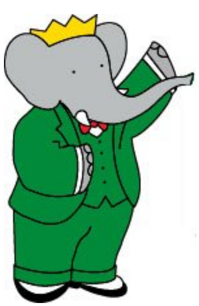
Indirect constraints on New Physics from the B-factories



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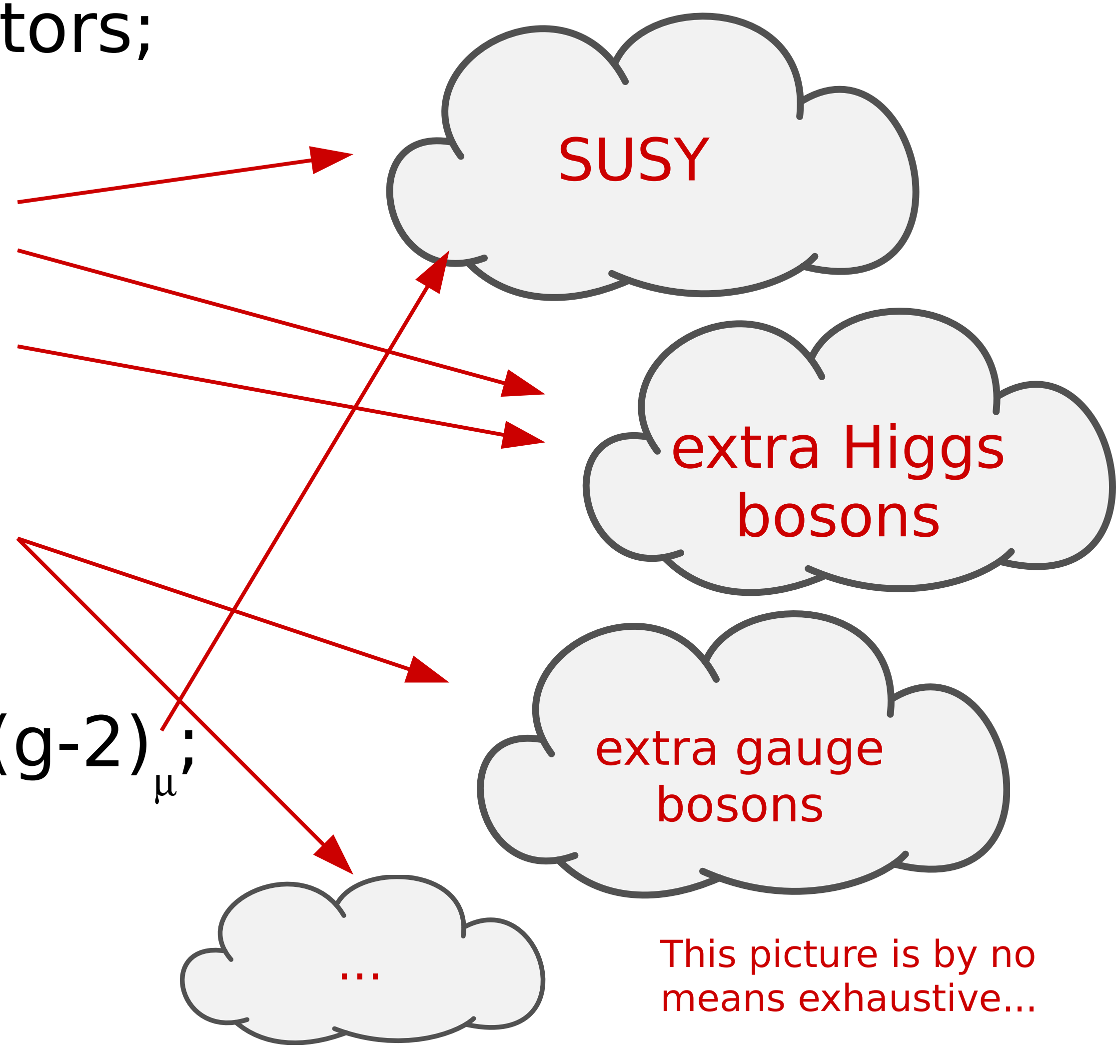
On behalf of the BaBar and Belle Collaborations

IPA2014, London, August 20th 2014

Outline

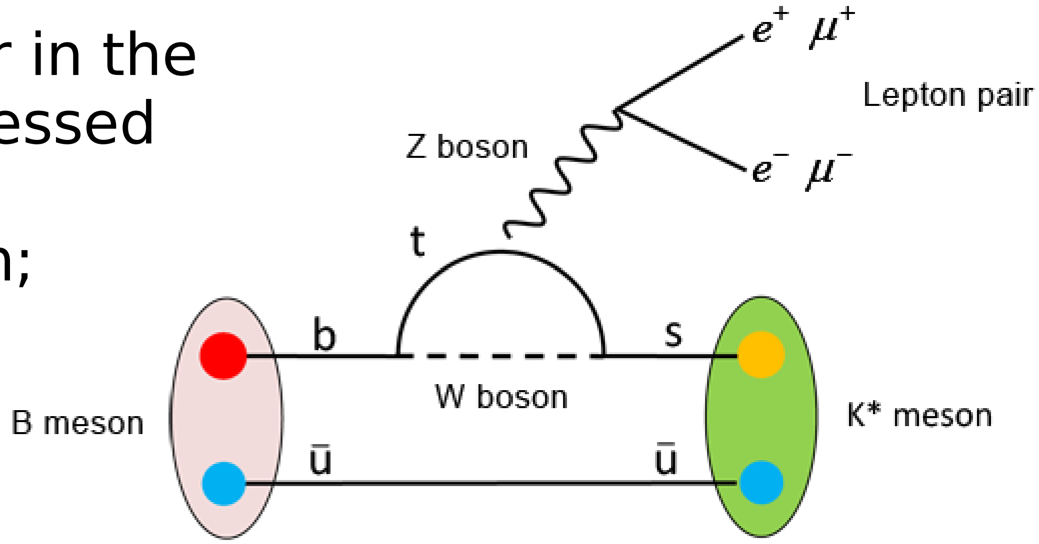
- Motivations;
- The PEP-II and KEKB B-factories and the BaBar and Belle detectors;
  - $B \to X_s \gamma$, $B \to X_s\, l^+ l^-$;
  - $B \to \tau \nu$, $B \to D^{(*)} \tau \nu$;
  - D^0 mixing and CPV;
  - Hadronic e^+e^- cross-sections and $(g-2)_\mu$;
- Conclusions.



This picture is by no means exhaustive...

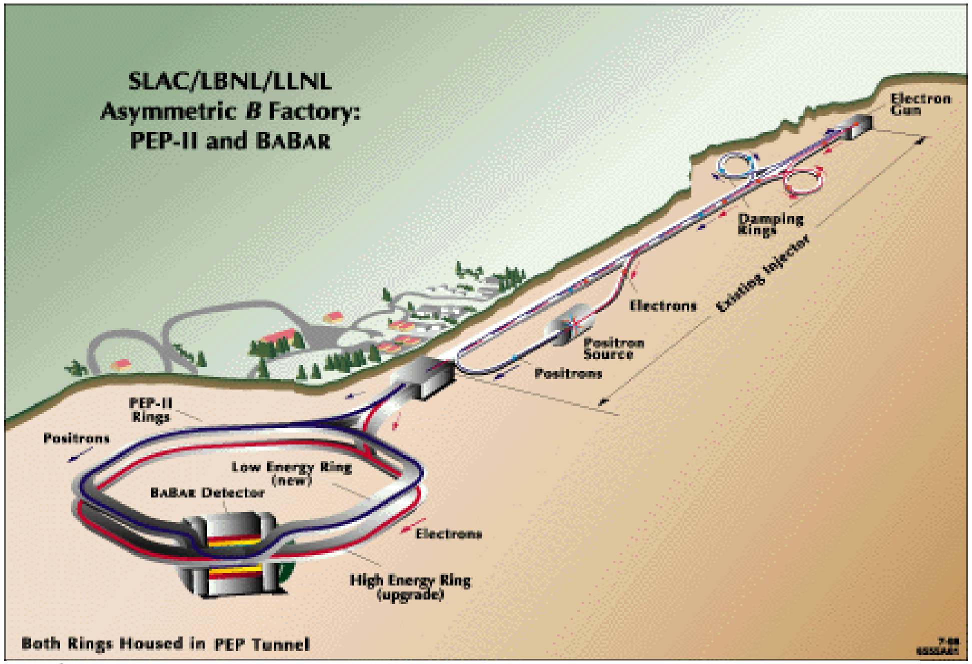
Motivations

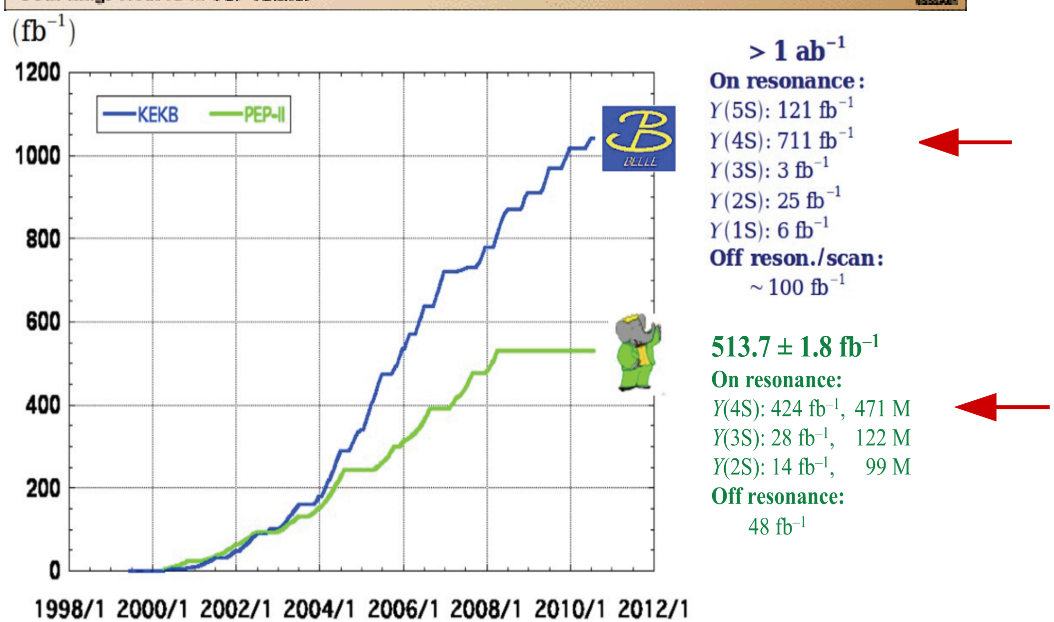
- Many physics processes at the GeV scale can be sensitive to New Physics at much higher energies;
- New Physics particles can enter in the loop/box diagrams of SM suppressed processes and modify the observables associated to them;
- Also at tree level, we could expect Lepton Universality to break due to the presence of Higgs-like particles;

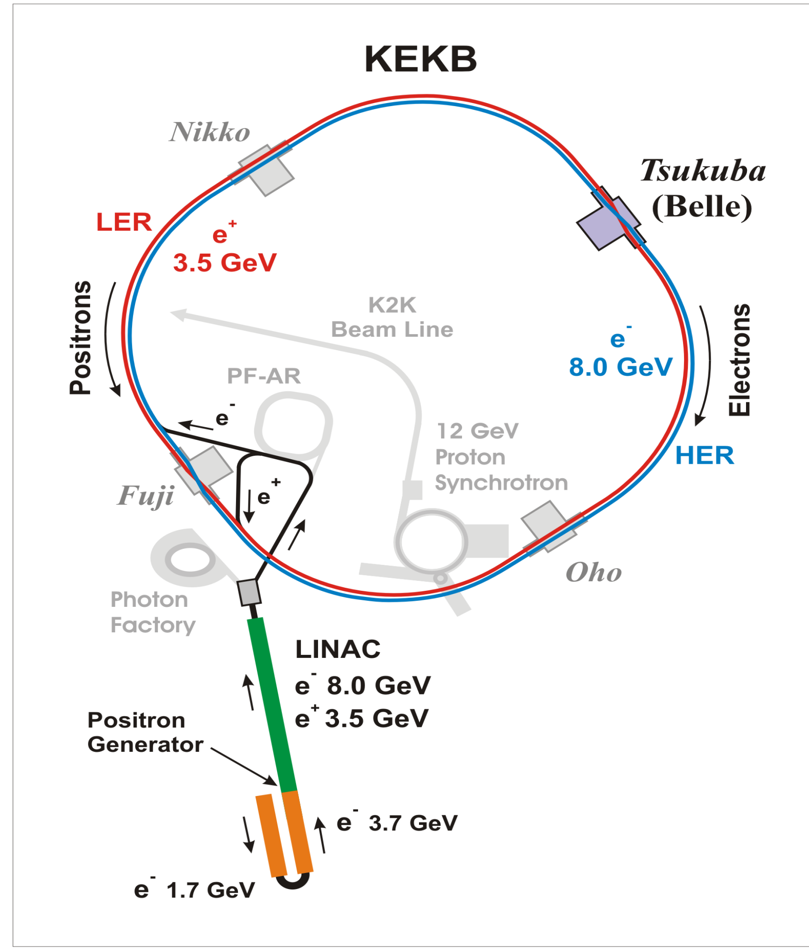


- These indirect searches are complementary to the direct searches of New Physics at the LHC;
- Today I will focus only on a few processes on which the BaBar and Belle Collaborations have recently published results.

PEP-II and KEKB



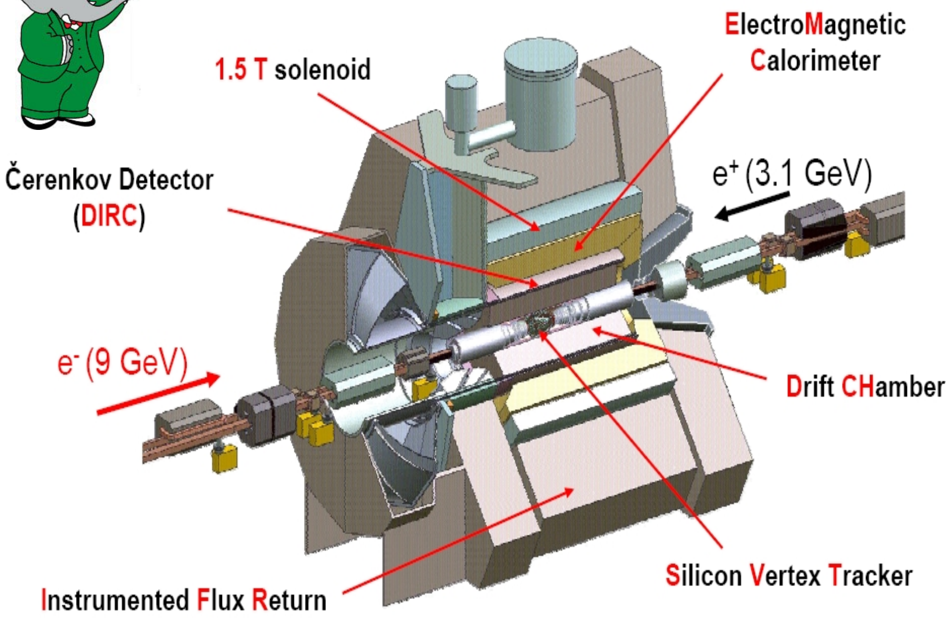


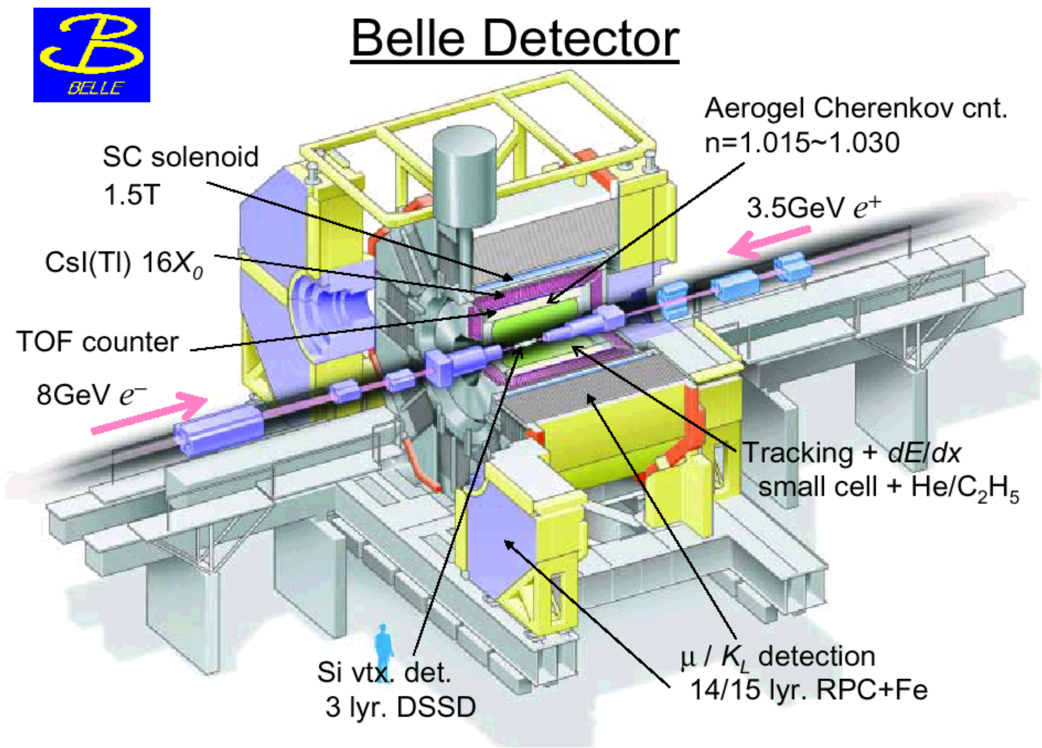


PEP-II and KEKB delivered in total ~1150 fb^{-1} at the Y(4S)

1 fb^{-1} ~ 10^6 $B\bar{B}$ pairs

The BaBar and Belle detectors





The BaBar and Belle detectors are conceptually similar. They performed reliably and provided:

- high tracking efficiency and momentum resolution;
- excellent vertexing resolution (~150 μm);
- great K-π separation capabilities;
- detection of neutral particles from 20 MeV to a few GeV;
- very good μ detection and identification performance.

Electroweak penguins

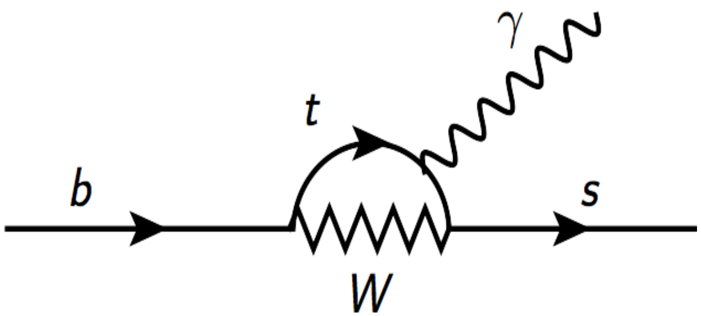
"Measurements of Direct CP Asymmetries in $B \to X_s \gamma$ decays using Sum of Exclusive Decays",
arXiv:1406.0534 [hep-ex], submitted to PRD

"Measurement of the $B \to X_s \ell^+\ell^-$ branching fraction and search for direct CP violation from a sum of exclusive final states",
arXiv:1312.5364 [hep-ex], PRL **112**, 211802 (2014)

"Measurement of the Lepton Forward-Backward Asymmetry in Inclusive $B \to X_s \ell^+\ell^-$ Decays",
arXiv:1402.7134 [hep-ex], submitted to PRL

CP asymmetry in $B \to X_s \gamma$

- $B \to X_s \gamma$ decays proceed through electroweak penguin diagrams;
- The inclusive branching fraction and CP asymmetry are precisely predicted in the SM:



$$\mathcal{B}(\bar{B} \to X_s \gamma) = (3.15 \pm 0.23) \times 10^{-4}$$ for $E_\gamma > 1.6$ GeV

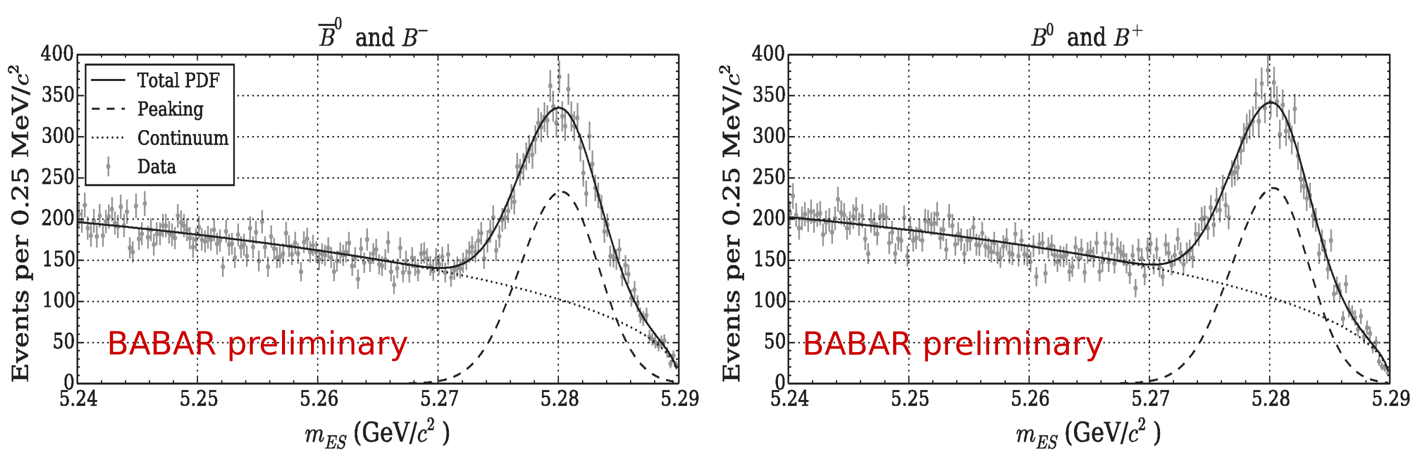
M. Misiak et al.
PRL 98, 022002 (2007)

$$-0.6\% < \mathcal{A}^{\mathrm{SM}}_{X_s\gamma} < 2.8\%$$ dominated by long distance effects

M. Benzke et al.
PRL 106, 141801 (2011)

- Scope of the measurement is to verify the SM prediction and constrain possible deviations to the Wilson Coefficients (short scale physics).

$$m_{ES} = M_{bc} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$



CP asymmetry in $B \to X_s \gamma$

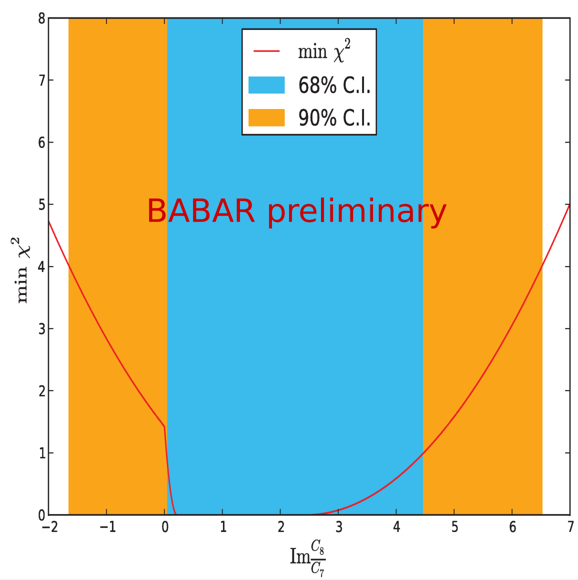
- Results:

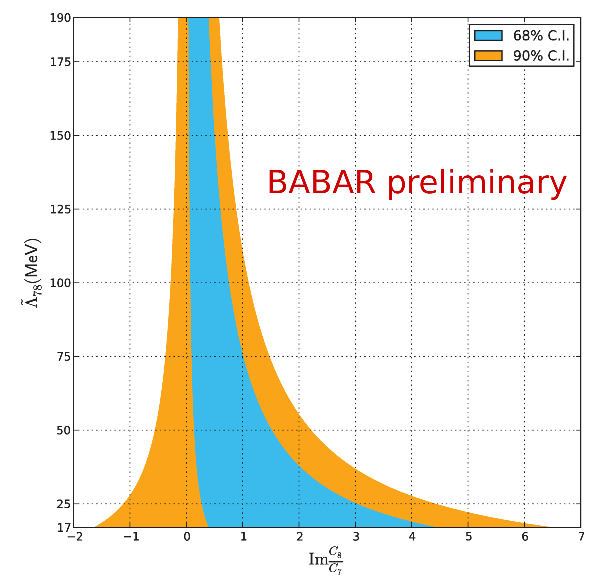
$$A_{CP} = \frac{\Gamma_{\overline{B}^0/B^- \to X_s\gamma} - \Gamma_{B^0/B^+ \to X_{\overline{s}}\gamma}}{\Gamma_{\overline{B}^0/B^- \to X_s\gamma} + \Gamma_{B^0/B^+ \to X_{\overline{s}}\gamma}} = +(1.7 \pm 1.9 \pm 1.0)\%$$

- Also the difference of A_{CP} between charged and neutral modes (SM predicts ~0) is measured:

$$\Delta A_{X_s\gamma} = A_{B^\pm \to X_s\gamma} - A_{B^0/\overline{B}^0 \to X_s\gamma} = +(5.0 \pm 3.9 \pm 1.5)\%$$

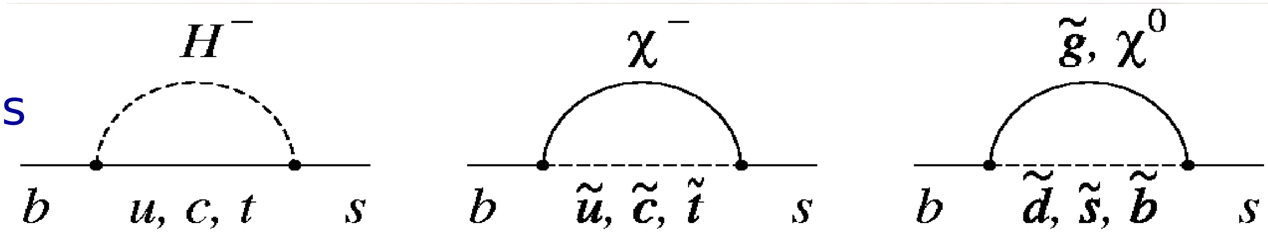
- This allows to constrain the imaginary part of the Wilson coefficients corresponding to the chromo-magnetic dipole and the electromagnetic dipole transitions.





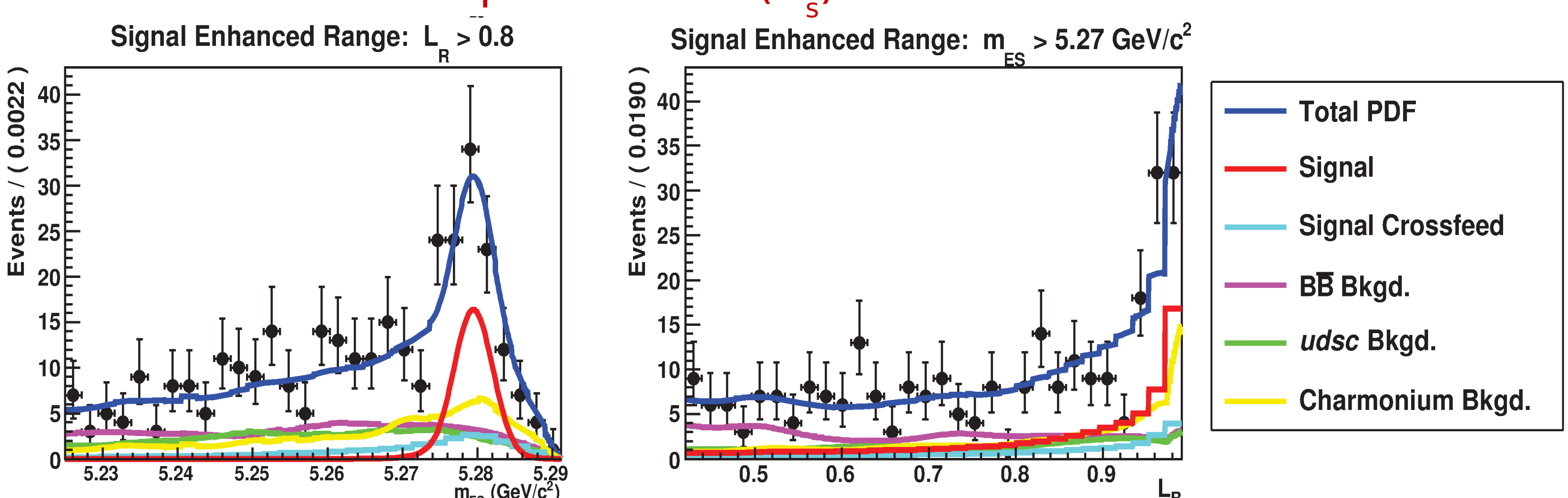
$B \to X_s\, l^+l^-$

These decays are potentially sensitive to e.g. SUSY particles or extra Higgs bosons.



- The inclusive branching fraction is measured from a sum of 10 exclusive X_s final states with $m(X_s) < 1.8$ GeV ;
- Signal yields are extracted with a ML fit to m_{ES} and a likelihood ratio L_R based on the BDT output that is used to suppress the combinatorial and continuum background.

Fit example: $0.6 < m(X_s) < 1.0$ GeV

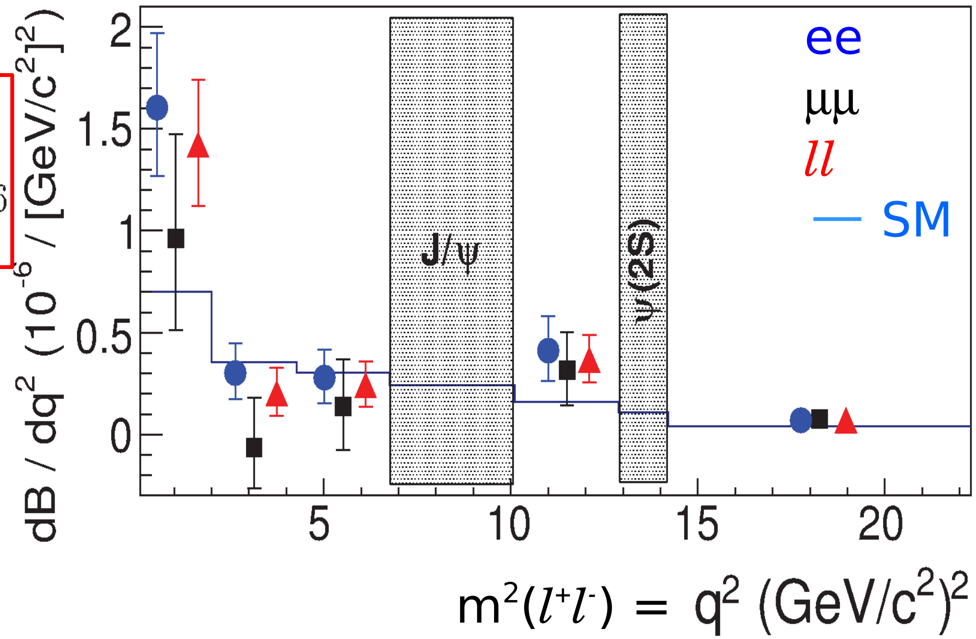


$B \rightarrow X_s\, l^+ l^-$

- Results:

$$\mathcal{B}(B \to X_s \ell^+\ell^-) = \left(6.73^{+0.70}_{-0.64}[\text{stat}]^{+0.34}_{-0.25}[\text{exp syst}] \pm 0.50[\text{model syst}]\right) \times 10^{-6}$$

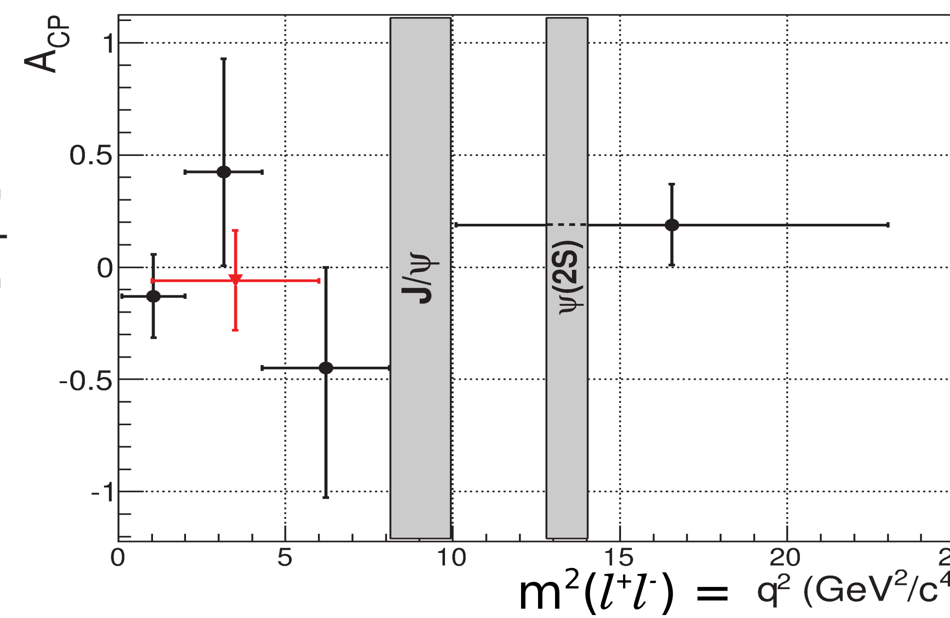
good agreement with SM predictions, e.g.
A. Ghinkulov et al. Nucl. Phys. B685, 351 (2004)



- The 7 self-tagging modes are used to measure the direct CP asymmetry (expected to be ~0):

$$A_{CP} = \frac{\mathcal{B}(\bar{B} \to \bar{X}_s \ell^+\ell^-) - \mathcal{B}(B \to X_s \ell^+\ell^-)}{\mathcal{B}(\bar{B} \to \bar{X}_s \ell^+\ell^-) + \mathcal{B}(B \to X_s \ell^+\ell^-)}$$

$$A_{CP} = 0.04 \pm 0.11 \pm 0.01$$



A_{FB} in $B \to X_s\, l^+l^-$

- First measurement of A_{FB} for the inclusive $B \to X_s\, l^+l^-$;
- The forward-backward asymmetry is defined as:

$$\mathcal{A}_{\rm FB}(q^2_{\rm min}, q^2_{\rm max}) = \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} dq^2 \int_{-1}^{1} d\cos\theta \, {\rm sgn}(\cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta}}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} dq^2 \int_{-1}^{1} d\cos\theta \frac{d^2\Gamma}{dq^2 d\cos\theta}}$$

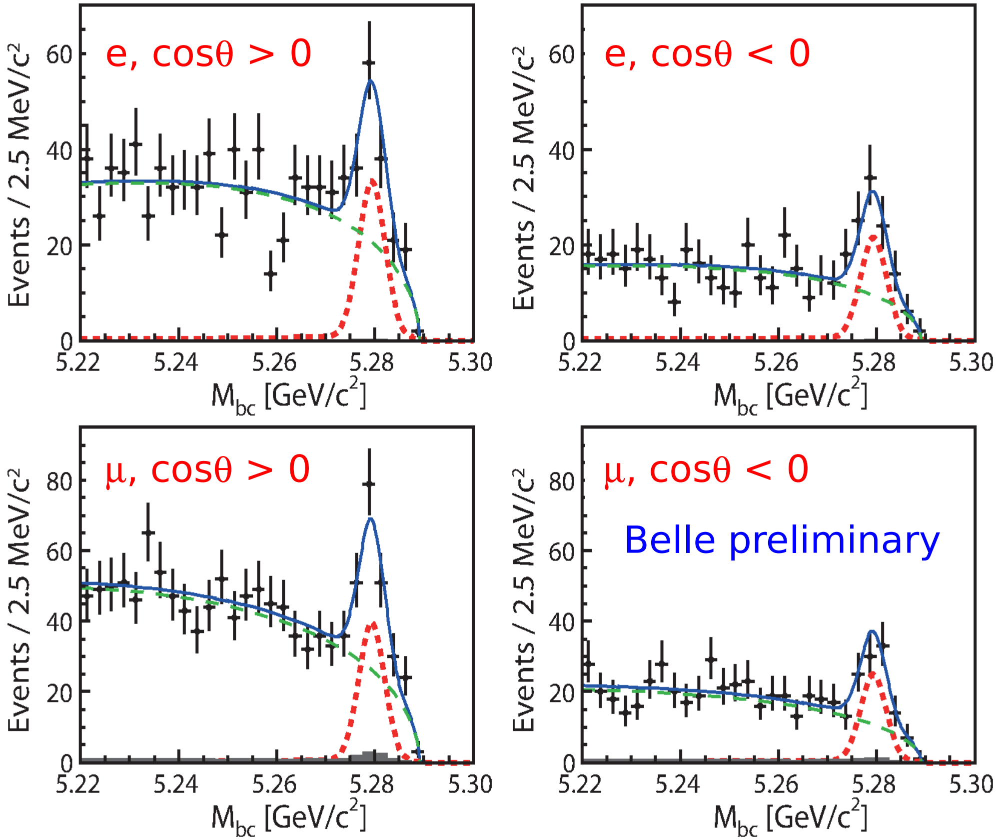
θ : angle between the l^+ (l^-) momentum and the $\bar{B}$ (B) momentum in the l^+l^- rest frame

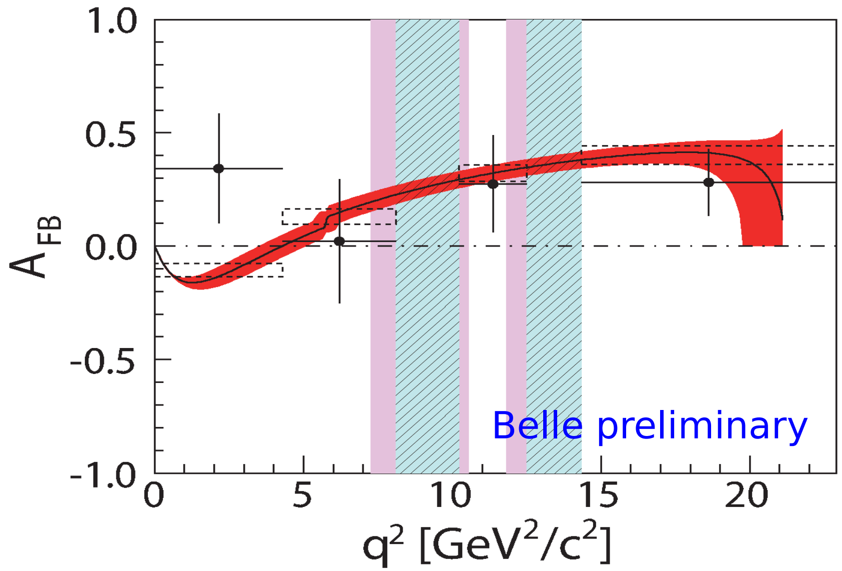
- 18 hadronic final states are used for the X_s system. 10 of them are used for the A_{FB} measurement:

$\bar{B}^0$ decays		B^- decays	
	(K_S^0)	K^-	
$K^-\pi^+$	$(K_S^0\pi^0)$	$K^-\pi^0$	$K_S^0\pi^-$
$K^-\pi^+\pi^0$	$(K_S^0\pi^-\pi^+)$	$K^-\pi^+\pi^-$	$K_S^0\pi^-\pi^0$
$K^-\pi^+\pi^-\pi^+$	$(K_S^0\pi^-\pi^+\pi^0)$	$K^-\pi^+\pi^-\pi^0$	$K_S^0\pi^-\pi^+\pi^-$
$(K^-\pi^+\pi^-\pi^+\pi^0)$	$(K_S^0\pi^-\pi^+\pi^-\pi^+)$	$(K^-\pi^+\pi^-\pi^+\pi^-)$	$(K_S^0\pi^-\pi^+\pi^-\pi^0)$

A_{FB} in $B \to X_s\, l^+ l^-$

- A_{FB} is determined from an unbinned ML fit to four (+/- , e/μ) M_{bc} distributions:
- New Physics could enhance or flip the sign of A_{FB}.





Good compatibility with the SM predictions, first bin 1.8σ away from expectations

B decays to τ's

"Evidence for B → τν with a Hadronic Tagging Method Using the Full Data Sample of Belle",
arXiv:1208.4678 [hep-ex], PRL **110**, 131801 (2013)

"Evidence of B → τν decays with hadronic B tags",
arXiv:1207.0698 [hep-ex], PRD **88**, 031102 (2013)

"Measurement of an Excess of B → $D^{(*)}$τν Decays and Implications for Charged Higgs Bosons",
arXiv:1303.0571 [hep-ex], PRD **88**, 072012 (2013)

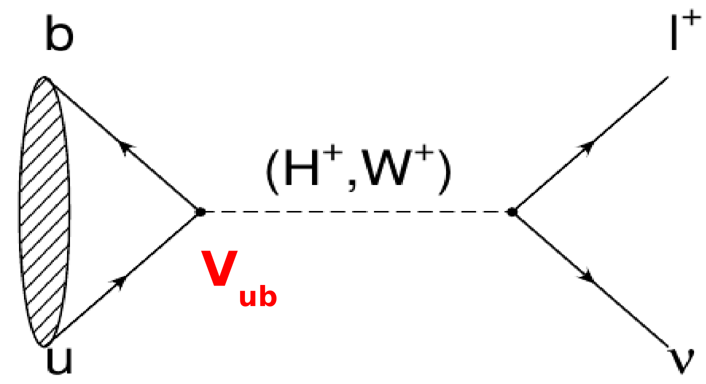
"Measurement of B → $D^{(*)}$τν using full reconstruction tags",
arXiv:0910.4301 [hep-ex]

$B \to \tau\nu$

- $B \to \tau\nu$ can be sensitive to the presence of charged Higgs particles;
- SM expectation (based on CKM fit):

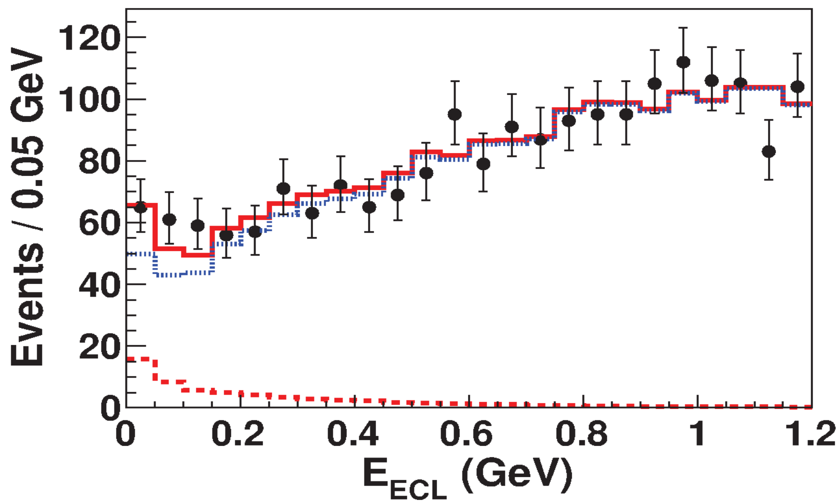
  $$BF(B \to \tau\nu) = (0.73^{+0.12}_{-0.07}) \times 10^{-4}$$

  CKMfitter, EPJ C41, 1 (2005)

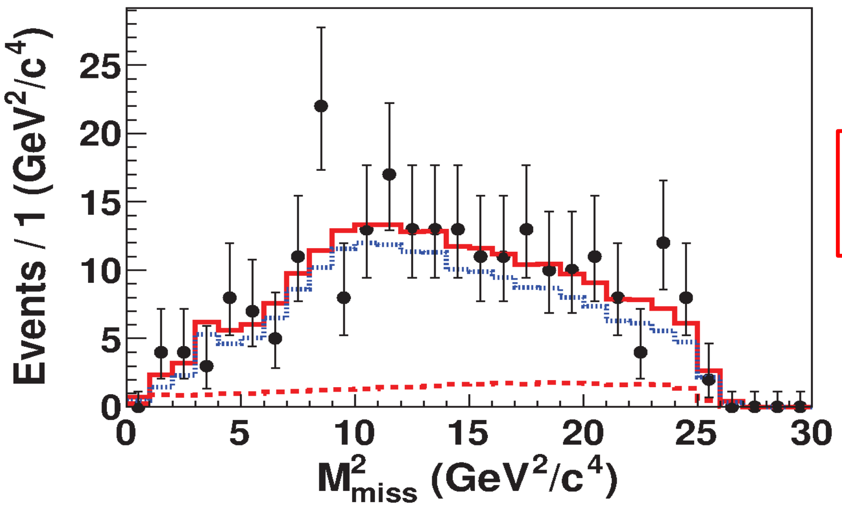


- Experimental challenge: the measurement can only be done on the recoil of hadronic (or semileptonic) B decays;
- Four τ decay channels are considered: $e\, \nu_e\, \nu_\tau$, $\mu\, \nu_\mu\, \nu_\tau$, $\pi\, \nu_\tau$, $\pi\, \pi^0\, \nu_\tau$;
- The main discriminating variable is E_{ECL}: the sum of the energy not associated to the hadronic B nor to the τ decay products (charged track and π^0 candidate).

$B \to \tau\nu$



Sub-mode	$N_{\rm sig}$	ϵ (10^{-4})	$\mathcal{B}$ (10^{-4})
$\tau^- \to e^-\bar{\nu}_e\nu_\tau$	16^{+11}_{-9}	3.0	$0.68^{+0.49}_{-0.41}$
$\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	26^{+15}_{-14}	3.1	$1.06^{+0.63}_{-0.58}$
$\tau^- \to \pi^-\nu_\tau$	8^{+10}_{-8}	1.8	$0.57^{+0.70}_{-0.59}$
$\tau^- \to \pi^-\pi^0\nu_\tau$	14^{+19}_{-16}	3.4	$0.52^{+0.72}_{-0.62}$
Combined	62^{+23}_{-22}	11.2	$0.72^{+0.27}_{-0.25}$

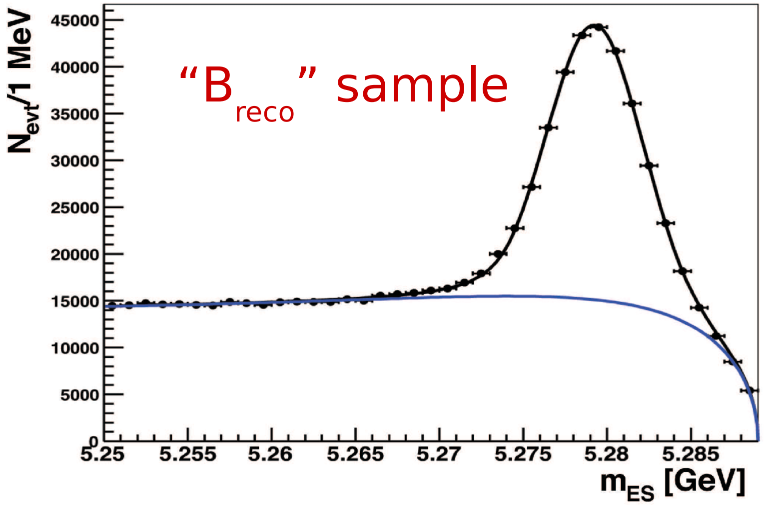


Result:

$$\mathcal{B}(B^- \to \tau^-\bar{\nu}_\tau) = [0.72^{+0.27}_{-0.25}(\text{stat}) \pm 0.11(\text{syst})] \times 10^{-4}$$

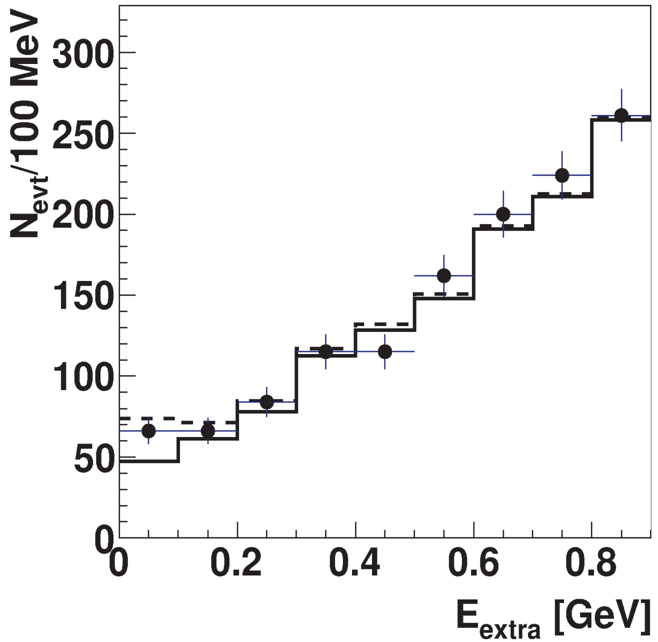
the significance is 3.0σ, and the measured BF is in good agreement with both the SM and previous measurements.

$B \to \tau\nu$



BaBar performed a similar measurement on its full dataset;

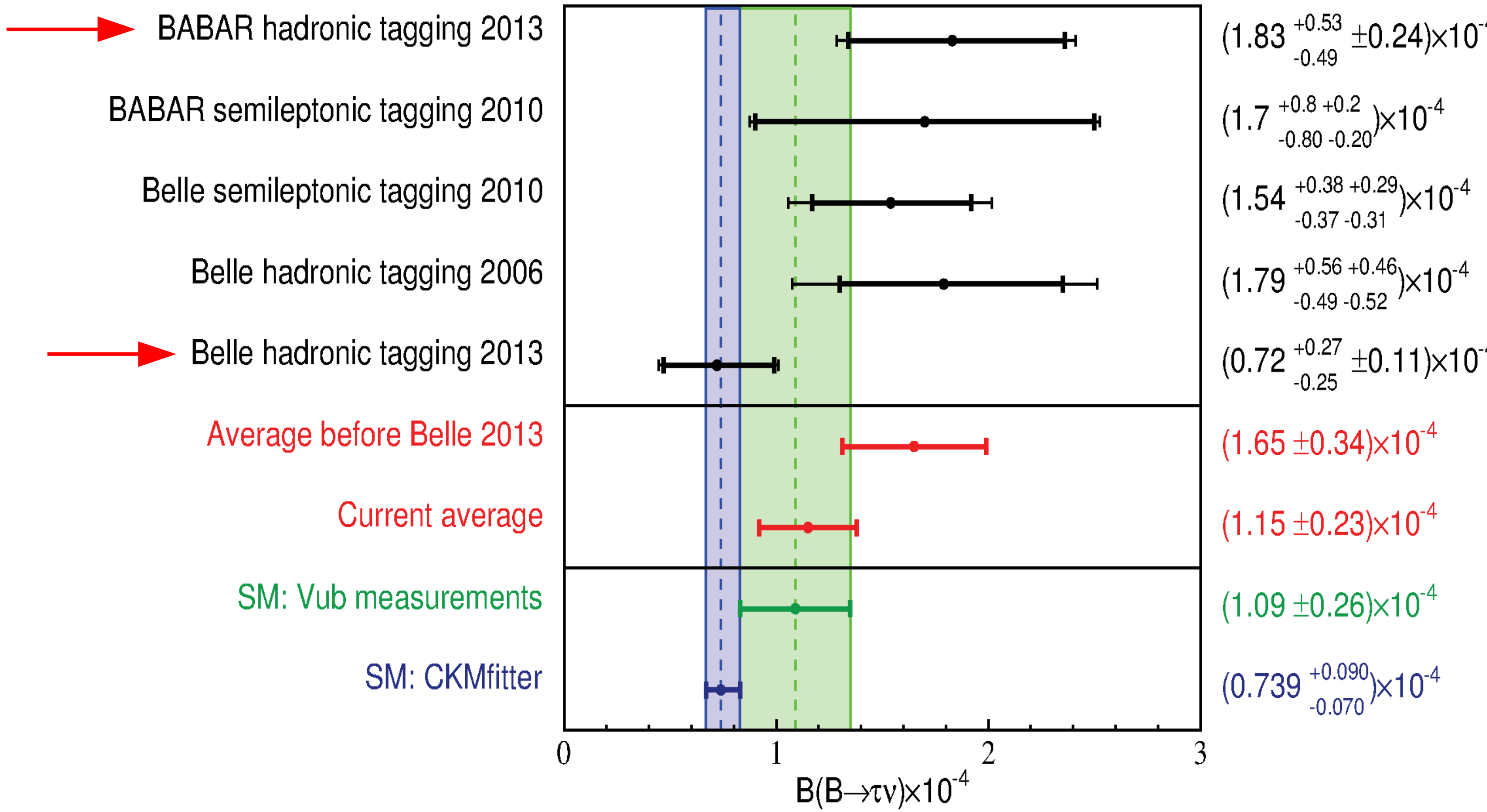
Decay Mode	$\epsilon_k(\times 10^{-4})$	Signal yield	$\mathcal{B}(\times 10^{-4})$
$\tau^+ \to e^+\nu\bar{\nu}$	2.47 ± 0.14	4.1 ± 9.1	$0.35^{+0.84}_{-0.73}$
$\tau^+ \to \mu^+\nu\bar{\nu}$	2.45 ± 0.14	12.9 ± 9.7	$1.12^{+0.90}_{-0.78}$
$\tau^+ \to \pi^+\nu$	0.98 ± 0.14	17.1 ± 6.2	$3.69^{+1.42}_{-1.22}$
$\tau^+ \to \rho^+\nu$	1.35 ± 0.11	24.0 ± 10.0	$3.78^{+1.65}_{-1.45}$
combined		62.1 ± 17.3	$1.83^{+0.53}_{-0.49}$



$$\mathcal{B}(B^+ \to \tau^+\nu) = \left(1.83^{+0.53}_{-0.49}(\text{stat.}) \pm 0.24(\text{syst.})\right) \times 10^{-4}$$

Significance: 3.8σ, ~2σ tension with the SM prediction.

$B \to \tau\nu$ (summary)

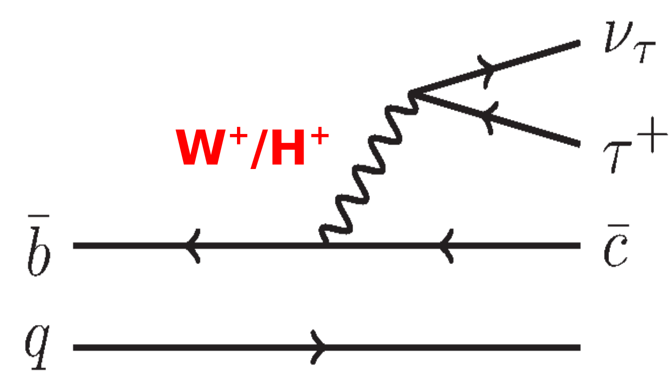


Despite the good agreement of Belle's recent hadronic tag measurement with the SM expectation, the picture has not been settled yet.

This is definitely a task for the Belle-II experiment.

$B \to D^{(*)}\tau\nu$

- Also these channels are sensitive to New Physics from extra Higgs bosons;
- Some of the quantities of interest (thanks to the fact that many uncertainties cancel in the ratios) are:



$$R(D^{(*)}) \equiv \frac{\Gamma(B \to \bar{D}^{(*)}\tau^+\nu_\tau)}{\Gamma(B \to \bar{D}^{(*)}\ell^+\nu_\ell)}$$

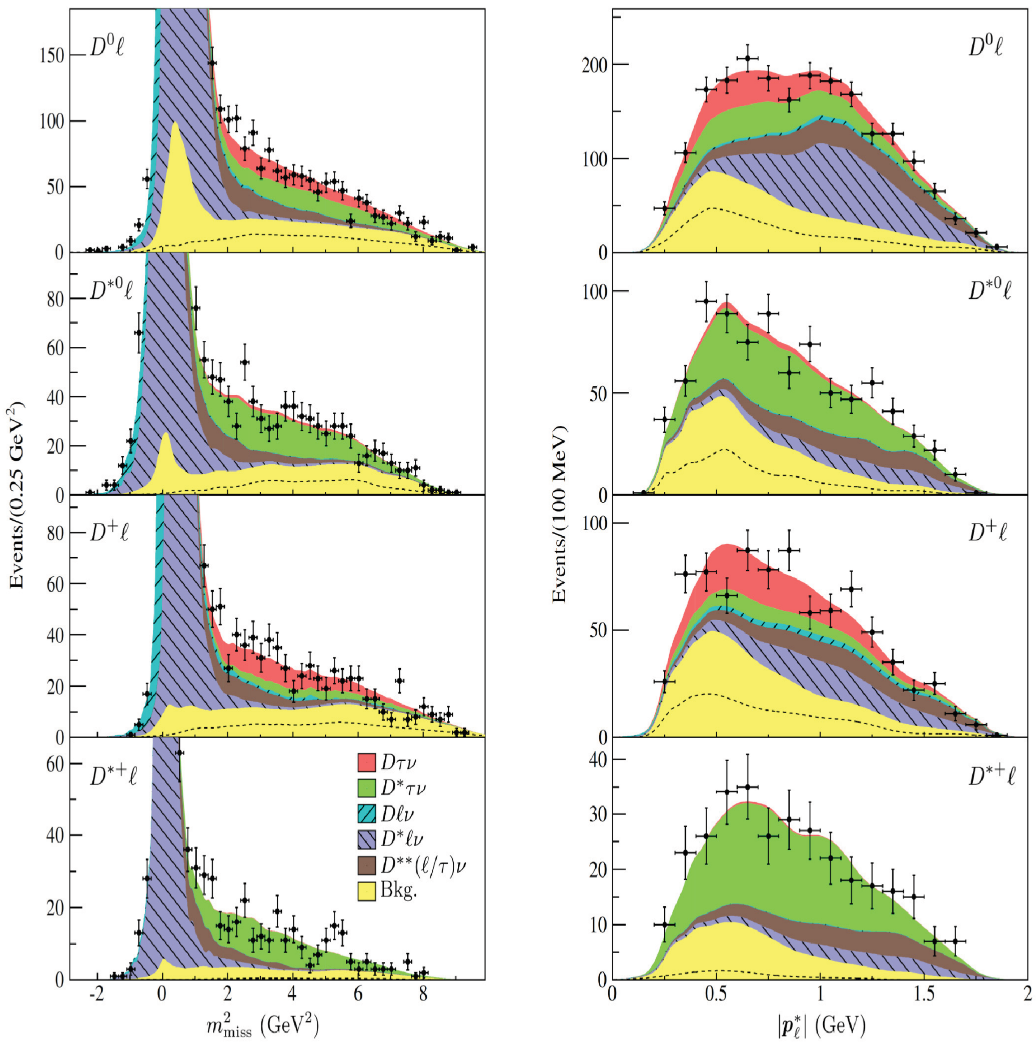
l = e, μ

for which the SM predicts:

$$R_{\mathrm{SM}}(D) = 0.297 \pm 0.017$$
$$R_{\mathrm{SM}}(D^*) = 0.252 \pm 0.03$$

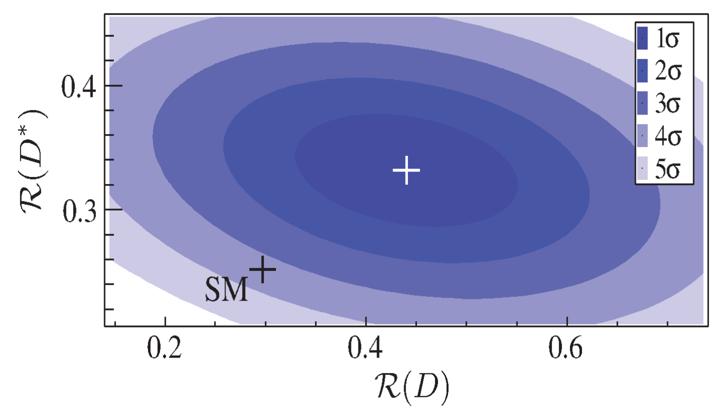
- The analysis is performed on the recoil of fully reconstructed hadronic B decays;
- The signal is extracted from a ML fit to m^2_{miss} and the charged lepton momentum p_{lep}.

$B \to D^{(*)}\tau\nu$



- BF's of D^* channels consistent with previous measurements and first observation of the D modes;
- The R ratios are higher than expected from SM:

$\mathcal{R}(D)$	$\mathcal{R}(D^*)$
$\mathcal{R}(D)_{\rm exp} = 0.440 \pm 0.072$	$\mathcal{R}(D^*)_{\rm exp} = 0.332 \pm 0.030$
$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017$	$\mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$
2.0σ	**2.7σ**

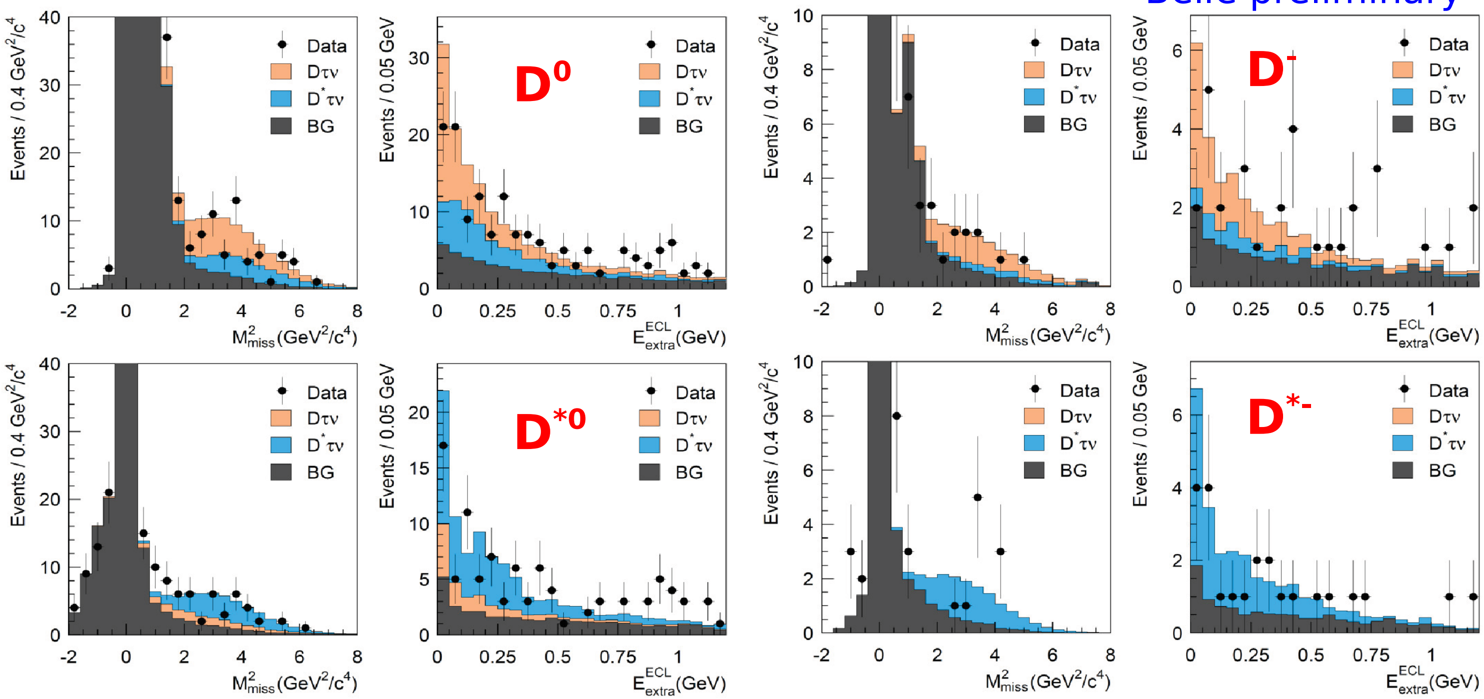


combined significance 3.2σ

$B \to D^{(*)}\tau\nu$

- Belle has performed a similar analysis (not yet on the full dataset) on 657 x 10^6 $B\overline{B}$ pairs;
- The fit variables are m^2_{miss} and E_{extra};

Belle preliminary



$$R(\overline{D}^0) = 0.70 \; {}^{+0.19}_{-0.18} \; {}^{+0.11}_{-0.09}$$

$$R(\overline{D}^{*0}) = 0.47 \; {}^{+0.11}_{-0.10} \; {}^{+0.06}_{-0.07}$$

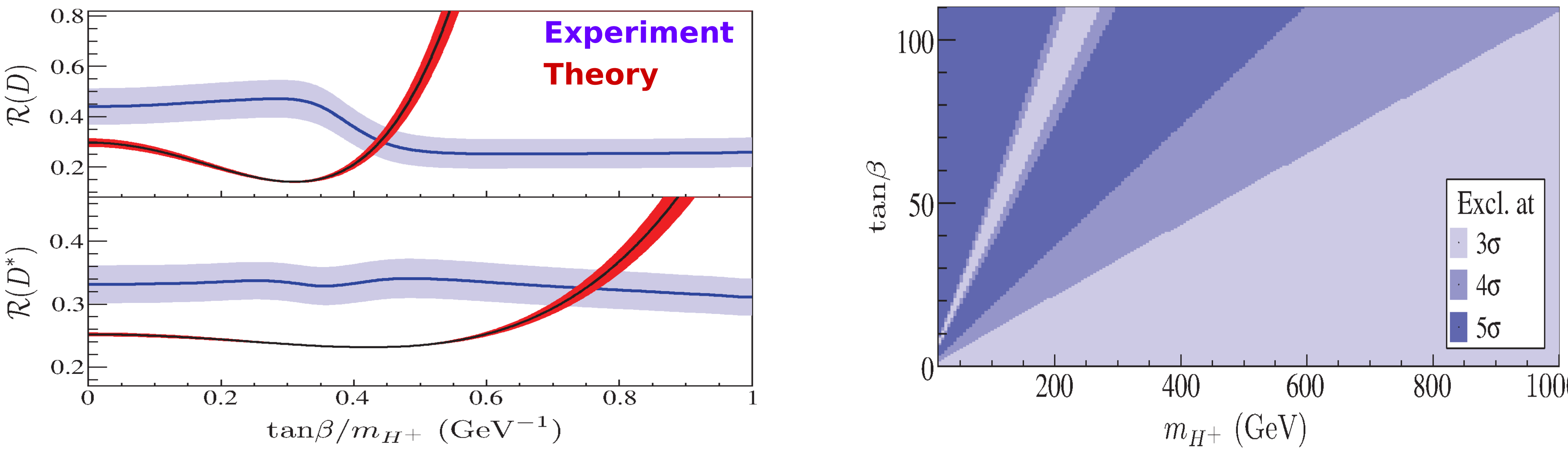
$$R(D^-) = 0.48 \; {}^{+0.22}_{-0.19} \; {}^{+0.06}_{-0.05}$$

$$R(D^{*-}) = 0.48 \; {}^{+0.14}_{-0.12} \; {}^{+0.06}_{-0.04}$$

The same kind of enhancement is seen in Belle's data

$B \to D^{(*)}\tau\nu$

- We can interpret these results in view of New Physics models;
- One of the most popular models (especially after the apparent excess of $B \to \tau\nu$) is type-II 2HDM:



- The effects predicted by type-II 2HDM are not consistent for the D and D^* modes: this model is basically excluded at the 3σ level;
- Other New Physics models (e.g. type-III 2HDM) seem to have regions of the parameter space that could explain the excesses observed better than the SM.

Charm mixing and CPV

“Observation of $D^0-\bar{D}^0$ Mixing in e^+e^- Collisions“,

arXiv:1401.3402 [hep-ex], PRL **112**, 111801 (2014)

“Measurement of $D^0-\bar{D}^0$ Mixing and CP Violation in Two-Body D^0 Decays“,

arXiv:1209.3896 [hep-ex], PRD **87**, 012004 (2013)

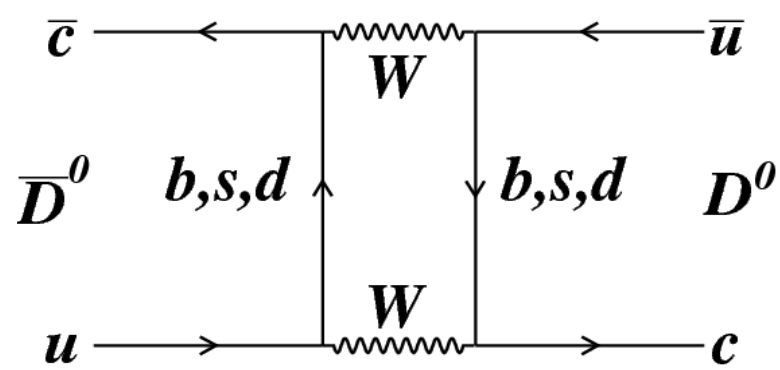
“Measurement of D^0-$\bar{D}^0$ Mixing and Search for Indirect CP Violation Using $D^0 \rightarrow K_S\pi^+\pi^-$ Decays“,

arXiv:1404.2412 [hep-ex], PRD **89**, 091103 (2014)

Charm mixing with $D^0 \to K\pi$

- D^0-$\bar{D}^0$ mixing is driven by the parameters:

$$x = \frac{\Delta m}{\Gamma} \qquad y = \frac{\Delta\Gamma}{2\Gamma}$$



- The SM cannot make reliable predictions on the values of x and y. CP violation phenomena at the ≳ 1% level would be an indication of New Physics;
- Charm mixing can be detected by searching for the "wrong sign" (WS) decays $D^0 \to K^+\pi^-$;
- In order to disentangle WS decays from charm mixing from Doubly Cabibbo Suppressed (DCS) decays, a time-dependent analysis is needed:

$$R(\tilde{t}/\tau) = \frac{\Gamma_{\rm WS}(\tilde{t}/\tau)}{\Gamma_{\rm RS}(\tilde{t}/\tau)} \approx R_D + \sqrt{R_D}\, y' \frac{\tilde{t}}{\tau} + \frac{x'^2 + y'^2}{4}\left(\frac{\tilde{t}}{\tau}\right)^2$$

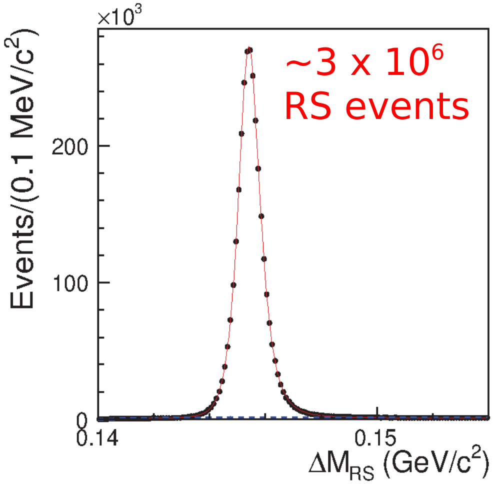
$$x' = x\cos\delta + y\sin\delta \qquad y' = y\cos\delta - x\sin\delta$$

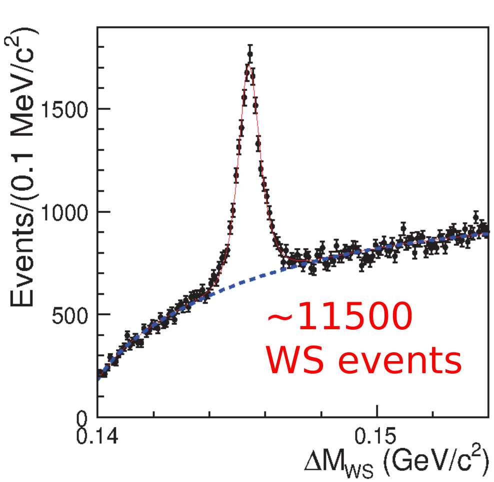
R_D: ratio of the rates of DCS over Cabibbo Favoured (CF) decays

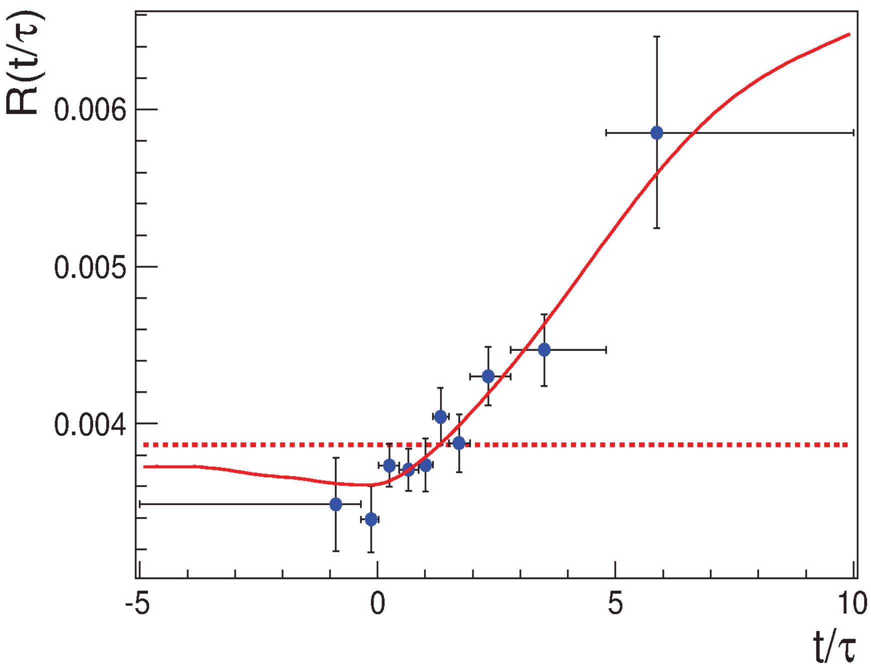
δ: strong phase difference between DCS and CF decays

More details in backup

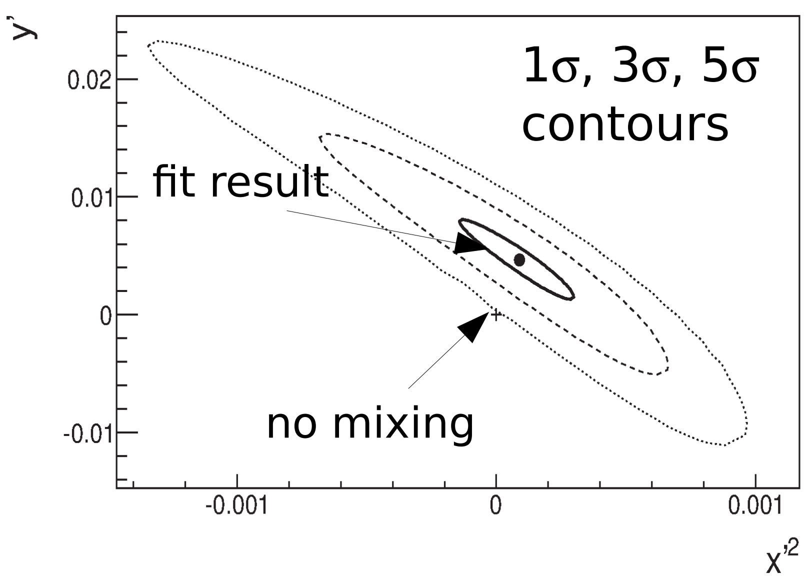
Charm mixing with $D^0 \rightarrow K\pi$







The initial flavor of the D^0's can be determined from the charge of the pion in $D^{*+} \rightarrow D^0 \pi^+_s$



Mixing hypothesis favored over the "no mixing" at 5.1σ level of significance. First observation of D^0 mixing from a single measurement at an e^+e^- collider.

$R_D = (3.53 \pm 0.13) \times 10^{-3}$

$x'^2 = (0.09 \pm 0.22) \times 10^{-3}$

$y' = (4.6 \pm 3.4) \times 10^{-3}$

Charm mixing with two body D^0 decays

- Charm mixing can be probed by measuring the ratio of lifetimes of D^0 decays to CP-even and CP-mixed final states;
- D^0's are reconstructed in the final states $K^{\mp}\pi^{\pm}$, K^+K^-, $\pi^+\pi^-$ and we define:

$$y_{CP} = \frac{\Gamma^+ + \overline{\Gamma}^+}{2\Gamma} - 1$$

$$\Delta Y = \frac{\Gamma^+ - \overline{\Gamma}^+}{2\Gamma}$$

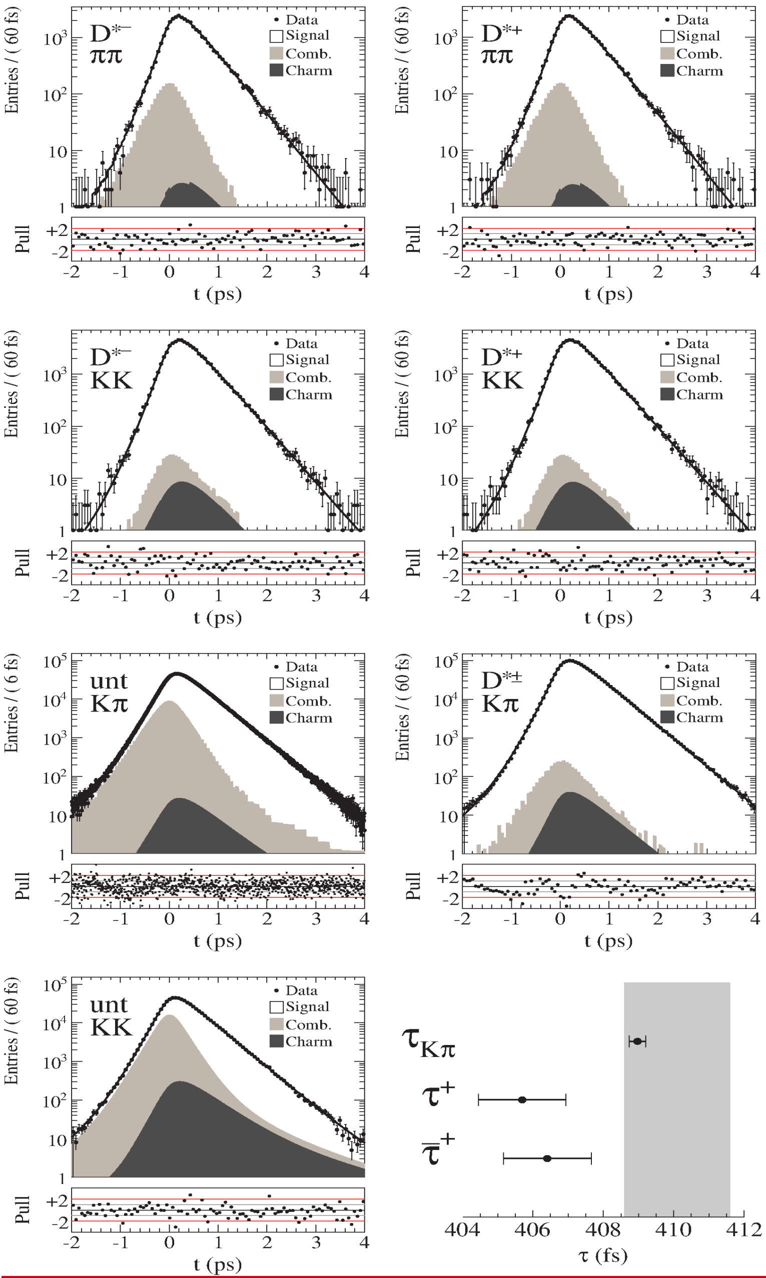
Γ: partial decay width to $K\pi$

Γ^+: partial decay width of D^0 to CP-even KK and $\pi\pi$

$\overline{\Gamma}^+$: partial decay width of $\overline{D}^0$ to CP-even KK and $\pi\pi$

- D^0's are can be tagged using the charge of the π from $D^{*+} \to D^0\pi^+$;
- The mixing analysis relies on the measurement of the lifetimes $\tau^{\pm}$, τ^+, and $\overline{\tau}^+$;
- Direct CP violation is not assumed, but CPV in the interference between mixing and decay is allowed in the overall fit.

Charm mixing with two body D^0 decays



Results:

$$y_{CP} = [0.72 \pm 0.18(\text{stat}) \pm 0.12(\text{syst})]\%$$
$$\Delta Y = [0.09 \pm 0.26(\text{stat}) \pm 0.06(\text{syst})]\%$$

The significance of the “mixing” vs “no mixing” hypothesis is 3.3σ.

No evidence of CP violation in the interference between mixing and decay is found.

Charm mixing in $D^0 \to K_s\pi^+\pi^-$

- The D^0 mixing parameters x and y can be extracted from a time-dependent Dalitz plot analysis of $D^0 \to K_s\pi^+\pi^-$;
- The decay rates for D^0 and $\bar{D}^0$ can be expressed as:

$$|\mathcal{M}(f,t)|^2 = \frac{e^{-\Gamma t}}{2}\{(|\mathcal{A}_f|^2 + |\tfrac{q}{p}|^2|\mathcal{A}_{\bar{f}}|^2)\cosh(\Gamma y t) + (|\mathcal{A}_f|^2 - |\tfrac{q}{p}|^2|\mathcal{A}_{\bar{f}}|^2)\cos(\Gamma x t) + 2\Re(\tfrac{q}{p}\mathcal{A}_{\bar{f}}\mathcal{A}_f{}^*)\sinh(\Gamma y t) - 2\Im(\tfrac{q}{p}\mathcal{A}_{\bar{f}}\mathcal{A}_f{}^*)\sin(\Gamma x t)\}$$

$$|\overline{\mathcal{M}}(f,t)|^2 = \frac{e^{-\Gamma t}}{2}\{(|\mathcal{A}_{\bar{f}}|^2 + |\tfrac{p}{q}|^2|\mathcal{A}_f|^2)\cosh(\Gamma y t) + (|\mathcal{A}_{\bar{f}}|^2 - |\tfrac{p}{q}|^2|\mathcal{A}_f|^2)\cos(\Gamma x t) + 2\Re(\tfrac{p}{q}\mathcal{A}_f\mathcal{A}_{\bar{f}}{}^*)\sinh(\Gamma y t) - 2\Im(\tfrac{p}{q}\mathcal{A}_f\mathcal{A}_{\bar{f}}{}^*)\sin(\Gamma x t)\}$$

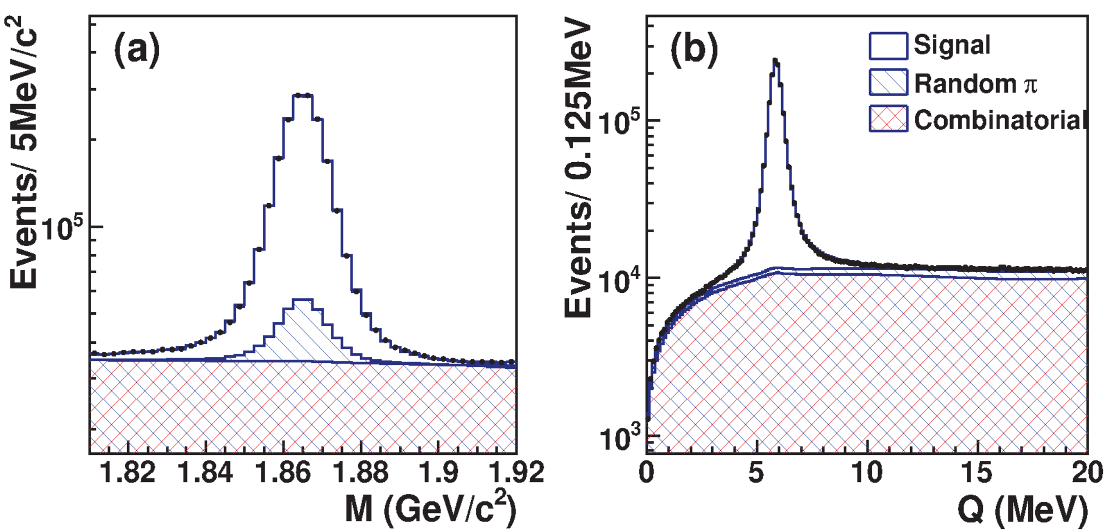
$$x = \frac{\Delta m}{\Gamma} \qquad y = \frac{\Delta\Gamma}{2\Gamma}$$

q/p drives CP violation:

$|q/p| \neq 1 \Rightarrow$ CPV in mixing

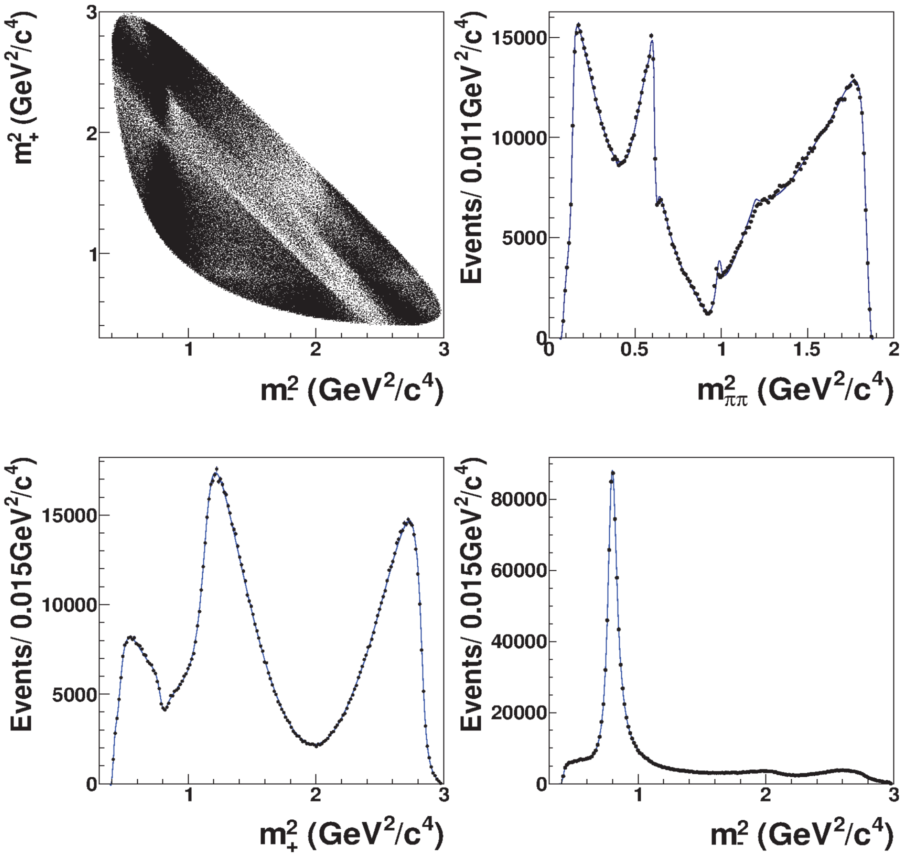
$\arg(q/p) \neq 0 \Rightarrow$ CPV in the interference between mixing and decay

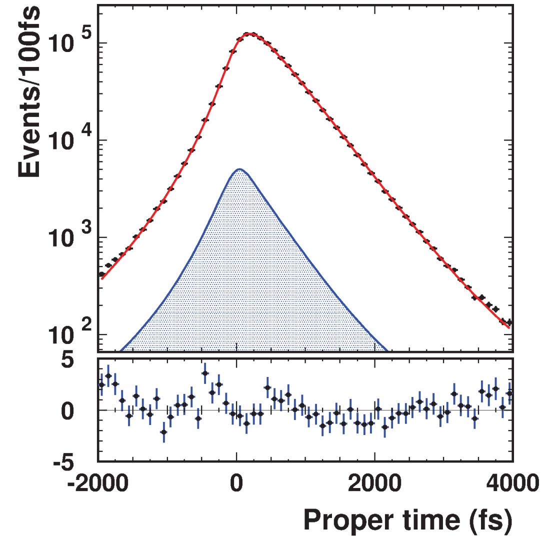
It is assumed that there is no direct CPV $\Rightarrow \overline{\mathcal{A}}_f = \mathcal{A}_{\bar{f}}$



$Q = m(D^*) - m(D^0) - m(\pi_s)$

Charm mixing in $D^0 \rightarrow K_s \pi^+ \pi^-$





Fit type	Parameter	Fit result
No CPV	$x(\%)$	$0.56 \pm 0.19^{+0.03+0.06}_{-0.09-0.09}$
	$y(\%)$	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.06}$
CPV	$x(\%)$	$0.56 \pm 0.19^{+0.04+0.06}_{-0.08-0.08}$
	$y(\%)$	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.07}$
	$\|q/p\|$	$0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$
	$\arg(q/p)(^\circ)$	$-6 \pm 11 \pm 3^{+3}_{-4}$

The “mixing” hypothesis is preferred over the “no mixing” at the 2.5σ level. There is no evidence of CPV in mixing or CPV in the interference between mixing and decay.

Hadronic contributions to $(g-2)_\mu$

"Precise Measurement of the $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$ Cross Section with the Initial-State Radiation Method at BABAR",
arXiv:1205.2228 [hep-ex], PRD **86**, 032013 (2012)

"Cross sections for the reactions $e^+e^- \rightarrow$ $K_S K_L$, $K_S K_L \pi^+\pi^-$, $K_S K_S \pi^+\pi^-$, $K_S K_S K^+ K^-$ from events with initial-state radiation",
arXiv:1403.7593 [hep-ex], PRD **89**, 092002 (2014)

Motivations and theory

- Long standing discrepancy between theory and experiment in the $(g\text{-}2)_\mu$:

E821 Collaboration, PRL **92**, 1618102 (2004)

$$\vec{\mu} = g \frac{e\hbar}{2mc} \cdot \vec{S}$$

anomalous magnetic moment

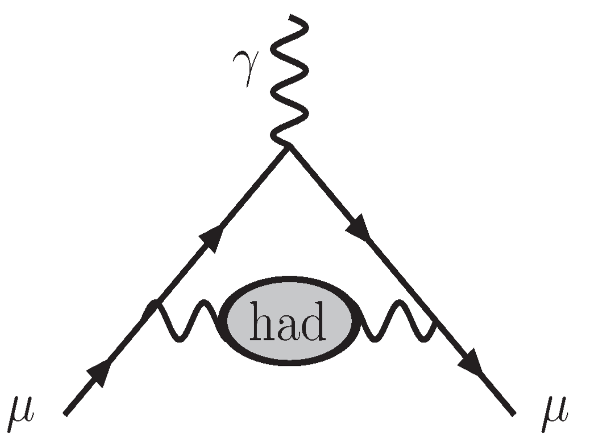
Experiment: $(g\text{-}2)_\mu/2 = 11659208.9\ (6.3) \times 10^{-10}$

Theory: $(g\text{-}2)_\mu/2 = 11659180.2\ (4.9) \times 10^{-10}$

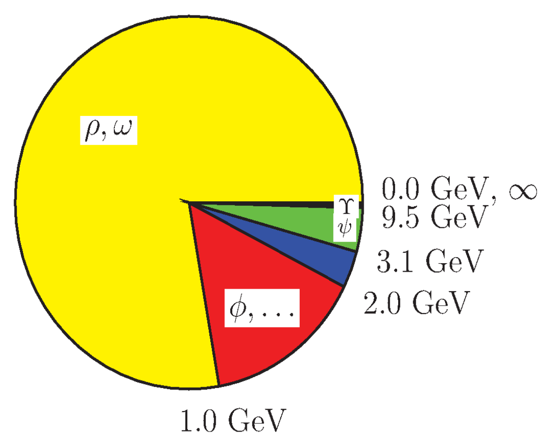
Discrepancy : $(28.7 \pm 8.0) \times 10^{-10}$

3.6σ discrepancy

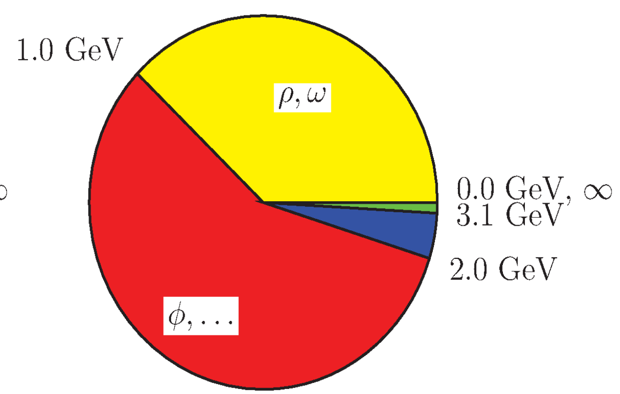
- Most of the uncertainty in the theory prediction comes from the hadronic contribution:



"hadronic vacuum polarization"



size



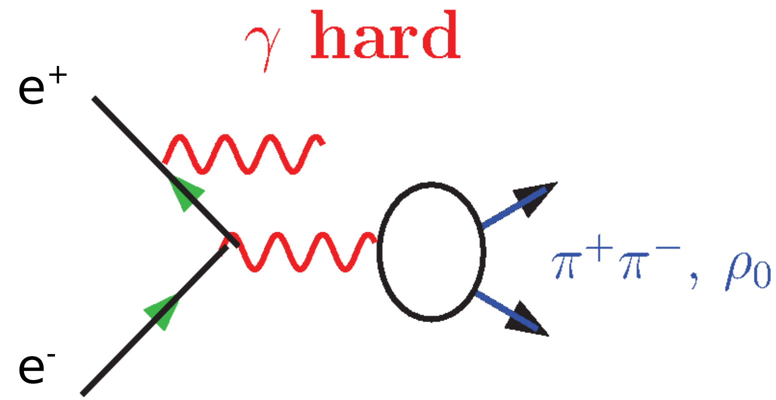
uncertainty

of the hadronic contribution

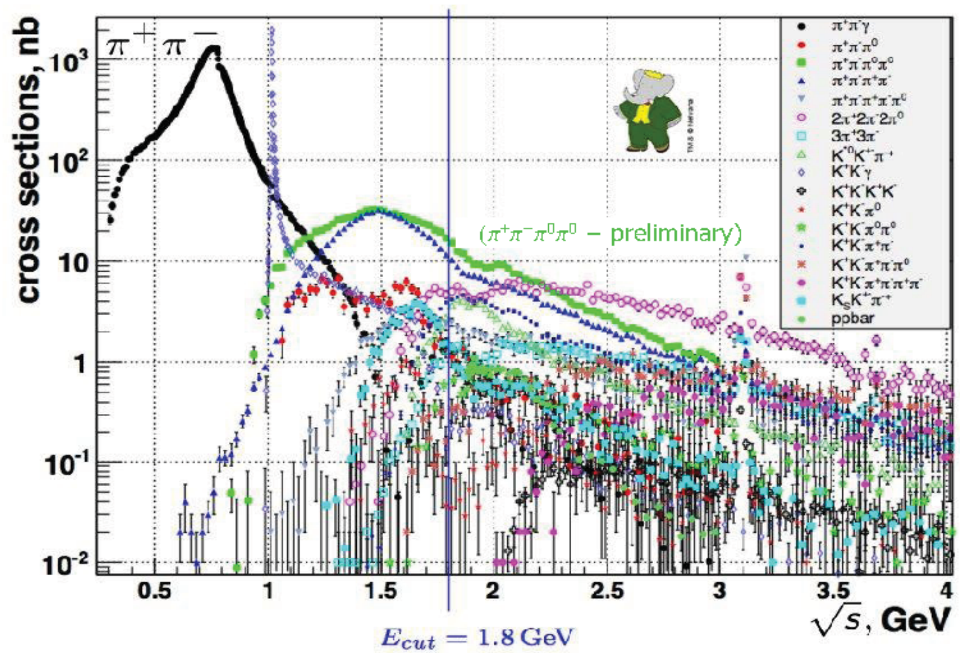
Phys. Rept. **447**, 1-110 (2009)

The ISR method

- The vacuum polarization is connected to the $e^+e^- \to$ hadrons through the optical theorem;
- At the B-factories we can exploit the initial state radiation (ISR) and the large integrated luminosity to effectively have a "scan" at low invariant masses;
- A large number of exclusive final states has been investigated and more will be added.



$$s = M^2_\gamma;\ s' = s\,(1-k),\ k = E_\gamma/E_{\rm beam}$$

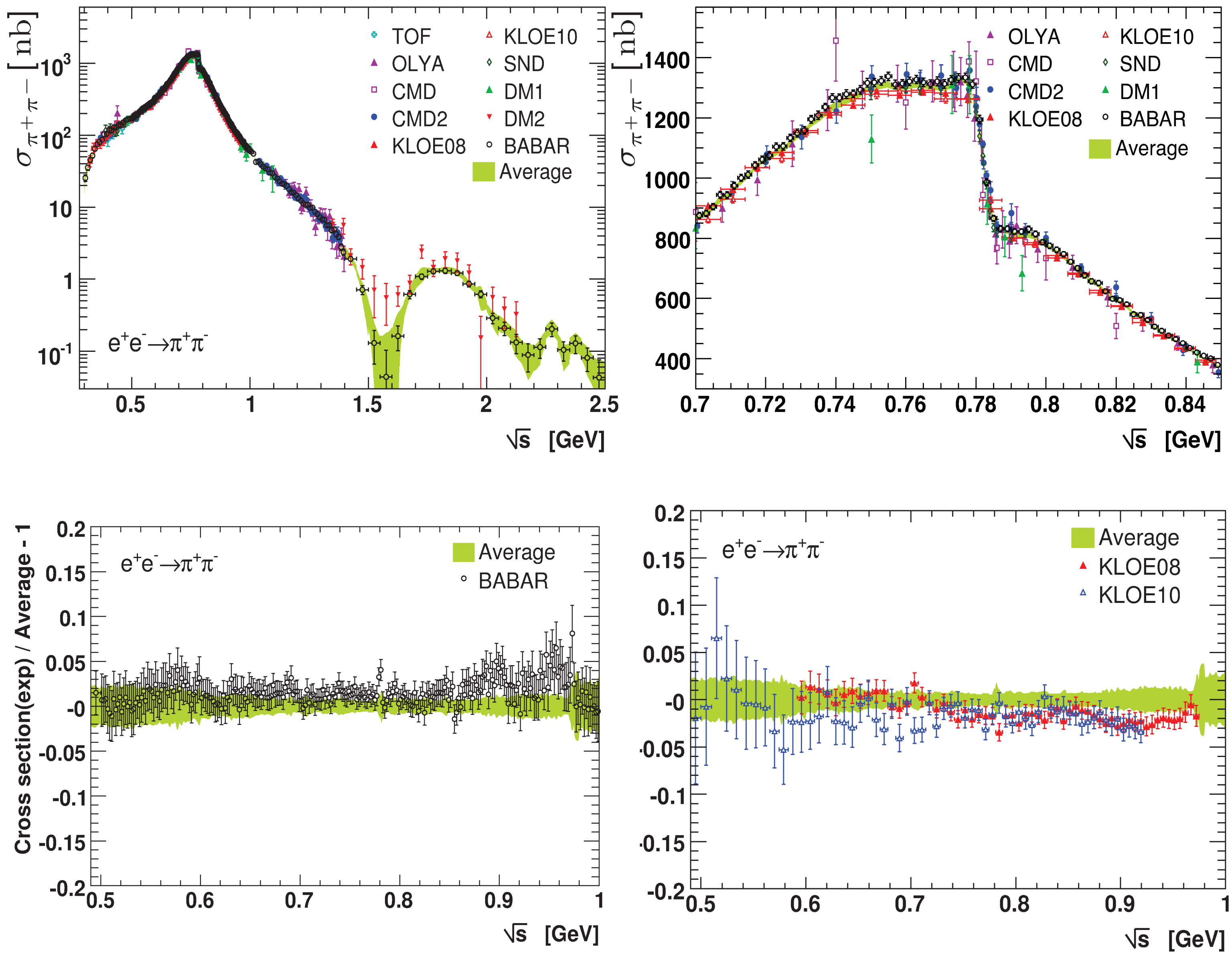


$e^+e^- \to \pi^+\pi^- (\gamma)$

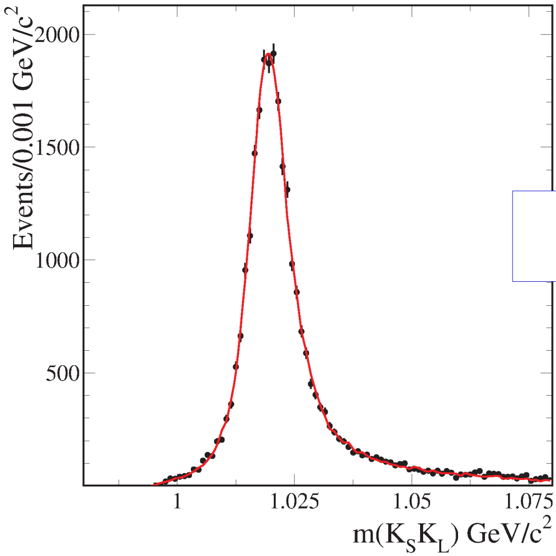
In general good agreement with the other experiments;

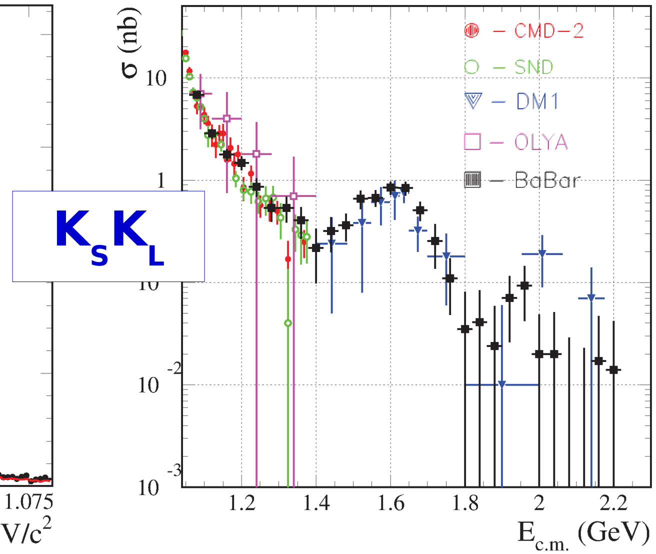
Some tension with KLOE above the ρ mass needs to be understood;

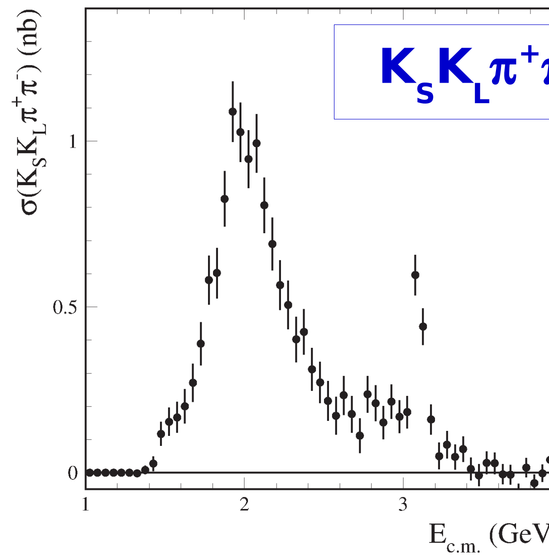
Significant progress in the overall uncertainty on $(g-2)_\mu/2$ (discrepancy with experiment increased)

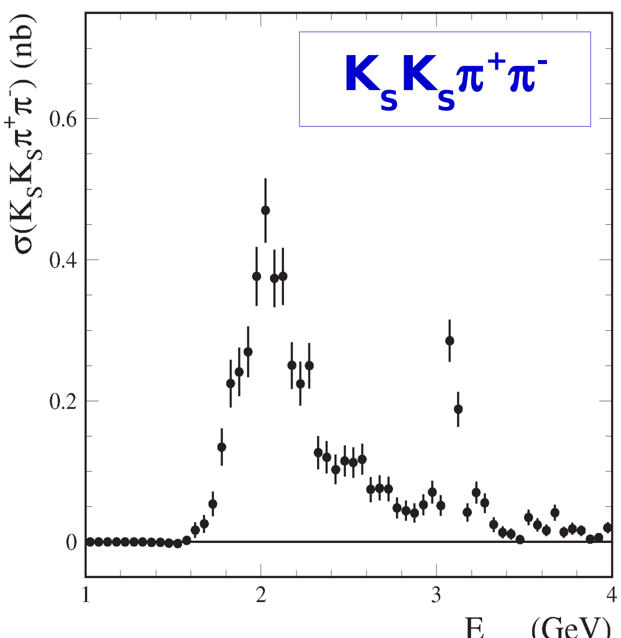


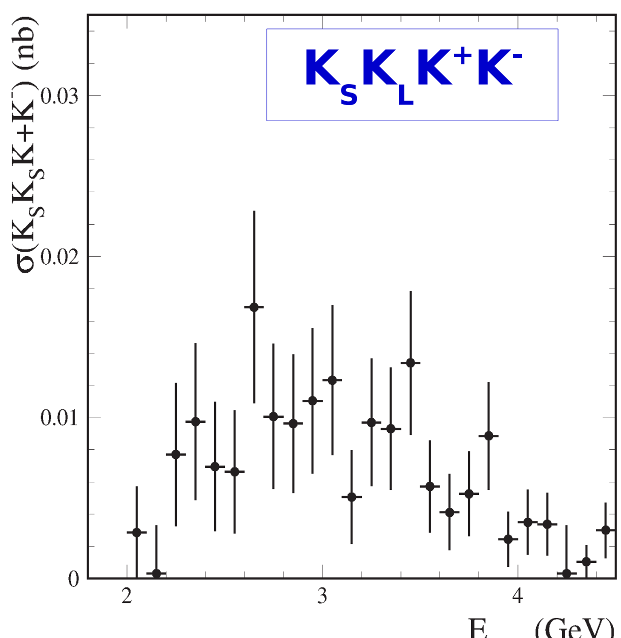
$e^+e^- \to K_SK_L$, $K_SK_L\pi^+\pi^-$, $K_SK_S\pi^+\pi^-$, $K_SK_LK^+K^-$











First observation of $J/\psi \to K^0K^0\pi\pi$

The new measurements (K_SK_L is the most important in size) will be included in the calculation of $(g-2)_\mu/2$

Conclusions

- Several years after the end of data-taking, the BaBar and Belle Collaborations continue to produce physics results;
- These searches, through indirect effects, are complementary to those at the LHC;
- No unambiguous signs of New Physics have been detected yet, but several hints in the most recent measurements deserve further investigation:
  - $B \rightarrow D^{(*)} \tau \nu$;
  - $B \rightarrow \tau \nu$ (?);
  - $(g\text{-}2)_\mu$;
  - ...
- Enormous progress is expected to come from LHCb and the upcoming start of the Belle-II experiment and from the other flavor physics experiments.

Backup Slides

CP asymmetry in $B \to X_s \gamma$

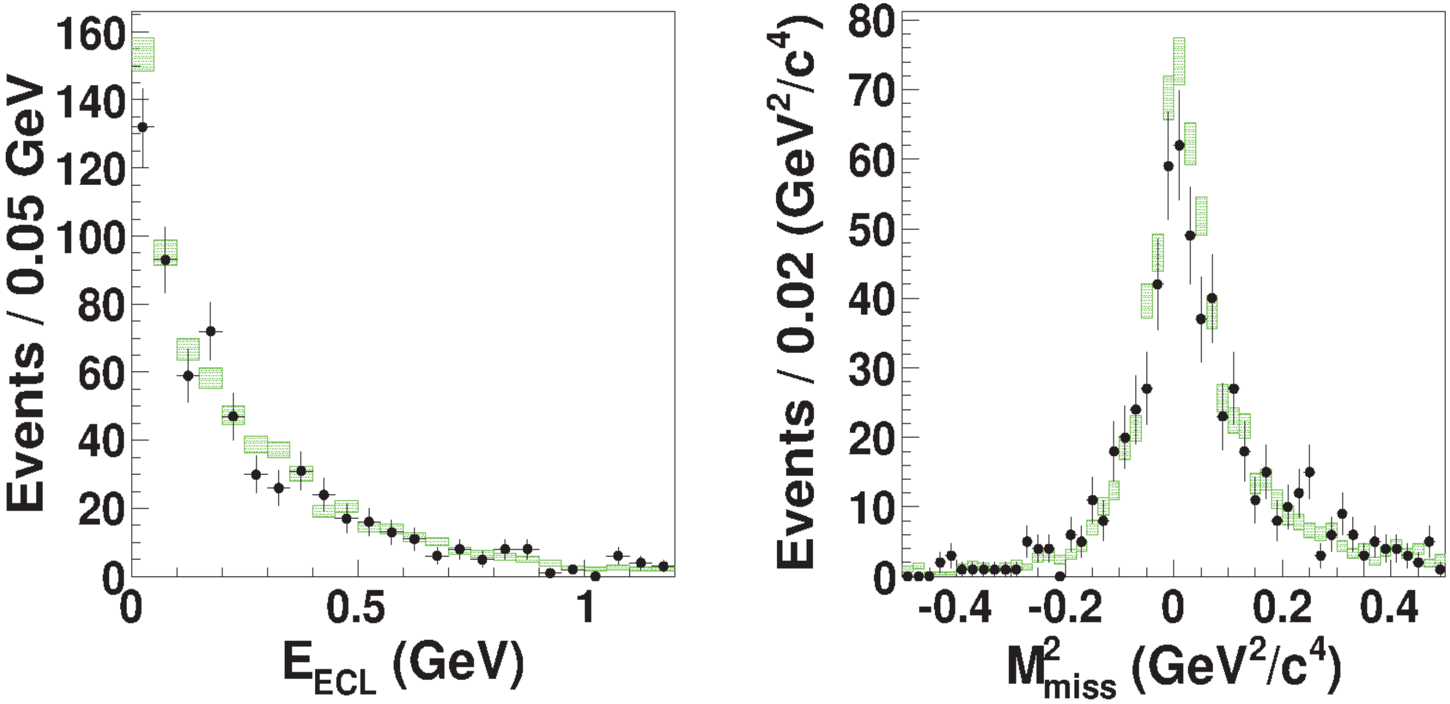
List of exclusive $B \to X_s \gamma$ modes.

Those indicated with a * are used for the A_{CP} measurement.

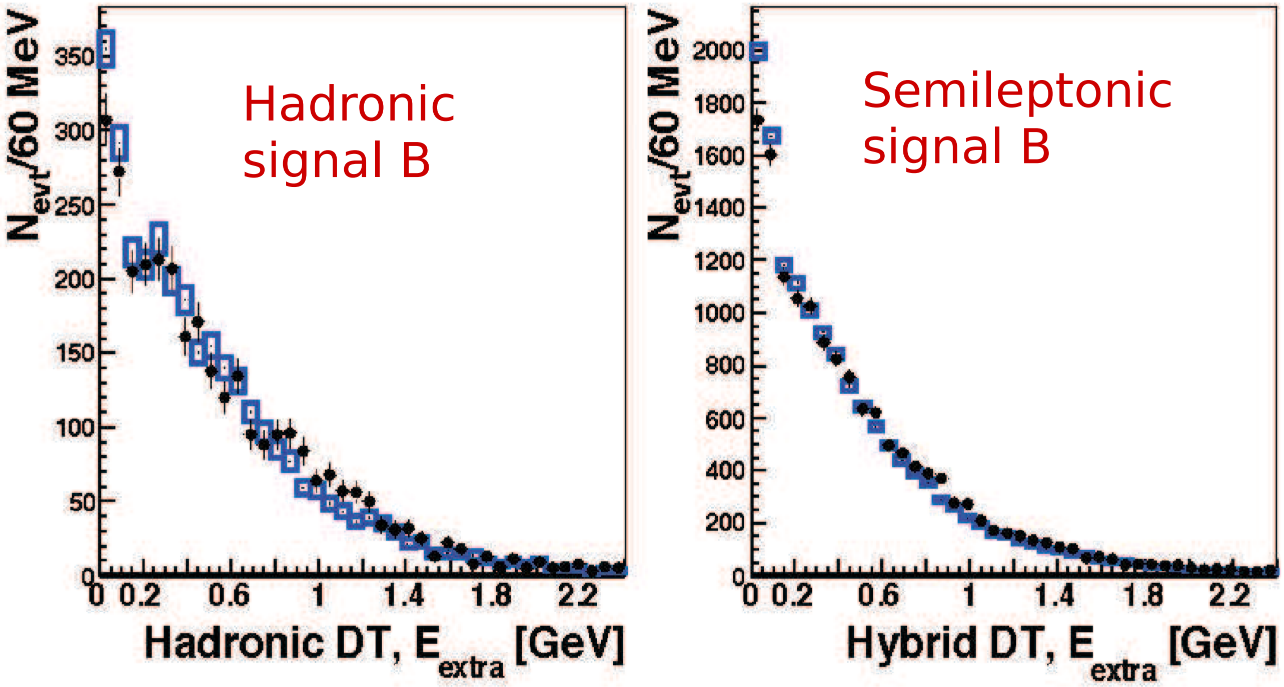
#	Final State	#	Final State
1*	$B^+ \to K_S \pi^+ \gamma$	20	$B^0 \to K_S \pi^+ \pi^- \pi^+ \pi^- \gamma$
2*	$B^+ \to K^+ \pi^0 \gamma$	21	$B^0 \to K^+ \pi^+ \pi^- \pi^- \pi^0 \gamma$
3*	$B^0 \to K^+ \pi^- \gamma$	22	$B^0 \to K_S \pi^+ \pi^- \pi^0 \pi^0 \gamma$
4	$B^0 \to K_S \pi^0 \gamma$	23*	$B^+ \to K^+ \eta \gamma$
5*	$B^+ \to K^+ \pi^+ \pi^- \gamma$	24	$B^0 \to K_S \eta \gamma$
6*	$B^+ \to K_S \pi^+ \pi^0 \gamma$	25	$B^+ \to K_S \eta \pi^+ \gamma$
7*	$B^+ \to K^+ \pi^0 \pi^0 \gamma$	26	$B^+ \to K^+ \eta \pi^0 \gamma$
8	$B^0 \to K_S \pi^+ \pi^- \gamma$	27*	$B^0 \to K^+ \eta \pi^- \gamma$
9*	$B^0 \to K^+ \pi^- \pi^0 \gamma$	28	$B^0 \to K_S \eta \pi^0 \gamma$
10	$B^0 \to K_S \pi^0 \pi^0 \gamma$	29	$B^+ \to K^+ \eta \pi^+ \pi^- \gamma$
11*	$B^+ \to K_S \pi^+ \pi^- \pi^+ \gamma$	30	$B^+ \to K_S \eta \pi^+ \pi^0 \gamma$
12*	$B^+ \to K^+ \pi^+ \pi^- \pi^0 \gamma$	31	$B^0 \to K_S \eta \pi^+ \pi^- \gamma$
13*	$B^+ \to K_S \pi^+ \pi^0 \pi^0 \gamma$	32	$B^0 \to K^+ \eta \pi^- \pi^0 \gamma$
14*	$B^0 \to K^+ \pi^+ \pi^- \pi^- \gamma$	33*	$B^+ \to K^+ K^- K^+ \gamma$
15	$B^0 \to K_S \pi^0 \pi^+ \pi^- \gamma$	34	$B^0 \to K^+ K^- K_S \gamma$
16*	$B^0 \to K^+ \pi^- \pi^0 \pi^0 \gamma$	35	$B^+ \to K^+ K^- K_S \pi^+ \gamma$
17	$B^+ \to K^+ \pi^+ \pi^- \pi^+ \pi^- \gamma$	36	$B^+ \to K^+ K^- K^+ \pi^0 \gamma$
18	$B^+ \to K_S \pi^+ \pi^- \pi^+ \pi^0 \gamma$	37*	$B^0 \to K^+ K^- K^+ \pi^- \gamma$
19	$B^+ \to K^+ \pi^+ \pi^- \pi^0 \pi^0 \gamma$	38	$B^0 \to K^+ K^- K_S \pi^0 \gamma$

$B \to \tau\nu$

The analysis is validated on the kinematically similar channel: $B \to D^{*0}\, l\, \nu_l$



B → τν



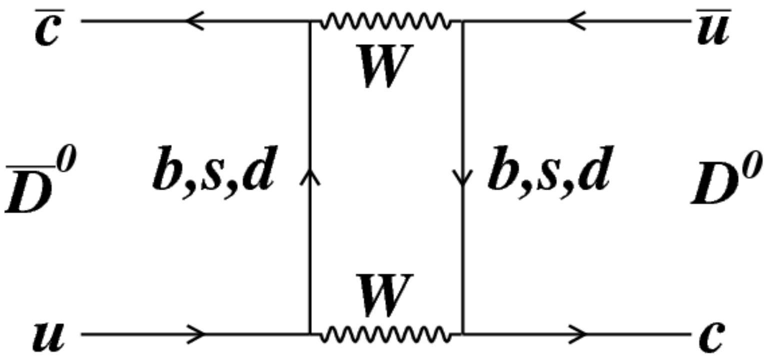
The analysis is validated on doubly tagged B decays

$B \to D^{(*)}\tau\nu$

Decay mode	N_{signal}	$R(D^{(*)})$	$\mathcal{B}(\%)$	Significance (σ)
$B^+ \to \bar{D}^0 \tau^+ \nu_\tau$	314 ± 60	$0.429 \pm 0.082 \pm 0052$	$0.99 \pm 0.19 \pm 0.13$	4.7
$B^0 \to D^- \tau^+ \nu_\tau$	177 ± 31	$0.469 \pm 0.084 \pm 0053$	$1.01 \pm 0.18 \pm 0.12$	5.2
$B^+ \to \bar{D}^{*0} \tau^+ \nu_\tau$	639 ± 62	$0.322 \pm 0.032 \pm 0022$	$1.71 \pm 0.17 \pm 0.13$	9.4
$B^0 \to D^{*-} \tau^+ \nu_\tau$	245 ± 27	$0.355 \pm 0.039 \pm 0021$	$1.74 \pm 0.19 \pm 0.12$	10.4
$B \to \bar{D} \tau^+ \nu_\tau$	489 ± 63	$0.440 \pm 0.058 \pm 0042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$B \to \bar{D}^* \tau^+ \nu_\tau$	888 ± 63	$0.332 \pm 0.024 \pm 0018$	$1.76 \pm 0.13 \pm 0.12$	13.2

Charm mixing with $D^0 \to K\pi$

$$x = \frac{\Delta m}{\Gamma} \quad y = \frac{\Delta\Gamma}{2\Gamma}$$



$$\Gamma_{\mathrm{RS}}(\tilde{t}/\tau) \approx |\mathcal{A}_{\mathrm{CF}}|^2 e^{-\frac{\tilde{t}}{\tau}}$$

$$\Gamma_{\mathrm{WS}}(\tilde{t}/\tau) \approx |\mathcal{A}_{\mathrm{CF}}|^2 e^{-\frac{\tilde{t}}{\tau}} \times \left(R_D + \sqrt{R_D} y' \frac{\tilde{t}}{\tau} + \frac{x'^2 + y'^2}{4} \left(\frac{\tilde{t}}{\tau}\right)^2\right)$$

R_D: ratio of the rates of DCS over Cabibbo Favoured (CF) decays

$$x' = x \cos\delta + y \sin\delta \quad y' = y \cos\delta - x \sin\delta$$

δ: strong phase difference between DCS and CF decays

$$R(\tilde{t}/\tau) = \frac{\Gamma_{\mathrm{WS}}(\tilde{t}/\tau)}{\Gamma_{\mathrm{RS}}(\tilde{t}/\tau)} \approx R_D + \sqrt{R_D} y' \frac{\tilde{t}}{\tau} + \frac{x'^2 + y'^2}{4} \left(\frac{\tilde{t}}{\tau}\right)^2$$