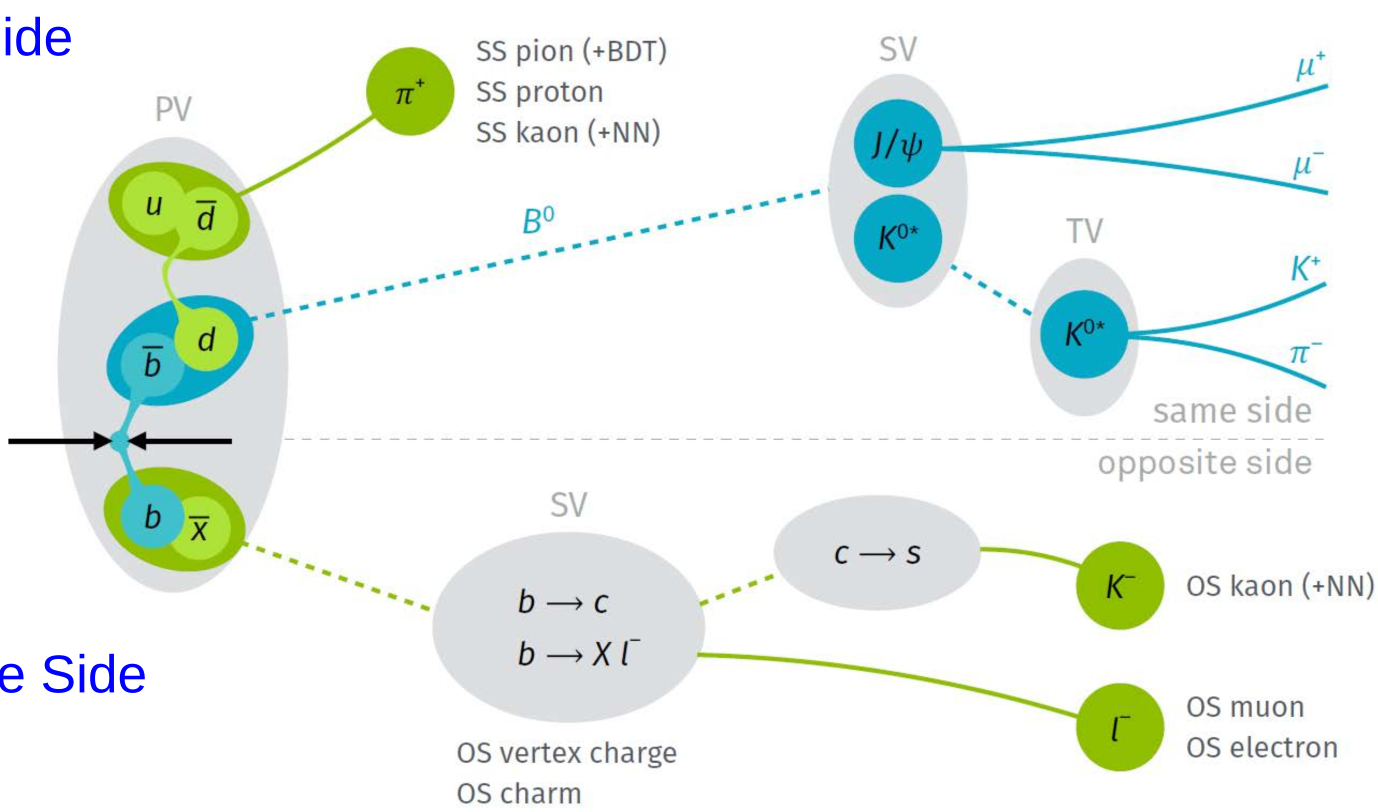
Finite time resolution: 44 fs.
Reduced amplitude by smearing.

Realistic tagging: reduces amplitude by swapping events

Flavor Tagging

Figure from J.Wishahi)

Same Side



signal

Opposite Side

Tagging algorithms not very efficient (ε_{tag} =2%-20%)

High mis-tag fraction (ω=30%-40%) ➡ $D = (1 - 2\omega)$ (dilution)

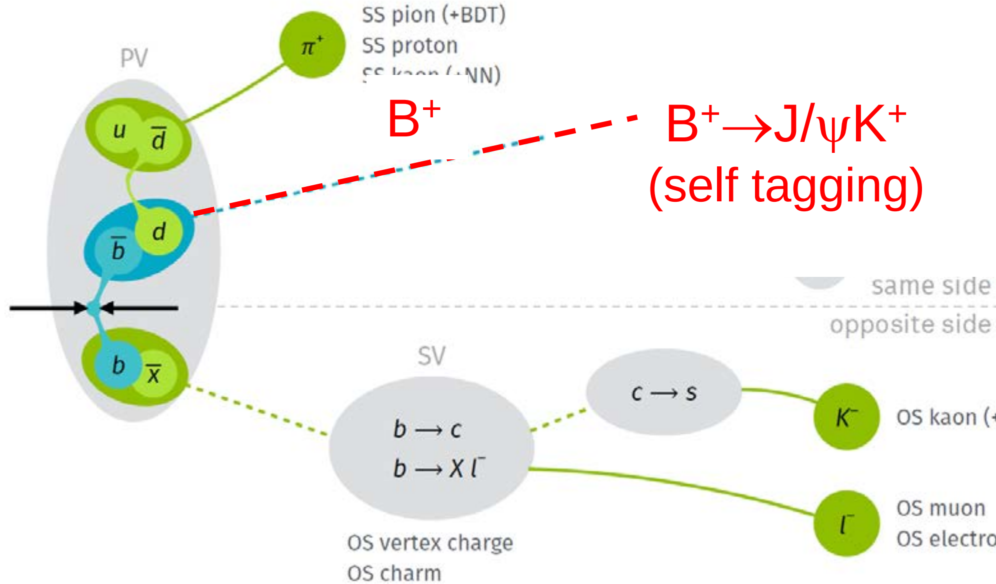
Effective Tagging efficiencies: $\varepsilon_{eff} \approx \varepsilon_{tag}\, D^2$

Statistical error of the mixing asymmetry: $\frac{1}{\sqrt{\varepsilon_{\text{eff}} N}}$.

Effective tagging efficiency scales event yield

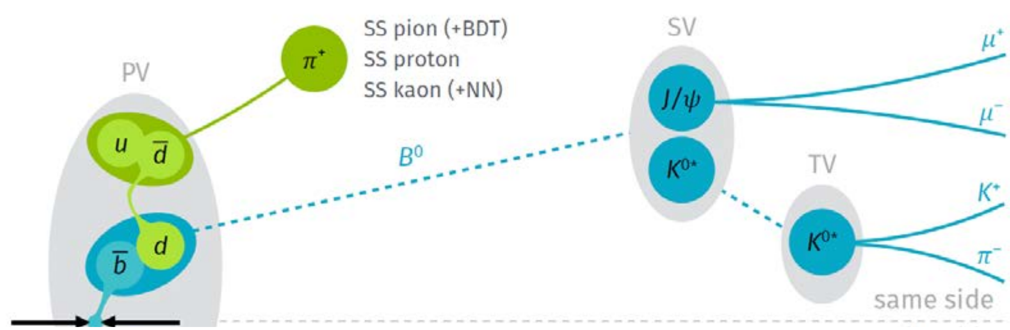
How to measure the mis-tag fraction?

Opposite side tagger:



Same side tagger:

need signal B_d or B_s



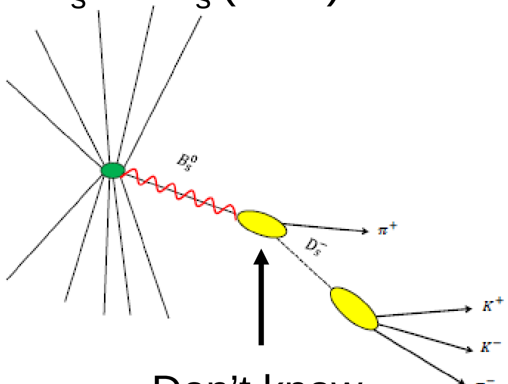
Dilution is determined
in the oscillation fit.

Proper Time

- Proper time result of vertex (mostly)resolution and momentum resolution.
- In principle the vertex fits provide the vertex resolution – can we trust error?

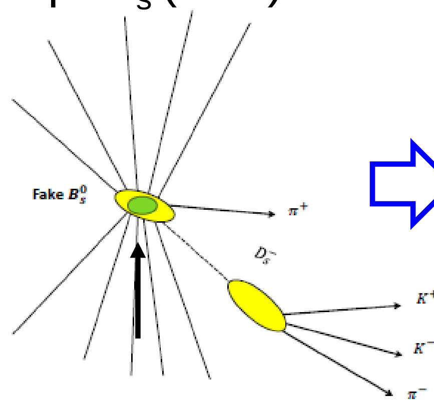
Need to check on data: true - reconstructed

$B_s \rightarrow D_s (KK\pi)\ \pi$

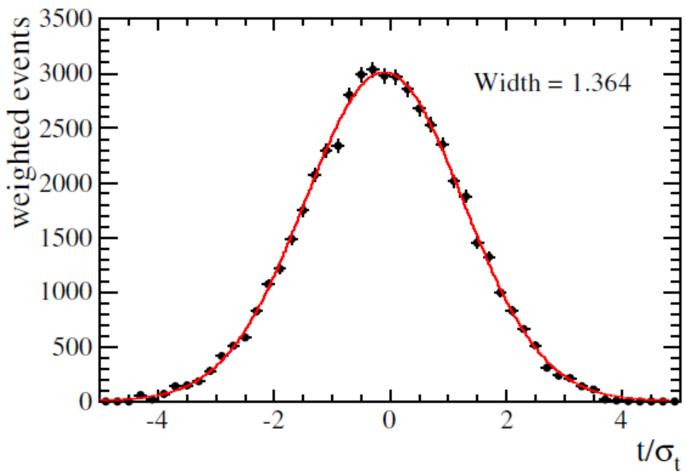


Don't know true vertex

Prompt $D_s (KK\pi)\ \pi$ event



true vertex = PV



z-scale and momentum scale uncertainty:

Prope rtime $t = \dfrac{Lm_B}{p}$

0.02% from each z- & momentum scale

B_s-Mixing

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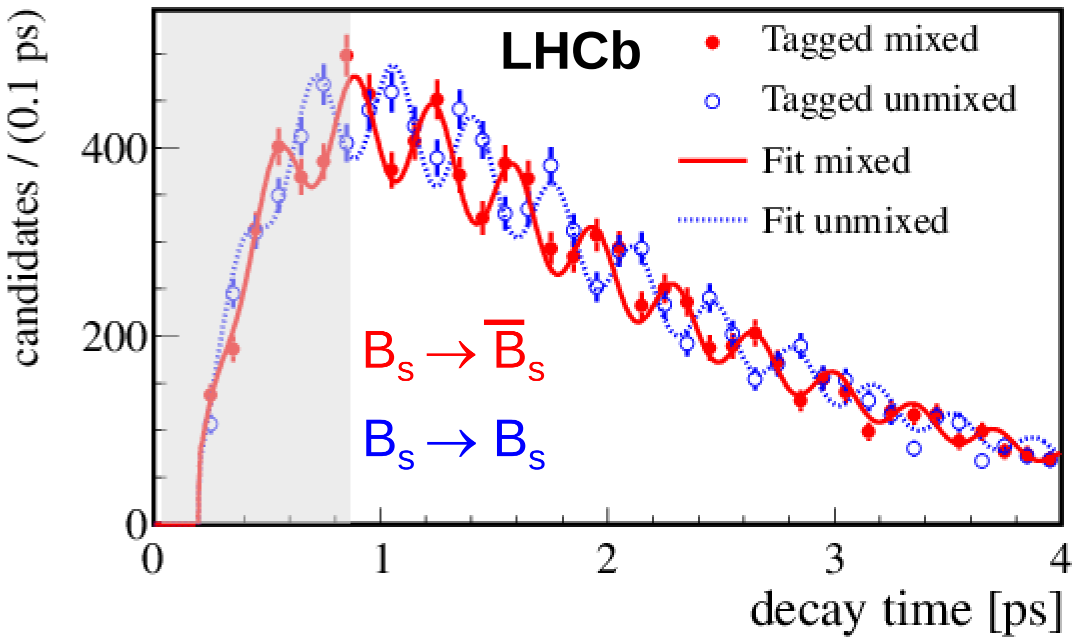


$\Delta m_s = 17.768 \pm 0.023 \pm 0.006\ ps^{-1}$

Theorie *(U.Nierste, 2012)*

$\Delta m_s = 17.3 \pm 1.5\ ps^{-1}$

1 per mille
(syst: z & p scale)

Unsatisfying: Hadronic uncertainties limit the precision of theoretical prediction

Parameters with better precision?

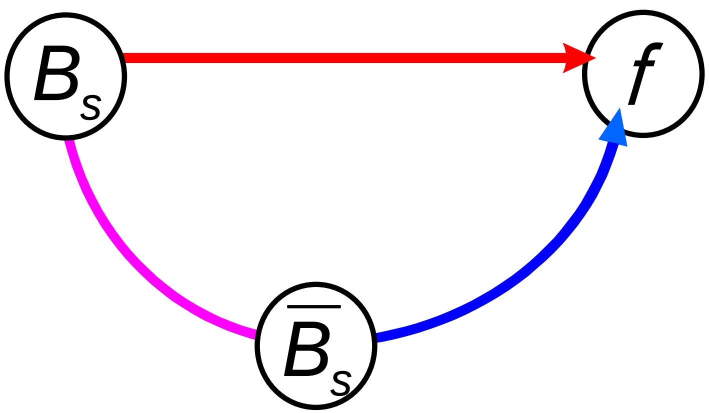
Phases have very small absolute theoretical uncertainties:

$$\phi_M = \arg(M_{12}) = \arg\left(\frac{q}{p}\right)$$

Theory: $\phi_M = -0.0364 \pm 0.0016$

$$\phi_{M/\Gamma} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

Theory: $\phi_{M/\Gamma} = 0.0038 \pm 0.0010$



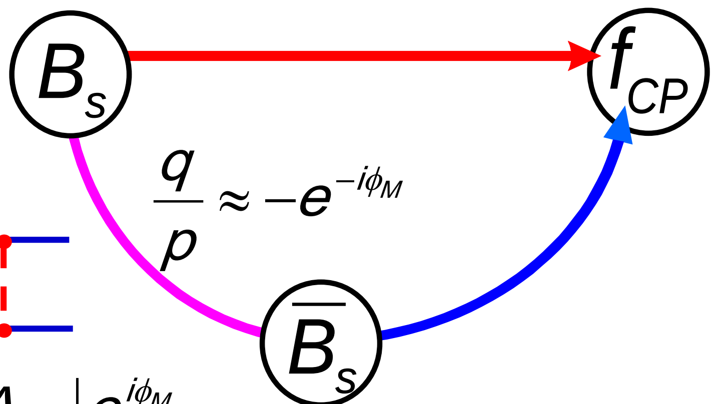
Time dependent CP-violation
of B_s decaying to a CP eigenstate

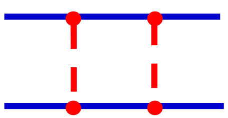
$$P(B^0 \longrightarrow \overline{B}^0) \neq P(\overline{B}^0 \longrightarrow B^0)$$

CP-violation in mixing

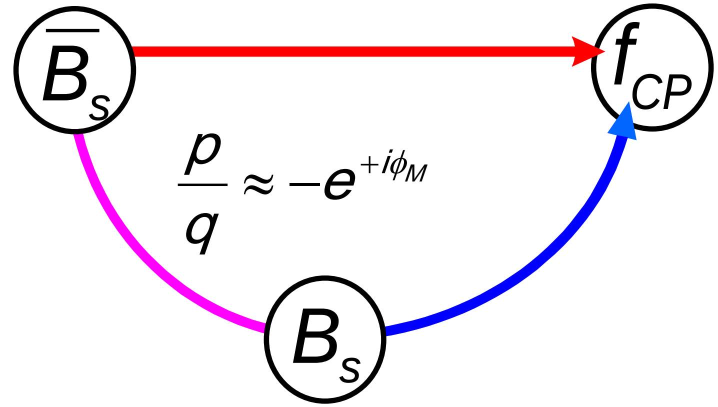
Phases are very sensitive to new effects in the loops.

Phase ϕ_M and mixing induced CPV (B_s)





$$A_{mix} = |A_{mix}| e^{i\phi_M}$$



CP

$\Delta\Gamma \approx 0$

$$\mathrm{P}(B_s \to f_{CP}, t) \propto e^{-\Gamma t}\left(1 + \sin(\phi_M)\ \sin(\Delta m\, t)\right)$$

$$\mathrm{P}(\overline{B}_s \to f_{CP}, t) \propto e^{-\Gamma t}\left(1 - \sin(\phi_M)\ \sin(\Delta m\, t)\right)$$

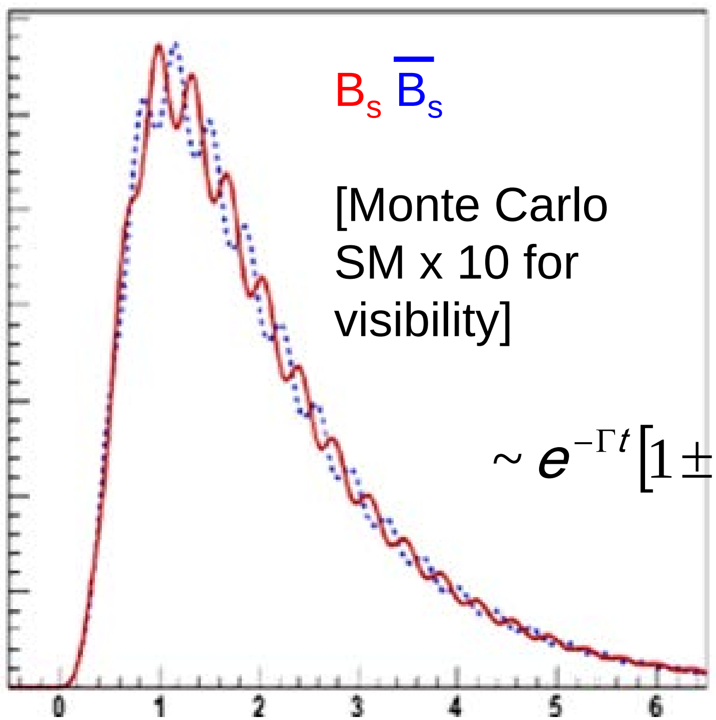
$$A_{CP}(t) = \frac{\mathcal{P}(\overline{B}_s \to f_{CP}) - \mathcal{P}(B_s \to f_{CP})}{\mathcal{P}(\overline{B}_s \to f_{CP}) + \mathcal{P}(B_s \to f_{CP})} \propto \sin(\phi_s)\sin(\Delta m\, t)$$

$\phi_M(B_s) \equiv \phi_s$
$\phi_M(B_d) \equiv \phi_d$

Standard Model

Precise Standard Model prediction:

$$\phi_s^{SM} = -0.0364 \pm 0.0016 \ \text{rad}$$



$$\sim e^{-\Gamma t}\left[1 \pm \sin\phi_s \sin(\Delta m_s t)\right]$$

➡ ϕ_s small:
expect very small CPV

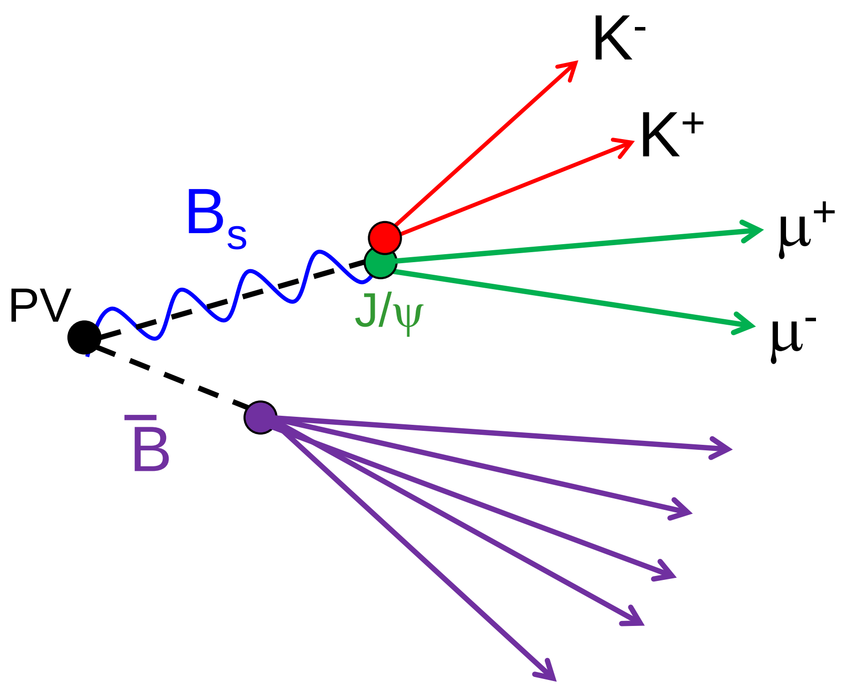
Complication: $\Delta\Gamma\ (B_s) \neq 0$

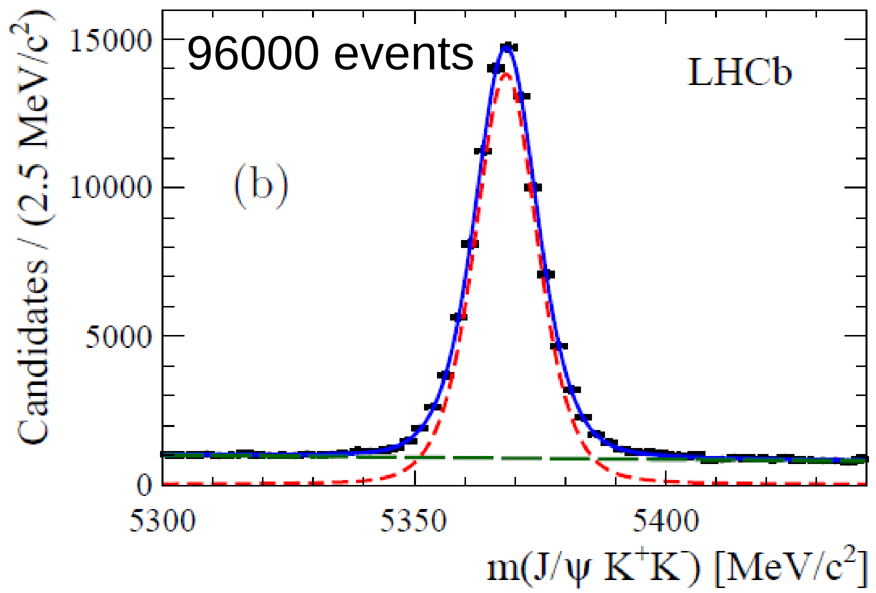
$$A_{CP}(t) = \frac{\mathcal{P}(\overline{B}_s \to f_{CP}) - \mathcal{P}(B_s \to f_{CP})}{\mathcal{P}(\overline{B}_s \to f_{CP}) + \mathcal{P}(B_s \to f_{CP})} \propto \sin(\phi_s)\sin(\Delta m\, t)$$

$$A_{CP}(t) = \frac{\mathrm{P}(\overline{B}_s \to f_{CP}) - \mathrm{P}(B_s \to f_{CP})}{\mathrm{P}(\overline{B}_s \to f_{CP}) + \mathrm{P}(B_s \to f_{CP})} \propto \frac{\sin(\phi_s)\ \sin(\Delta m\, t)}{\cosh(\Delta\Gamma t/2) - \cos(\phi_s)\sinh(\Delta\Gamma t/2)}$$

Golden Decay $B_s \to J/\psi\ (\mu\mu)\ \phi(KK)$

arXiv:1411.3104
LHCb-PAPER-2014-059

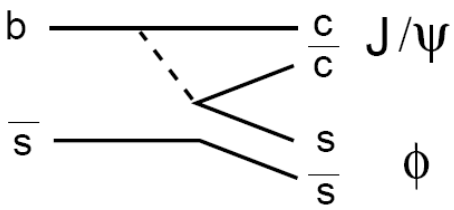




Problem:
The final state is not a pure CP eigenstate but a mixture of CP even and CP odd states: $A_{CP}(CP=+1) = A_{CP}(CP=-1)$. I.e., if we are unlucky we don't see CP violation even if the two CP components max. violate CP.

$B_s \to J/\psi\ (\mu\mu)\ \phi(KK)$

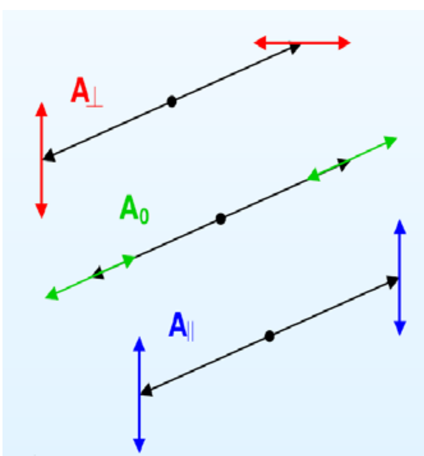
- VV final state:



$$\left.\begin{array}{l} J^{PC} = 1^{--} \\ J^{PC} = 1^{--} \end{array}\right\}$$

$$CP(J/\psi\phi) = CP(J/\psi)CP(\phi)(-1)^L$$

(L = 0, 1,2 = relative orbital momentum)



3 different polarization amplitudes with different relative orbital momentum:

CP-odd $(\ell = 1)$: $A_\perp$

CP-even $(\ell = 0, 2)$: $A_0,\ A_\parallel$

angular analysis to disentangle CP even/odd state

Angular analysis

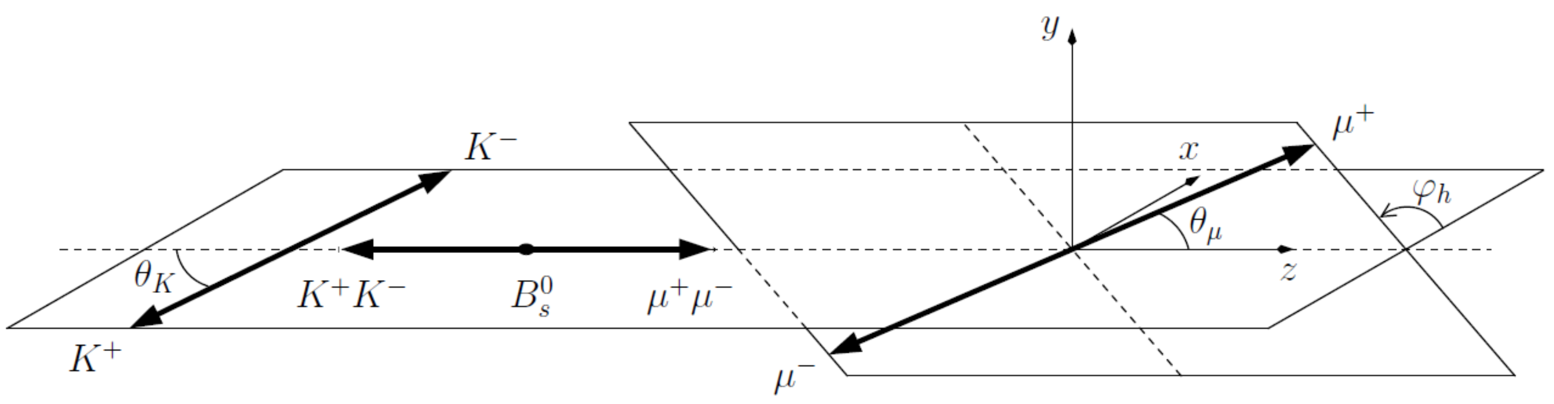
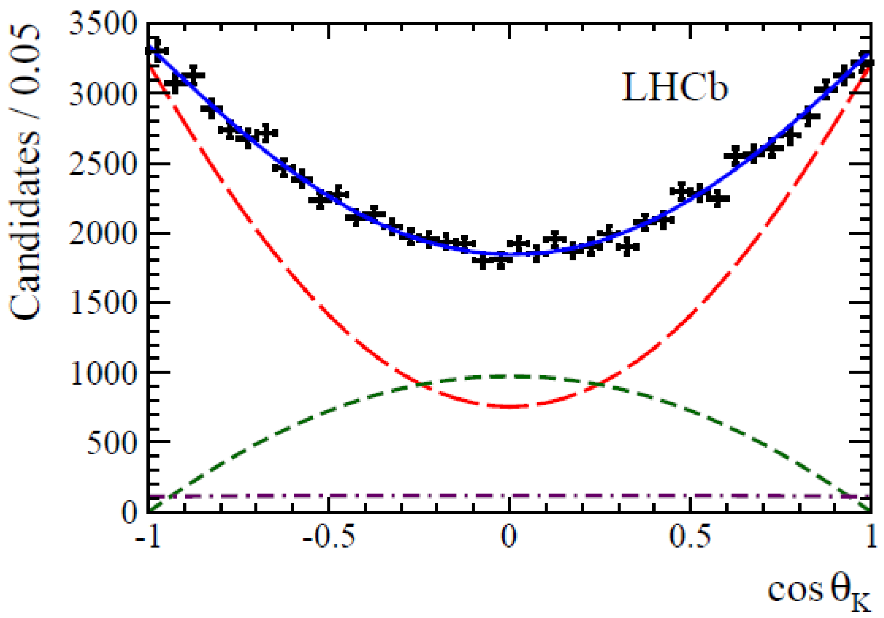
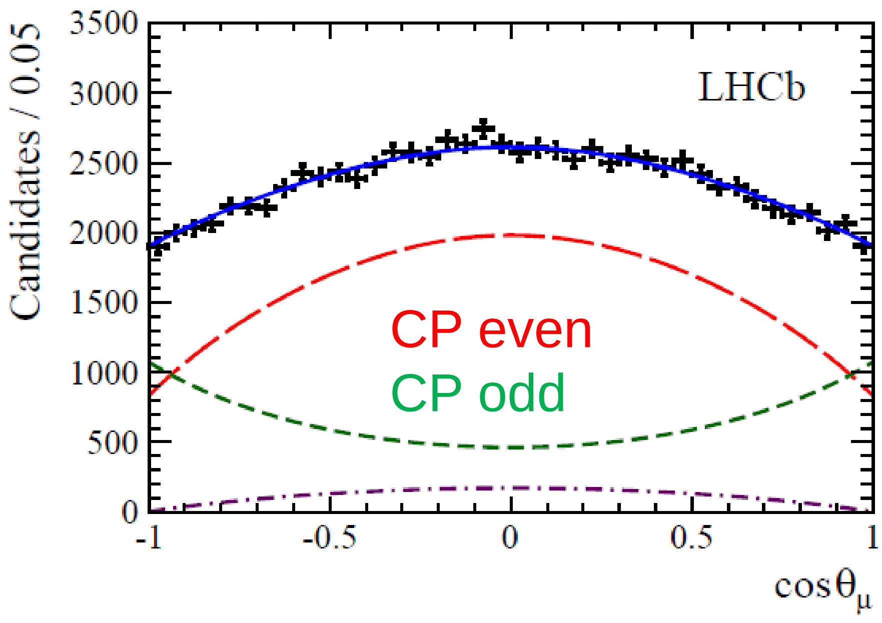
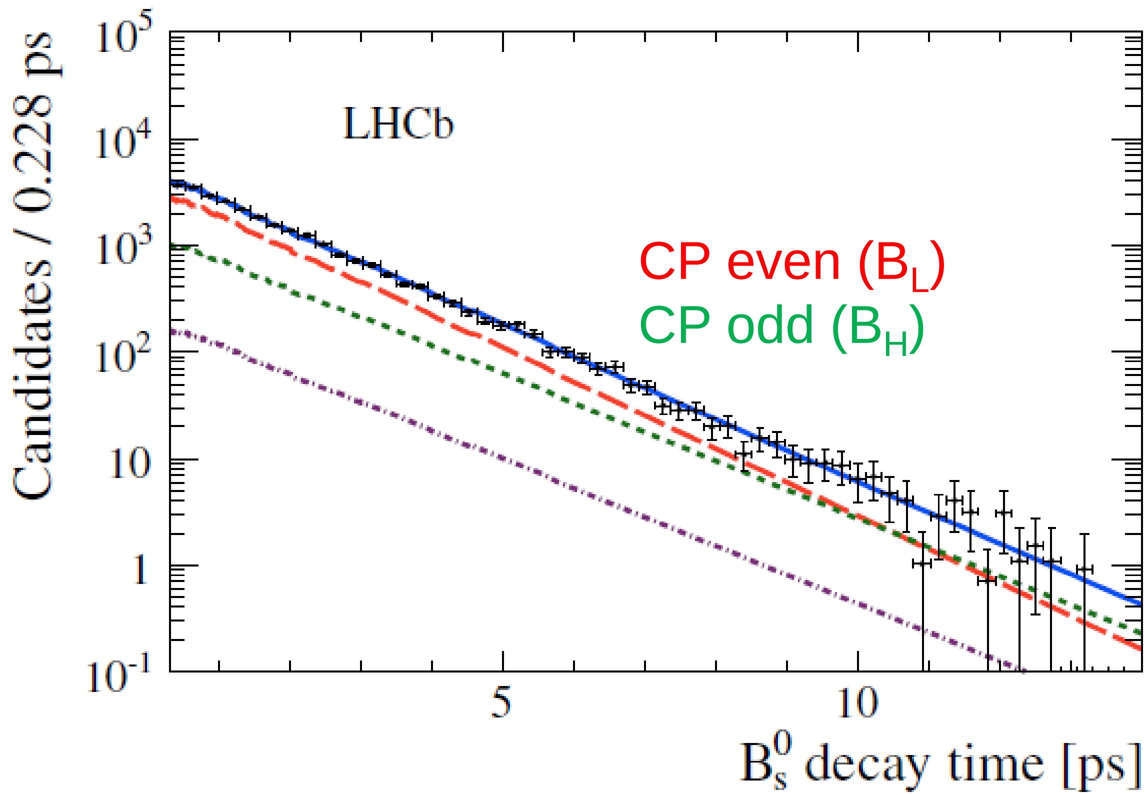


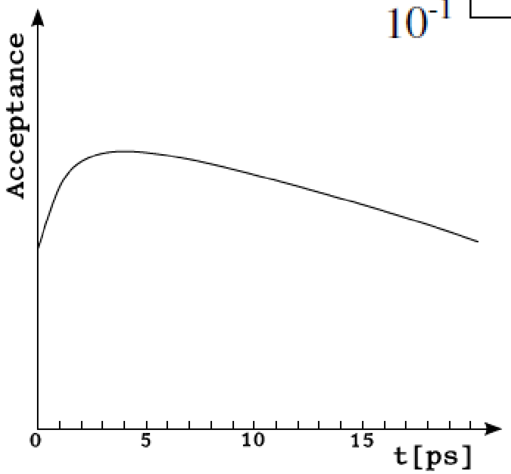
Figure 3: Definition of helicity angles.





Lifetime plot – Γ and ΔΓ measurement



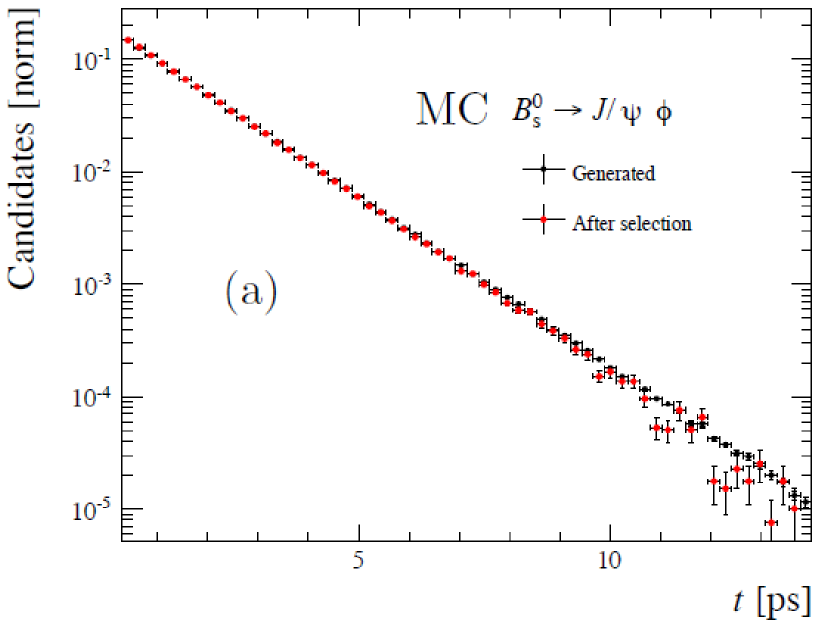


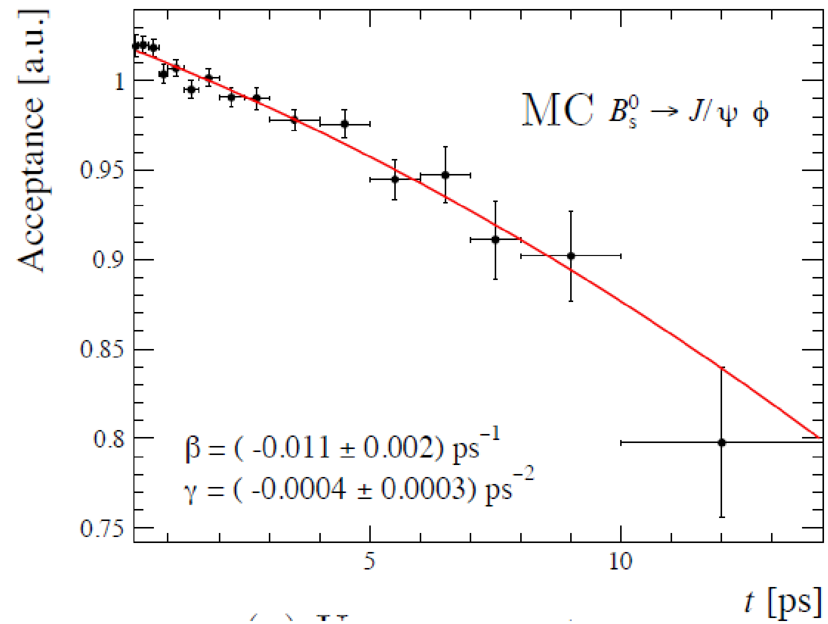
Experimental problem:
Non uniform lifetime acceptance

$$\left[e^{-(t/\tau_{H_b})} \otimes \mathcal{R}(t)\right] \times \mathrm{Acc}(t)$$

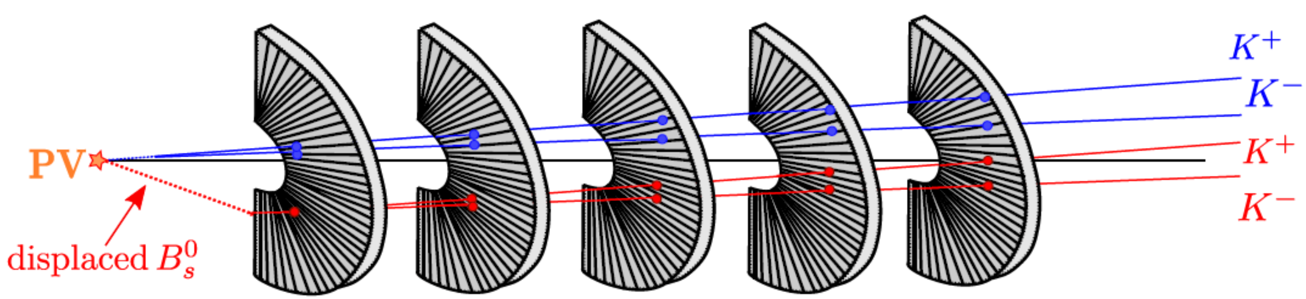
Decay Time Acceptance

Non-uniform decay-time acceptance in simulation:





Artefact of detector, trigger & reconstruction



Need to be measured

$$\begin{aligned} \Delta\Gamma_s &= 0.0805 \pm 0.0091 \pm 0.0033\,\text{ps}^{-1}, \\ \Gamma_s &= 0.6603 \pm 0.0027 \pm 0.0015\,\text{ps}^{-1}. \end{aligned}$$

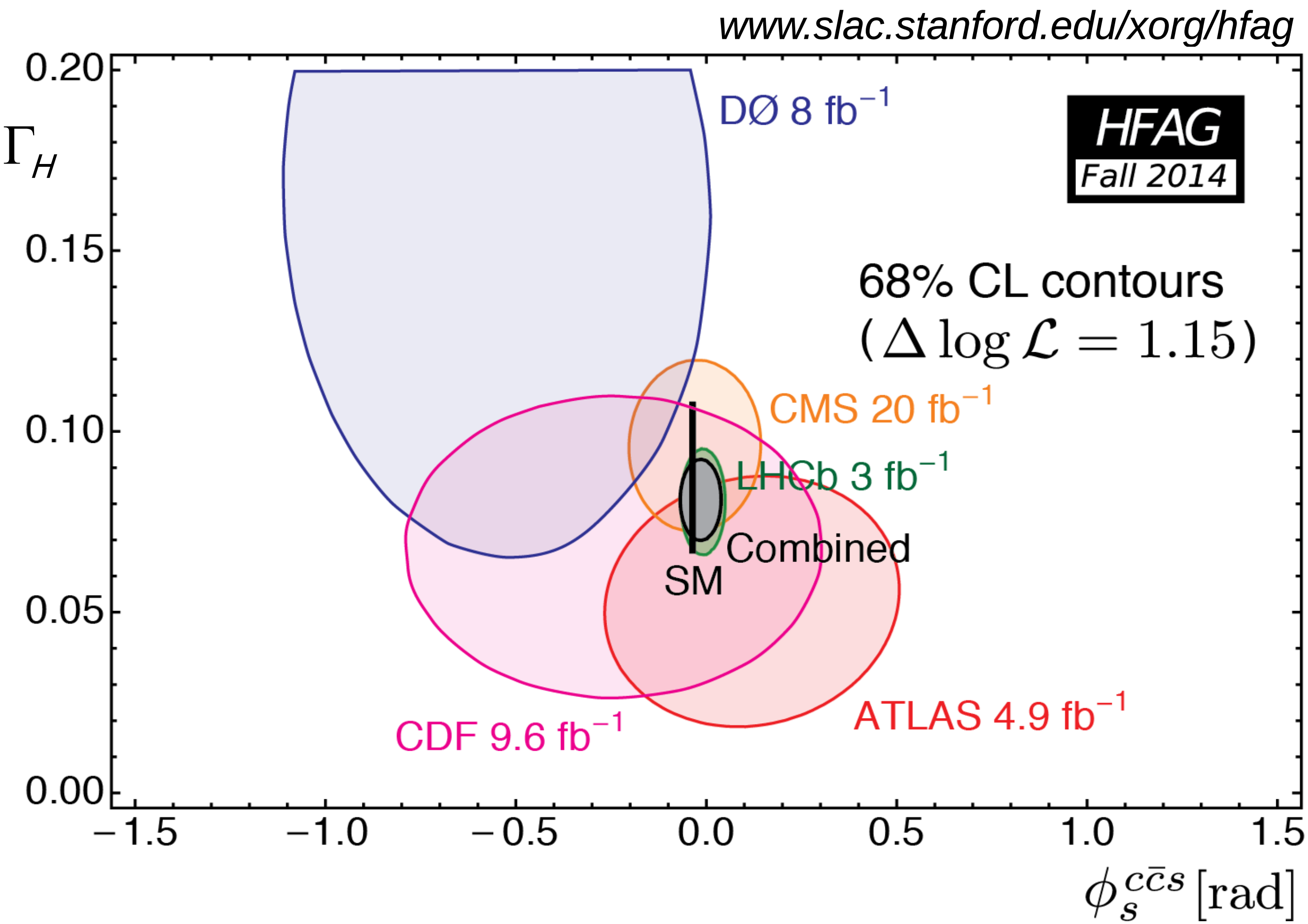
5 per mille

Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]
Statistical uncertainty	0.0027	0.0091
VELO reconstruction	0.0005	0.0002
Residual bias in simulation	0.0007	0.0029
Mass factorisation	–	0.0007
Trigger efficiency	0.0011	0.0009
Background and mass modelling	0.0001	0.0008
Peaking background	0.0005	0.0004
LHCb length scale	0.0002	–
Angular efficiency	0.0001	0.0002
Total systematic	0.0015	0.0033

Determination of Phase ϕ_s

$\phi_s = 0.010 \pm 0.039$ PRL 114 (2015) 041801

$\Delta\Gamma_s = \Gamma_L - \Gamma_H$



CP Violation in mixing

$$\phi_{M/\Gamma} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

Theory: B_s $\quad \phi_{M/\Gamma} = 0.0038 \pm 0.0010$

B_d $\quad \phi_{M/\Gamma} = -0.0750 \pm 0.0244$

CP-violation in mixing

$B^0 \longrightarrow \bar{B}^0 \longrightarrow \bar{f}: \mu^- X$ $\quad\Big|\quad$ $\bar{B}^0 \longrightarrow B^0 \longrightarrow f: \mu^+ X$

$\cancel{CP}$

$$a_{sl}^q \equiv \frac{\Gamma(\bar{B}_q^0 \to B_q^0 \to \mu^+ X) - \Gamma(B_q^0 \to \bar{B}_q^0 \to \mu^- X)}{\Gamma(\bar{B}_q^0 \to B_q^0 \to \mu^+ X) + \Gamma(B_q^0 \to \bar{B}_q^0 \to \mu^- X)}, \quad q = d, s$$

$$= \frac{1 - |q/p|^4}{1 + |q/p|^4} \approx \left|\frac{\Gamma_{12}}{M_{12}}\right| \sin\phi_{M/\Gamma} \approx \frac{\Delta\Gamma}{\Delta m} \sin\phi_{M/\Gamma}$$

A.Lenz and U.Nierste

B_s $\quad a_{SL}^s = (1.9 \pm 0.3) \times 10^{-5}$

B_d $\quad a_{SL}^s = -(4.1 \pm 0.6) \times 10^{-4}$

Measurement of a_{SL}

- Tagging of the initial state reduces the statistical power drastically

$$B^0 \longrightarrow \bar{B}^0 \longrightarrow \mu^- X \quad \Big| \quad \bar{B}^0 \longrightarrow B^0 \longrightarrow \mu^+ X$$

- An untagged but time dependent analysis is possible:

$$\bar{B}^0 \longrightarrow \mu^- X \quad \Big| \quad B^0 \longrightarrow \mu^+ X$$

$$A_{\rm meas}(t) = \frac{\Gamma[f,t] - \Gamma[\bar{f},t]}{\Gamma[f,t] + \Gamma[\bar{f},t]} = \frac{a_{\rm sl}}{2} - \frac{a_{\rm sl}}{2}\frac{\cos(\Delta M t)}{\cosh(\Delta\Gamma t/2)}$$

reduction of stat. power only by factor 2.

- However this approach that there are the same number of B and B produced and that the production asymmetry is zero:

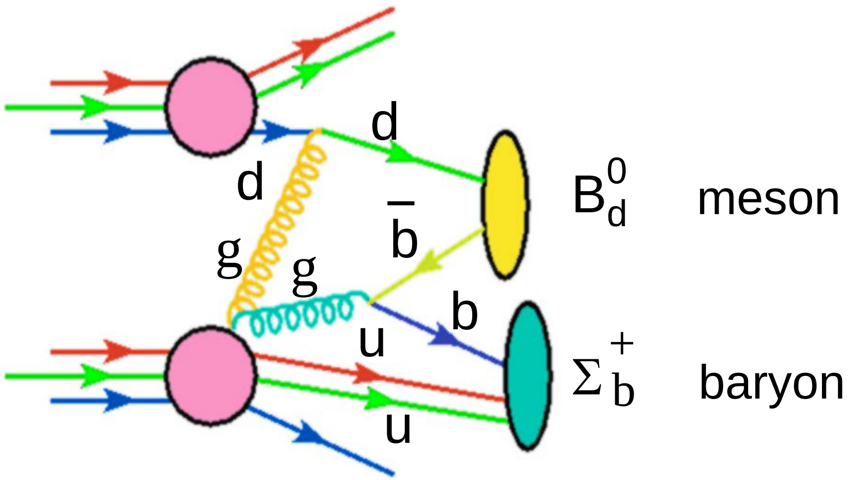
$$A_P = \frac{\mathcal{P}(B^0) - \mathcal{P}(\overline{B}^0)}{\mathcal{P}(B^0) + \mathcal{P}(\overline{B}^0)}$$

Production asymmetry – O(1%)

Two main effects:

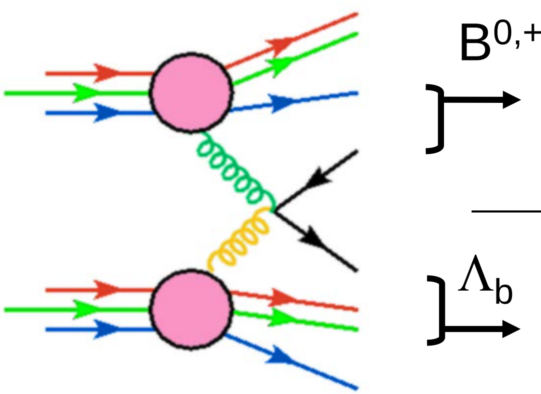
Cluster Collapse at low p_T

Enhances the production of species containing beam remnants at low transverse momentum (pt)

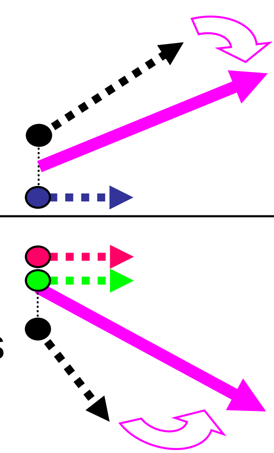


Beam Drag

Redistributes particle-antiparticles as function of rapidity



Color connections with remnant quarks 'drag' mesons w/ anti-quarks towards beam



Color connections with di-quark remnants 'drag' baryons towards the beam

Production asymmetry

Can be measured simultaneously with a_{SL} using time-dependence

$$A_{\mathrm{meas}}(t) = \frac{\Gamma[f,t] - \Gamma[\bar{f},t]}{\Gamma[f,t] - \Gamma[\bar{f},t]} = \frac{a_{\mathrm{sl}}}{2} - \left(A_{\mathrm{P}} + \frac{a_{\mathrm{sl}}}{2}\right)\frac{\cos(\Delta M t)}{\cosh(\Delta\Gamma t/2)}$$

Difference between fast oscillating B_s and slowly oscillating B_d mesons:

- For B_s mesons the oscillating term can be completely neglected. (A time integrated analysis is thus possible)
- For B_d we cannot neglect the term and should include it into the fit.

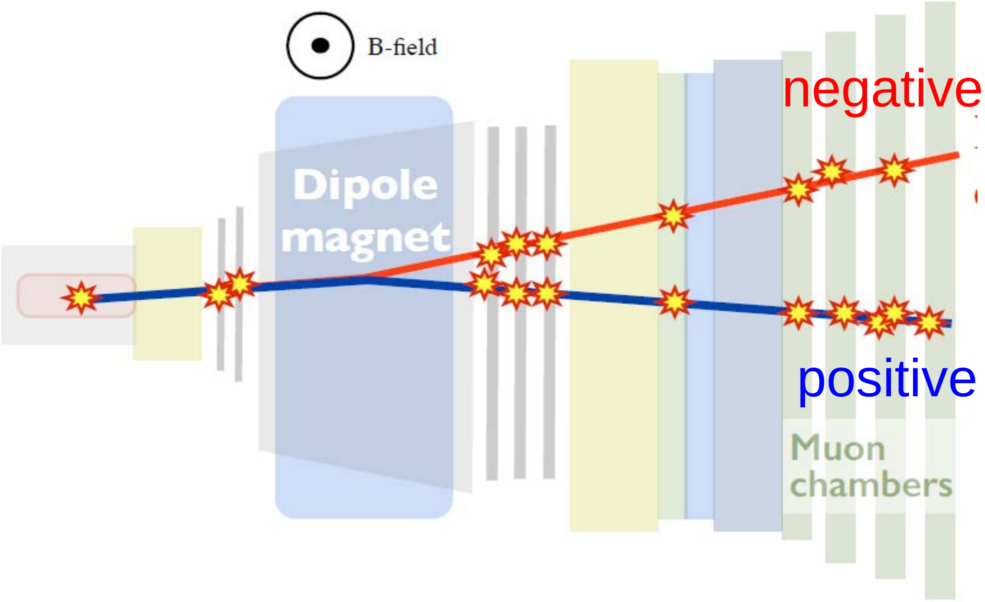
Additional corrections? Yes, we are looking for small effects!

Detection Asymmetry

$$A_D = \frac{\varepsilon(f) - \varepsilon(\overline{f})}{\varepsilon(f) + \varepsilon(\overline{f})}$$

Efficiency to detect & reconstruct a particle.

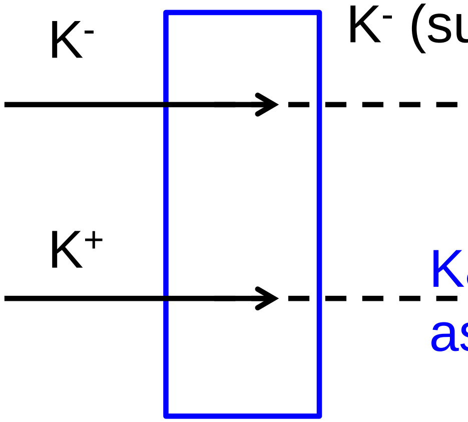
- Difference in tracking efficiency for positively/negatively charged tracks: Mostly related to acceptance problems.



→ inversion of magnetic field of spectrometer would invert the effect, thus by averaging effects are to first order gone!

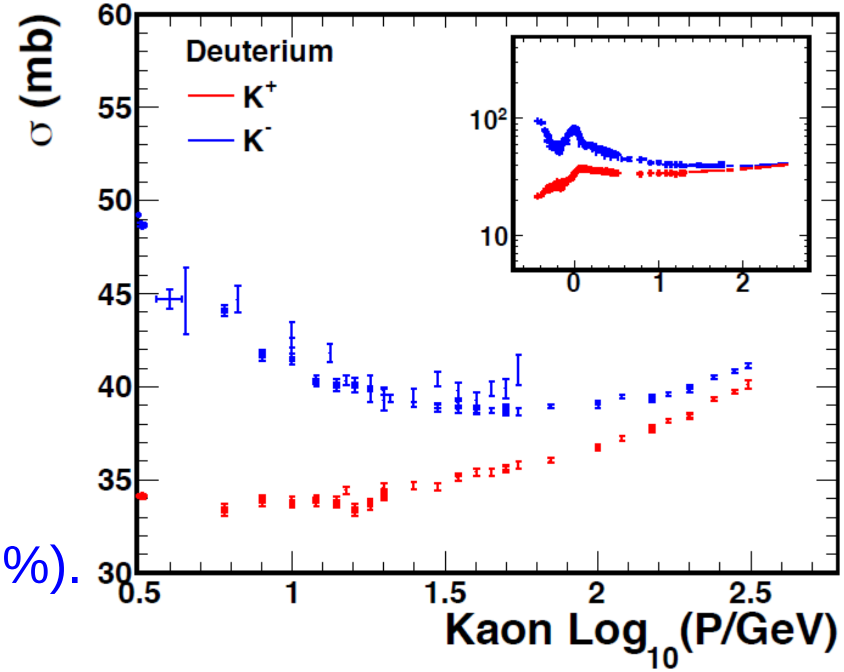
Different material interaction

- Different material interaction: most prominent for $K^{\pm}$

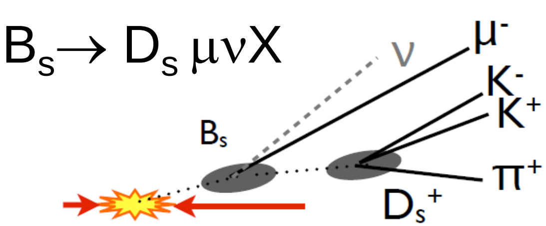


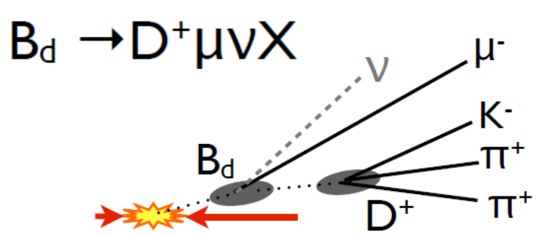
$K^- (su) + N \rightarrow \Lambda + \ldots$

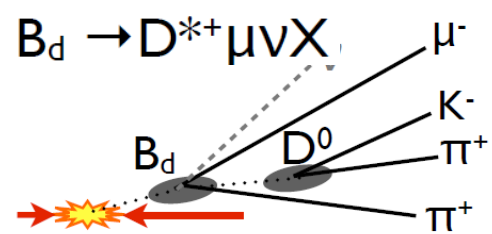
Kaon detection asymmetry = O(1%).



Detection asymmetry depends on final state particle of the decays.



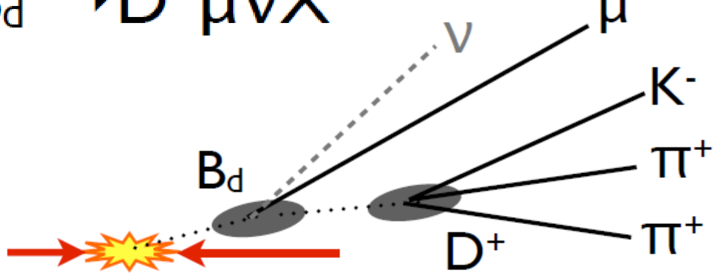




Measure detection asymmetry

e.g.

$B_d \rightarrow D^+ \mu \nu X$



$f = \mu^+ K^+ \pi^- \pi^-$

Split in

$A_D(\mu^+\pi^-)$, $\boxed{A_D(K^+\pi^-)}$

Prinzip:

$$A_{K\pi} \equiv \frac{\epsilon(K^+\pi^-) - \epsilon(K^-\pi^+)}{\epsilon(K^+\pi^-) + \epsilon(K^-\pi^+)}$$

$$= A(D \rightarrow K\pi\pi)$$

$$- A(D \rightarrow K_S\pi)$$

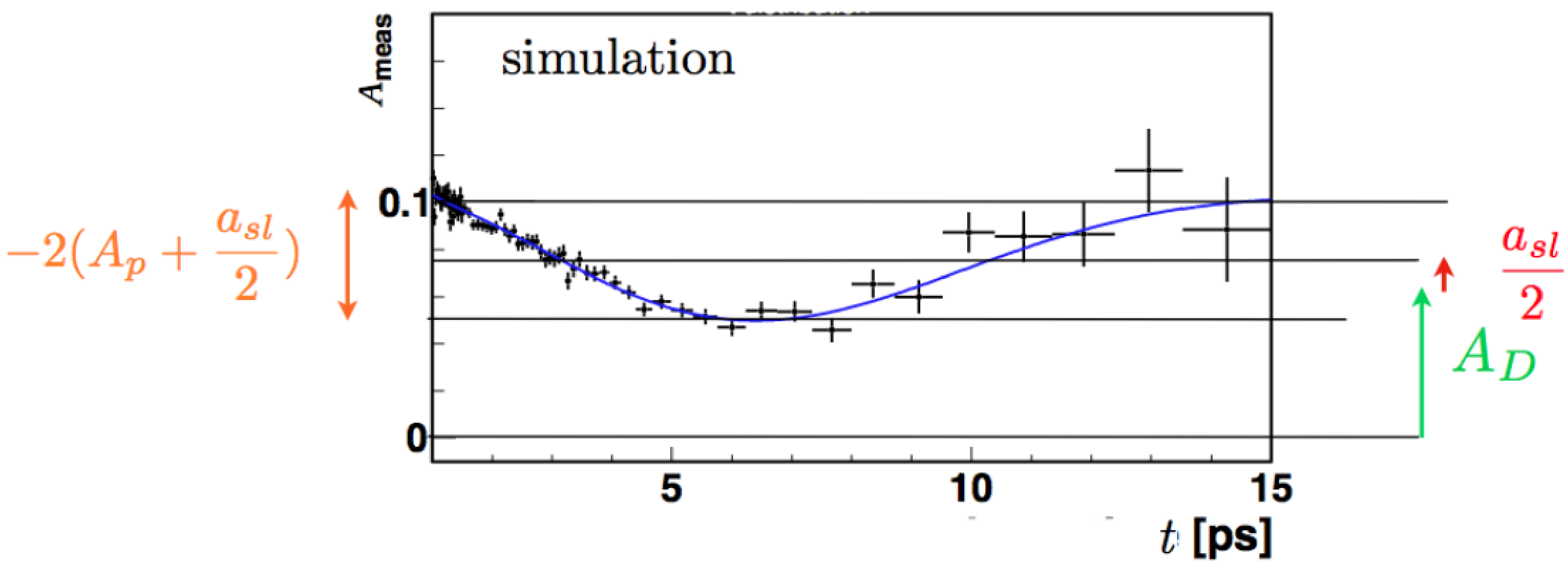
$$- A(K_S)$$

Need two decay modes of the same D species to cancel the production asymmetry

$$\boxed{A_{K\pi} = (1.15 \pm 0.08_{\mathrm{stat}} \pm 0.07_{\mathrm{syst}})\%}$$

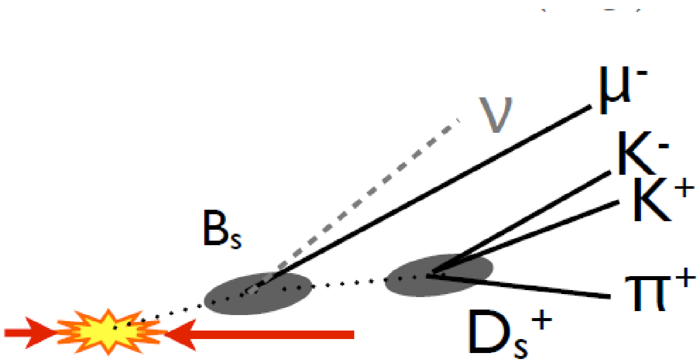
Measured asymmetry $B_d - \overline{B}_d$

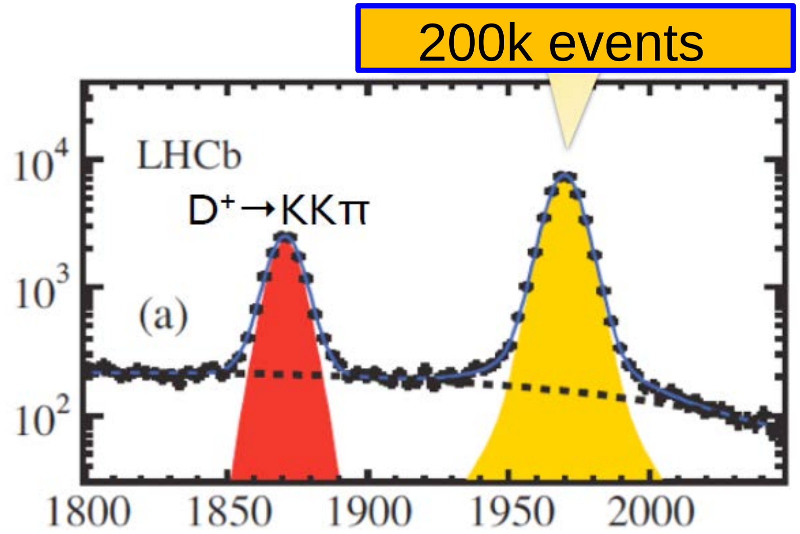
Illustration:



a_{SL}=0.1% A_P=-2.5% A_D=7.5%

CP Violation in B_s mixing





Time integrated:

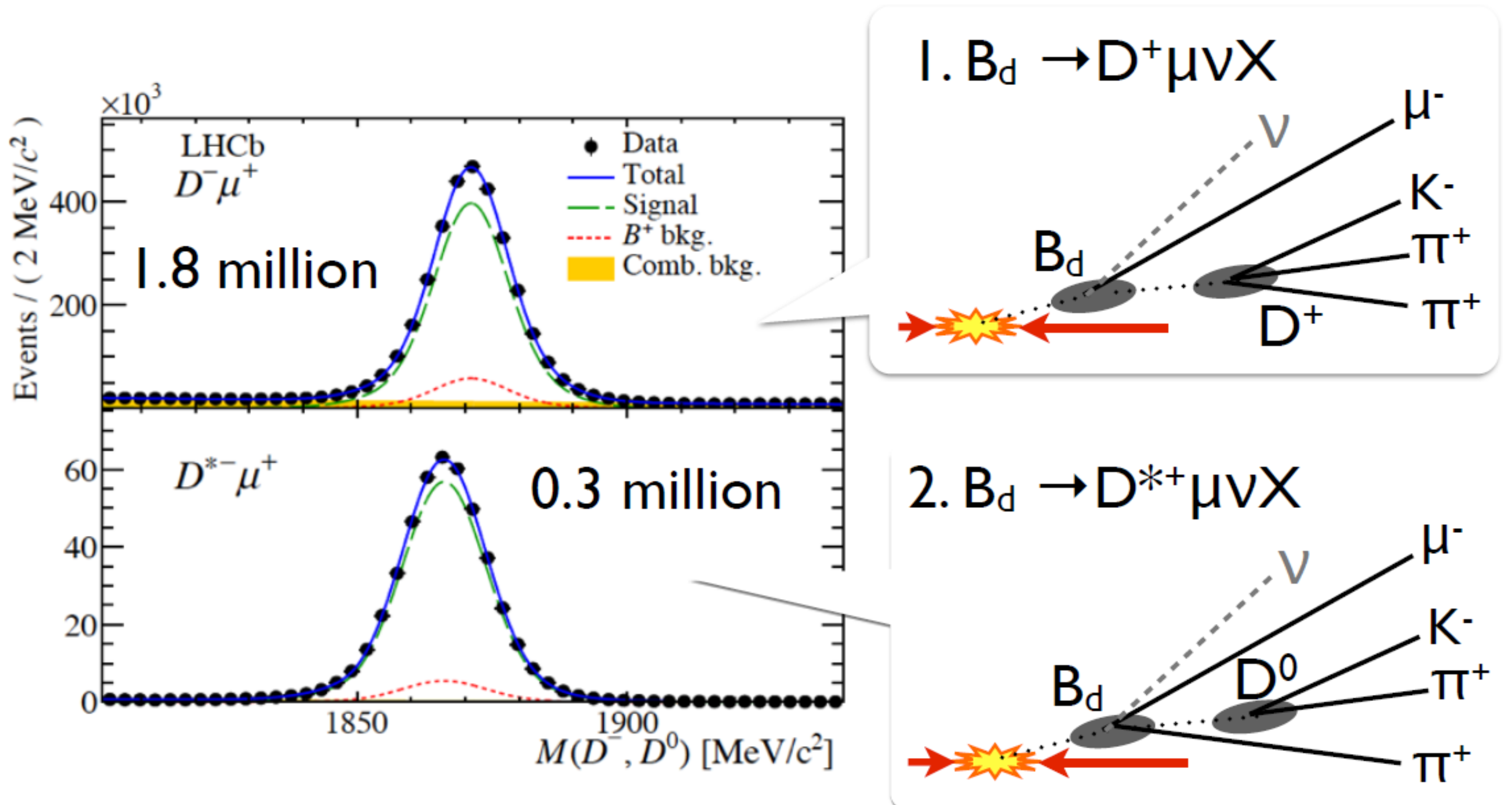
$$A_{meas} \equiv \frac{\Gamma(D_s^+\mu^-X) - \Gamma(D_s^-\mu^+X)}{\Gamma(D_s^+\mu^-X) - \Gamma(D_s^-\mu^+X)} = \frac{a_{sl}^d}{2}$$

$a_{sl}^s = (-0.06 \pm 0.50_{stat} \pm 0.36_{syst})\%$

Source	δ (%)
Tracking asymmetries	0.26
Muon asymmetries	0.16
Fitting	0.15
Backgrounds	0.10
Quadratic sum	0.36

… CP violation in B_d mixing

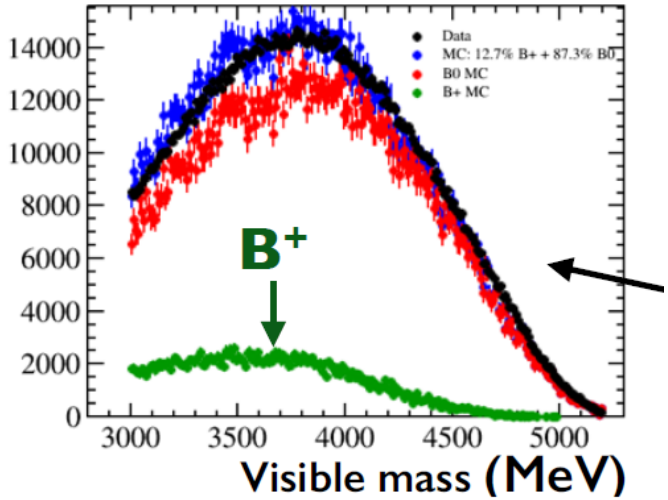
Time dependent analysis to separate production from CP asymmetry:



But: missing neutrino → more background and problems to reconstruct the decay time: don't know momentum: K-factor

$$t = L \cdot \frac{M}{|p|}$$

Disturbing problem …



No B mass peak because of missing neutrino: irreducible B^+ background (10%) (no mixing asymmetry, but production asymmetry)

B^+ production asymmetry:

$$
\begin{aligned}
A_P(B^+) &= A_{\mathrm{raw}}(B^+ \to J/\psi K^+) \\
&\quad - A_{\mathrm{CP}}(B^+ \to J/\psi K^+) \\
&\quad - A_{\mathrm{det}}(K^+)
\end{aligned}
$$

From LHCb data [1]

Other exp'ts [2]

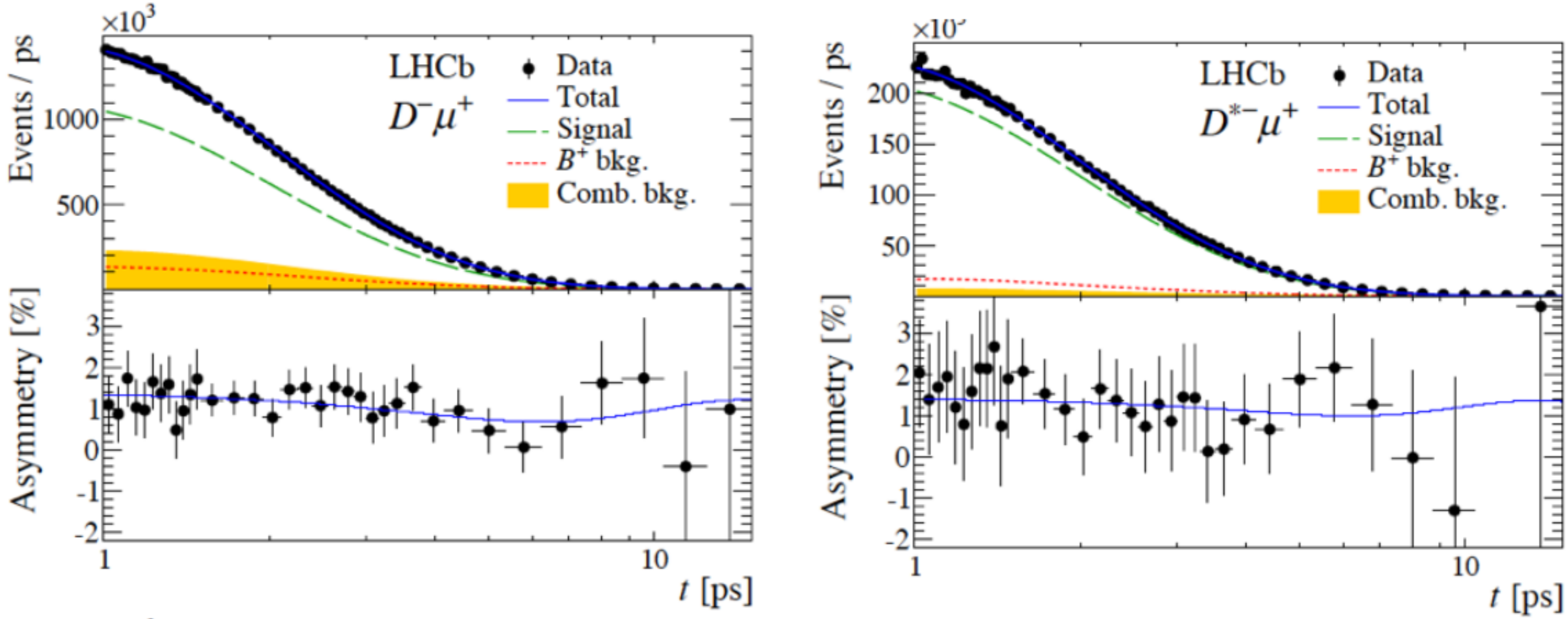
Measured

$$A_P(B^+) = (-0.6 \pm 0.6)\%$$

Second largest systematic.

Lifetime fit…

$$N(f,t) \propto e^{-\Gamma_d t}\left[1 \pm A_D \pm \frac{a_{\rm sl}^d}{2} \mp (A_p + \frac{a_{\rm sl}^d}{2})\cos\Delta m_d t\right]$$



$a_{sl}^d = (-0.02 \pm 0.19_{stat} \pm 0.30)\%$

$a_p(B_d, 7\text{ TeV}) = (-0.66 \pm 0.26 \pm 0.22)\%$

$a_p(B_d, 8\text{ TeV}) = (-0.48 \pm 0.15 \pm 0.17)\%$

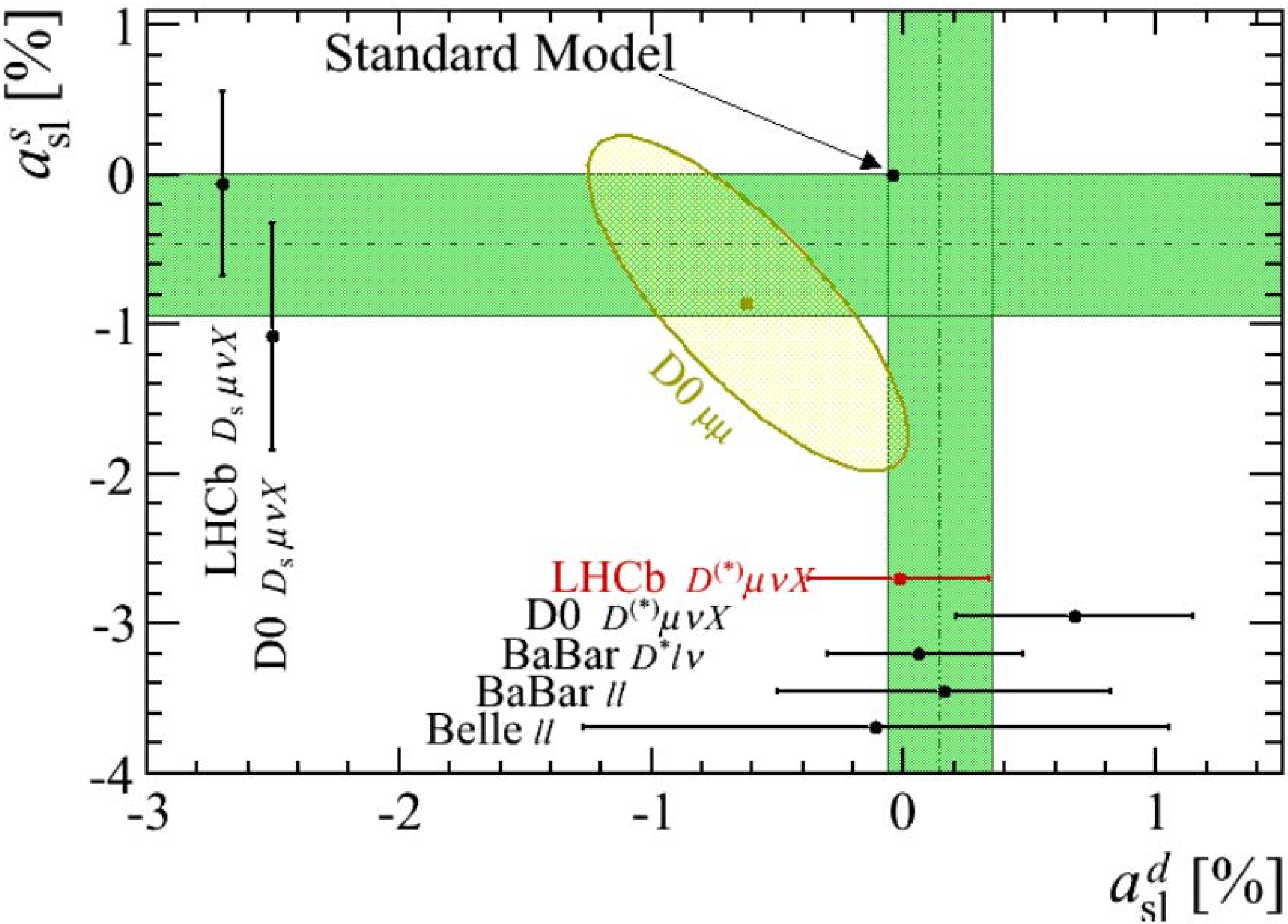
Systematics

$$a_{sl}^{d} = (-0.02 \pm 0.19_{stat} \pm 0.30)\%$$

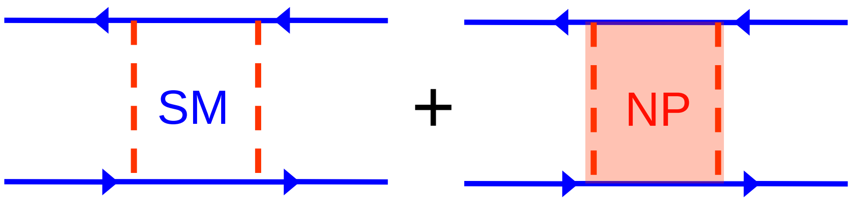
3 per mille.
We know how
to improve!

Source	δ (%)
Detection asymmetry	0.26
B plus	0.13
Baryonic background	0.07
Bs background	0.03
Fake D background	0.03
K-factor model	0.03
Decay time acceptance	0.03
Mixing frequency	0.02
Quadratic sum	0.30

Comparison w/ other measurements



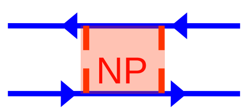
What have we learned about NP



$$\mathcal{A}_{mix} = \mathcal{A}_{mix}^{SM} + \mathcal{A}_{mix}^{NP}$$
$$= \mathcal{A}_{mix}^{SM} \cdot \Delta$$

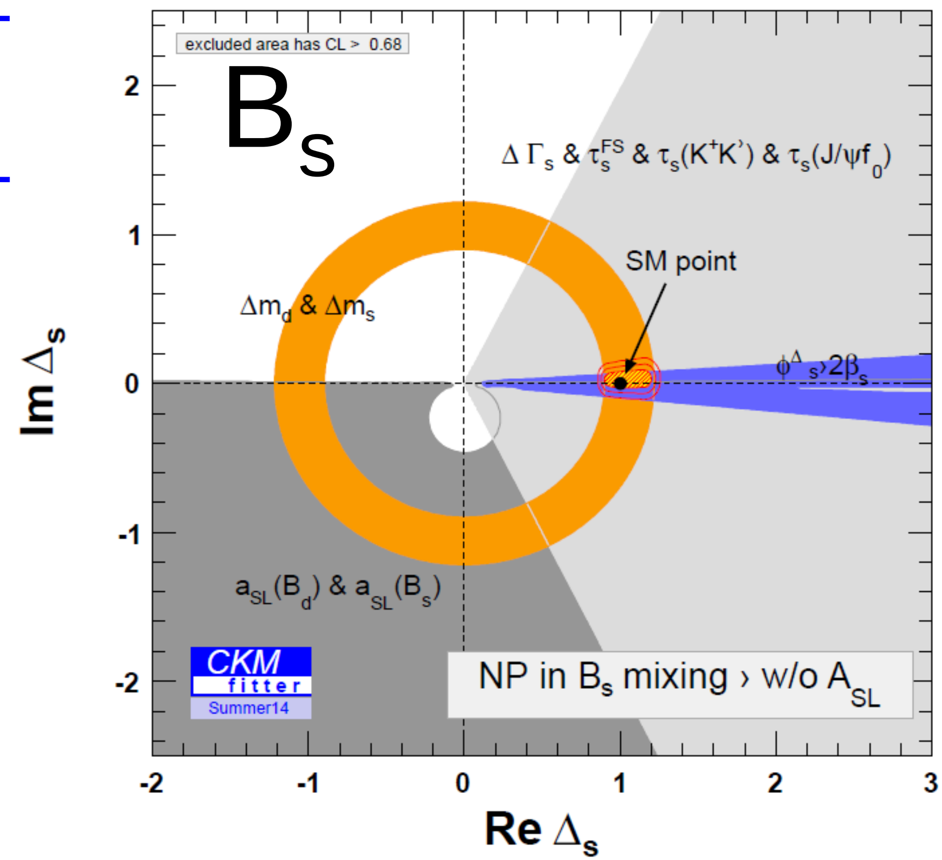
$B_s^0\ (\bar{b}s)$ < 20%

$B_d^0\ (\bar{b}d)$ < 30%



U.Nierste

A.Lenz, U.Nierste & ckmfitter.in2p3.fr



Summary

- Searches for new effects in quantum loop require precise theoretical predictions as well as precise measurements. The B mixing measurements we have not yet reached the precision to realy challenge the Standard Model

- Theoretically "clean" observables are:
  – CP asymmetries (measure phases)
  – Angular distributions (test Lorentz structure of couplings)

Experimentally favored

- Theoretically more challenging are absolute rates (large hadronic uncertainties)

Experimentally difficult

- Rule of thumb for experimental (systematic) uncertainties:
  - few % is "easy"
  - 1% starts to become difficult
  - Few per mille is really challenging