PANIC11

RUTHERFORD CENTENNIAL

July 24th·29th, 2011

Massachusetts Institute of Technology, Cambridge, MA, USA

Recent CKM and CP violation results from BABAR

On Behalf of the BaBar Collaboration

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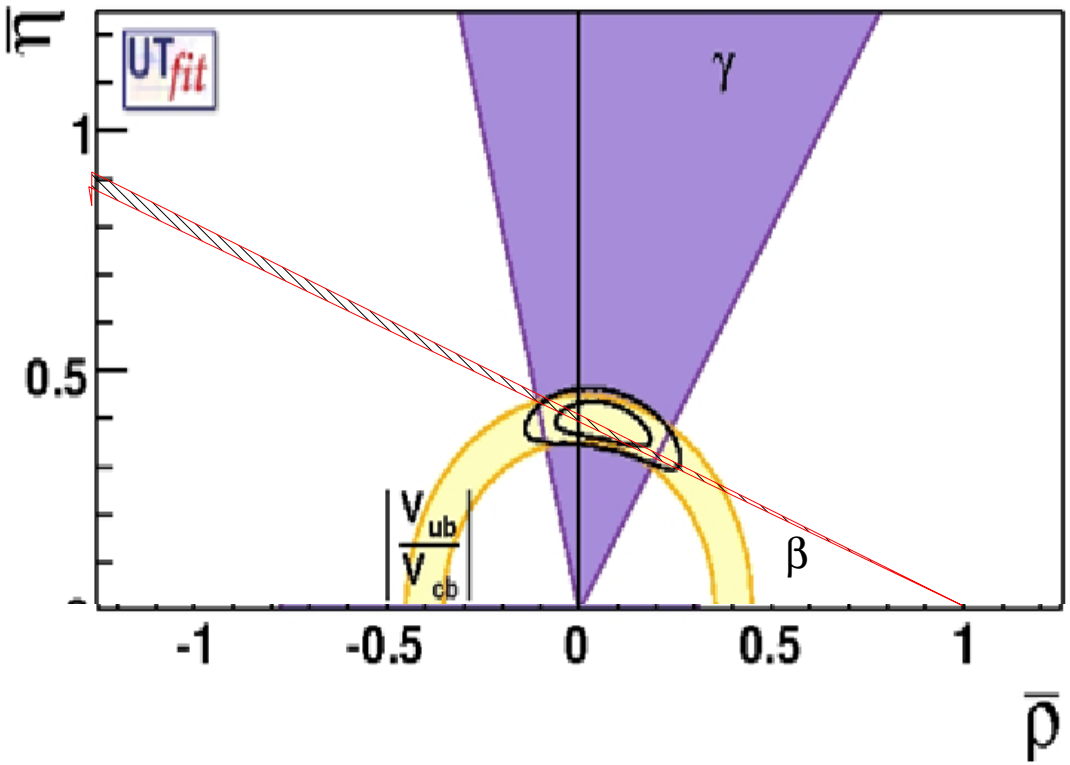
(INFN Padova)

CKM Matrix and CP violation

- *Leading source of CP violation established: CKM mechanism (BaBar & Belle)*
- *New Physics search in the flavor sector require **precise** & **redundant** measurements of sides and angles of the Unitarity Triangle*



- *Charmless SL Decays:*
  - *Access to $|V_{ub}|$, side opposite to angle β*
- *Charmless Hadronic Decays*
  - *Trees and Penguin contribute and lead to CP violation*
  - *Access the CKM angle α (golden mode $\rho\rho$ and $\pi\pi$) and angle γ*
  - *Open puzzles that need to be solved:*
    - *Direct CP violation in $K\pi$, polarization in $B \to VV$ (not covered here)*

- *Search for NP in Cabibbo Favored SL decays $B \to D^{(*)}\tau\nu$*

$|V_{ub}|$ *from SL decays* $B \to \pi / X_u \ell \nu$

$B \to K\pi\pi^0$

$B \to \phi\phi K$

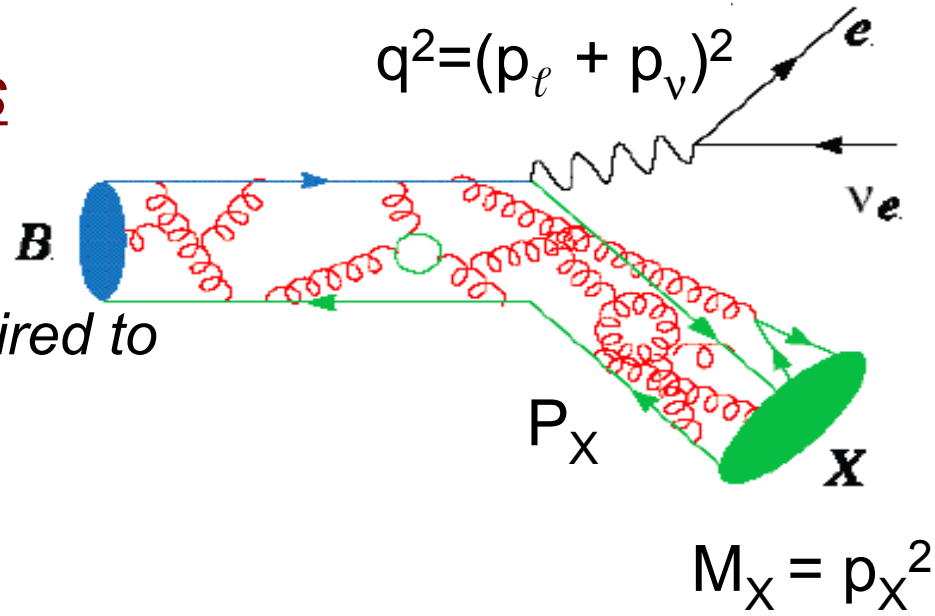
$B \to D^{(*)}\tau\nu$

Semileptonic B decays: $|V_{ub}|$

- *Large BF, only one hadronic current:*

$$\Gamma(B \to \pi/X_u \ell \nu) = |V_{ub}|^2 \mathcal{F}^2(q^2, M_x, p_\ell)$$

Complementary Measurements



- *Exclusive decays* $B \to \pi \ell \nu$ *:*
  - *QCD predictions of Form Factor required to parameterize hadronic effects*
  - *Lattice QCD, LCSR...*
- *Inclusive decays* $B \to X_u \ell \nu$*:*
  - *QCD corrections to parton level decay rate*
  - *Need perturbative and non-perturbative corrections*
    - *4 approaches* ***BLNP***, ***DGE***, ***GGOU***, ***ADFR***
    - *Non-pert. parameters* (m_b, μ_π^2) *from* $B \to X_c \ell \nu$ *and* $B \to X_s \gamma$

Neubert et al PRD72, 073006 (2005)
Gardi et al JHEP0601, 097 (2006)
Gambino et al JHEP 0710, 058 (2007)
Aglietti et al EPJC 59, 831 (2009)

Exclusive $|V_{ub}|$ with $B \to \pi \ell \nu$

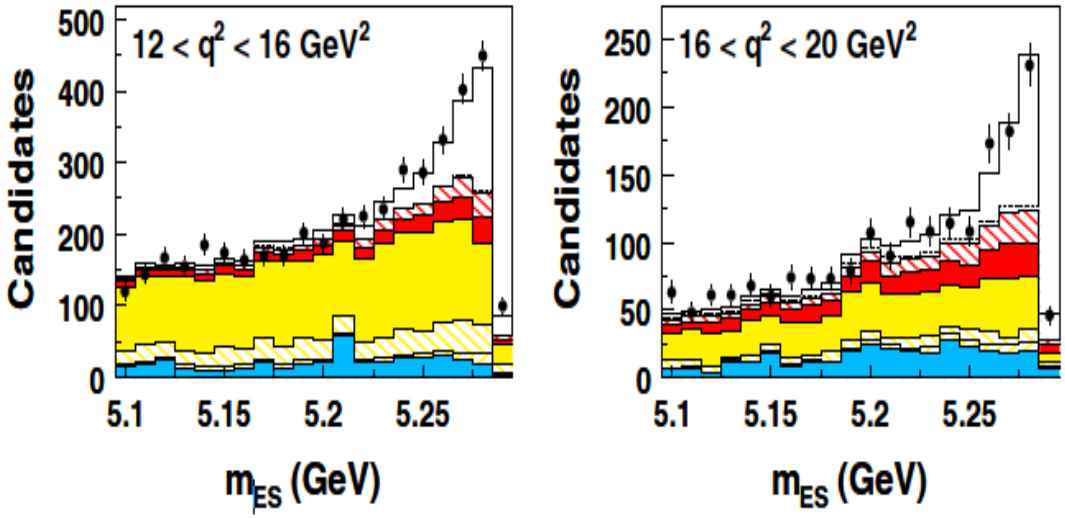
- *Two analysis recently published by BaBar:*
  - *Untagged analysis: reconstruct π+e/μ*
  - *Neutrino from the rest of the event*

$$m_{ES} = \sqrt{E^{*2}_{beam} - \mathbf{p}^{*2}_{\pi\ell\nu}}$$
$$\Delta E = E^{*}_{\pi\ell\nu} - E^{*}_{beam}$$

6-bin analysis

- *Background reduced with a NN*
- ***S/B = 0.20***
- *combined m_{ES}-ΔE fit to $\pi^+/\pi^0/\rho^+/\rho^0\ \ell\ \nu$*
- *6 bins of q^2*

Fitted signal events:
- ***π^+: 6660 ± 278***
- ***π^0: 606 ± 43***

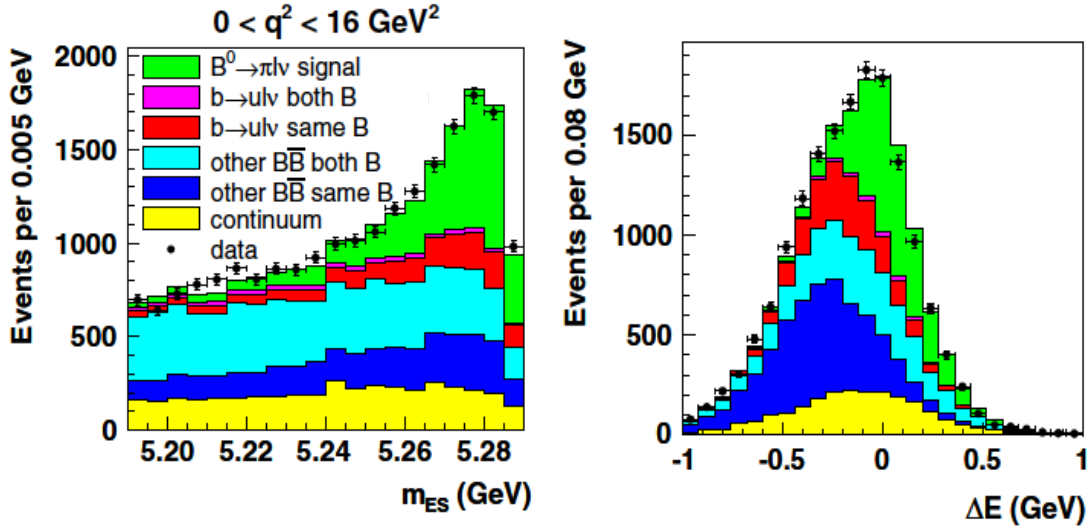


Phys.Rev.D83, 032007 (2011)

12-bin analysis

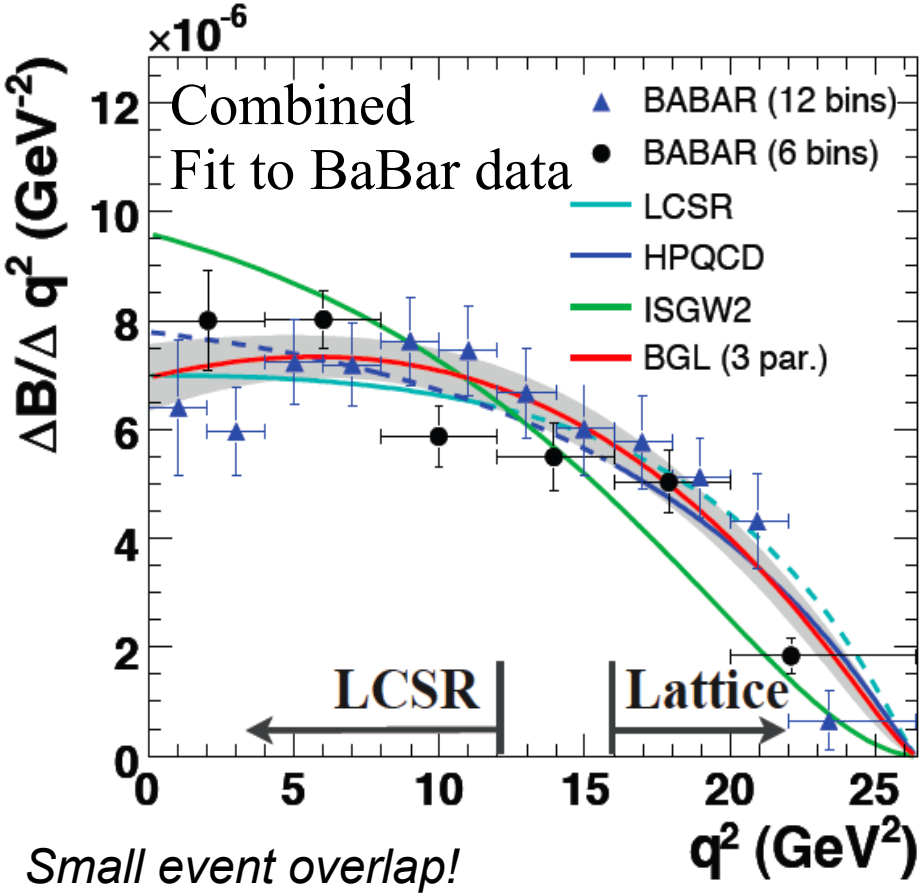
- *Background reduced with q^2-dependet cuts*
- ***S/B = 0.09***
- *m_{ES}-ΔE fit to $\pi^+\ell\ \nu$*
- *12 bins of q^2*

Fitted signal events:
- ***π^+: 11778 ± 435***

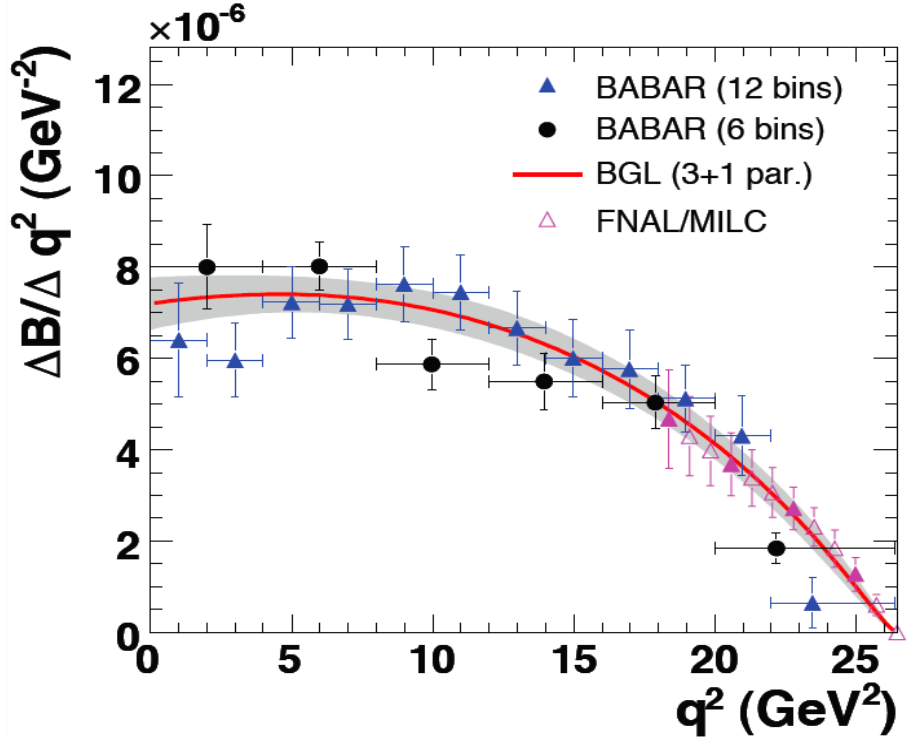


Phys.Rev.D83, 052011 (2011)

Untagged $B \to \pi^+ \ell \nu$



Small event overlap! BaBar results compatible



BaBar comb fit + FNAL lattice pts

- $|V_{ub}| = (3.13 \pm 0.14 \pm 0.27) \cdot 10^{-3}$

Theory error reduced: FF shape from data

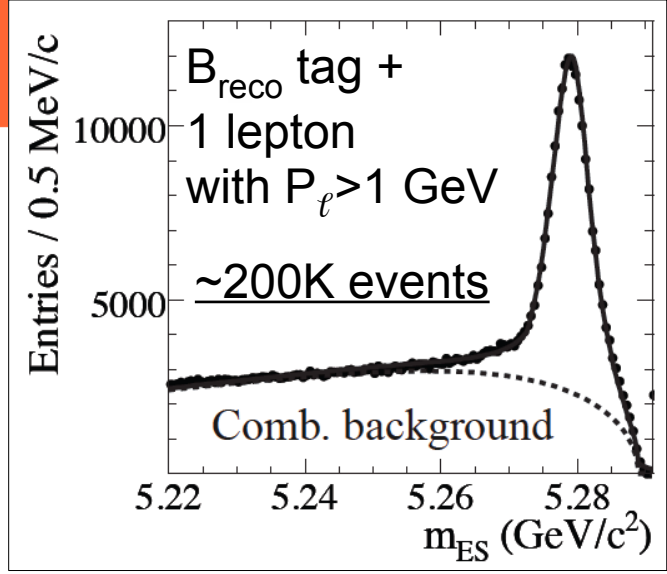
$\times 10^{-3}$	12 bins	6 bins	Combined
$\|V_{ub}\|_{\mathrm{HPQCD}}$	3.28 ± 0.20	3.21 ± 0.18	$3.23 \pm 0.16^{+0.57}_{-0.37}$
$\|V_{ub}\|_{\mathrm{FNAL}}$	3.14 ± 0.18	3.07 ± 0.16	$3.09 \pm 0.14^{+0.35}_{-0.29}$
$\|V_{ub}\|_{\mathrm{LCSR}}$	3.70 ± 0.11	3.78 ± 0.13	$3.72 \pm 0.10^{+0.54}_{-0.39}$

- $q^2 > 16$ GeV^2
- $q^2 < 12$ GeV^2

Result compatible with Belle and WA

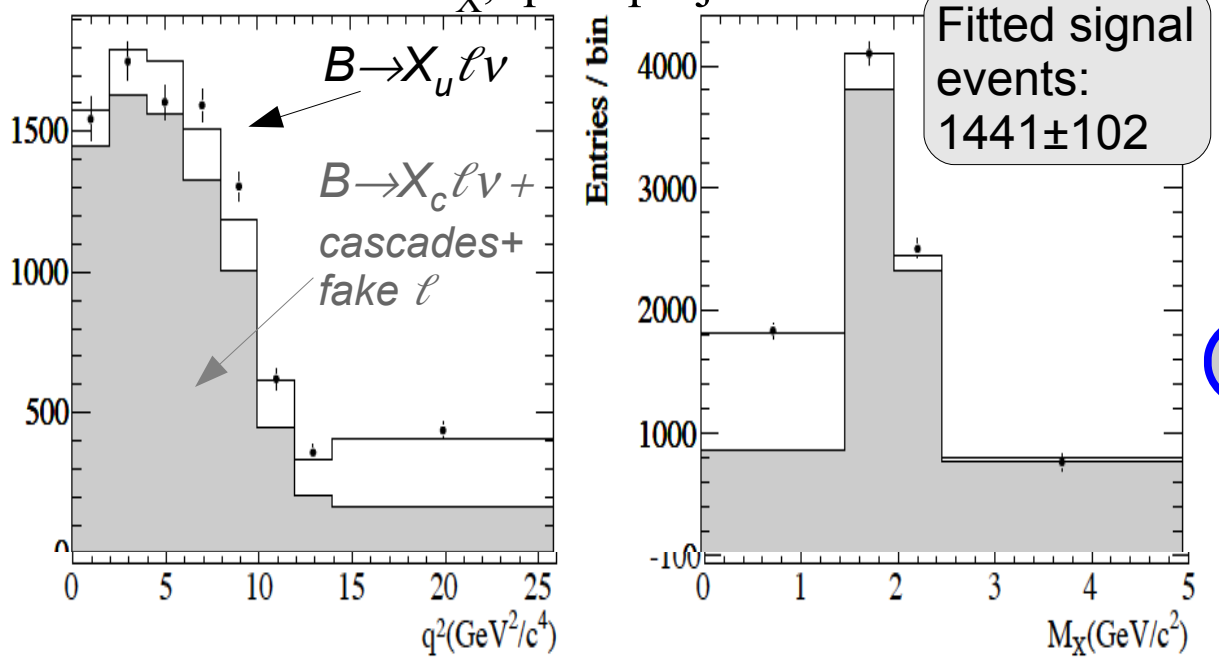
Fits Provided by Jochen Dingfelder

$|V_{ub}|$ From Inclusive $B \to X_u \ell \nu$



- *Large background from $B \to X_c \ell \nu$*
  - *Kinematics to extract the signal (lepton endpoint, M_X<M_D,...)*
- *Use hadronic tag $B_{tag} \to D^{(*)}Y$ ($Y=n\pi, m\pi^0, pK_s, qK$), to reduce combinatorial and reconstruct M_X, q^2 and $P_+ = E_X - p_X$ with good resolution*
- *Veto $B \to D(*)\ell\nu$ with Kaons, soft pions, and missing mass*

M_X, q^2 fit projections



Final BaBar result, to be submitted to PRD

- *Most precise ($\sigma_{exp} \oplus \sigma_{theory}$) result from a 2-D fit in q^2-M_x (P_ℓ>1 GeV)*

QCD Calculation	$\lvert V_{ub}\rvert (10^{-3})$
BLNP	$4.27 \pm 0.15 \pm 0.18^{+0.23}_{-0.20}$
DGE	$4.34 \pm 0.16 \pm 0.18^{+0.22}_{-0.15}$
GGOU	$4.29 \pm 0.15 \pm 0.18^{+0.11}_{-0.14}$
ADFR	$4.35 \pm 0.19 \pm 0.20^{+0.15}_{-0.15}$
Arithm. Average	$4.31 \pm 0.25_{exp.} \pm 0.16_{th.}$

- *Compatible fitting other kinematic variables. Good consistency with WA and Belle*
- ***2σ Discrepancy with Exclusive***

$|V_{ub}|$ *from SL decays* $B \to \pi / X_u \ell \nu$

$B \to K\pi\pi^0$

$B \to \phi\phi K$

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

$B^0 \to K\pi\pi$ and γ measurement

- *Rich resonance structure, many observables:*
  - *Direct CP asymmetry*
  - *Branching Ratios*
  - *Relative phases between components*

$$A_{CP} = \frac{N(B^-) - N(B^+)}{N(B^-) + N(B^+)}$$

- *Direct CP violation in the $K^*\pi$ decays: „$K\pi$ puzzle in $K^*\pi$ decays?*

- *Access UT angle γ from phases related to the $K^*\pi$ intermediate states in $B^0 \to K^+\pi^-\pi^0$ and $B^0 \to K_s\pi^+\pi^-$*
  - *Combination free of QCD penguins*

Ciuchini, Pierini, Sivestrini
PRD74,051301(2006)

$$3A^0_{3/2}(K^*\pi) = A(K^{*+}\pi^-) + \sqrt{2}A(K^{*0}\pi^0)$$

$$3\overline{A}^0_{3/2}(K^*\pi) = A(K^{*-}\pi^+) + \sqrt{2}A(\overline{K}^{*0}\pi^0)$$

$$\Phi_{3/2} = -0.5\mathrm{Arg}(\overline{A}_{3/2}/A_{3/2}) \approx \gamma$$

- *Same argument can be extended to $B^0 \to \rho K^+$*

$$A_{\frac{3}{2}}(\rho K) = \frac{1}{\sqrt{2}}A(B^0 \to \rho^- K^+) + A(B^0 \to \rho^0 K^0)$$

From $B^0 \to K^+\pi^-\pi^0$ DP

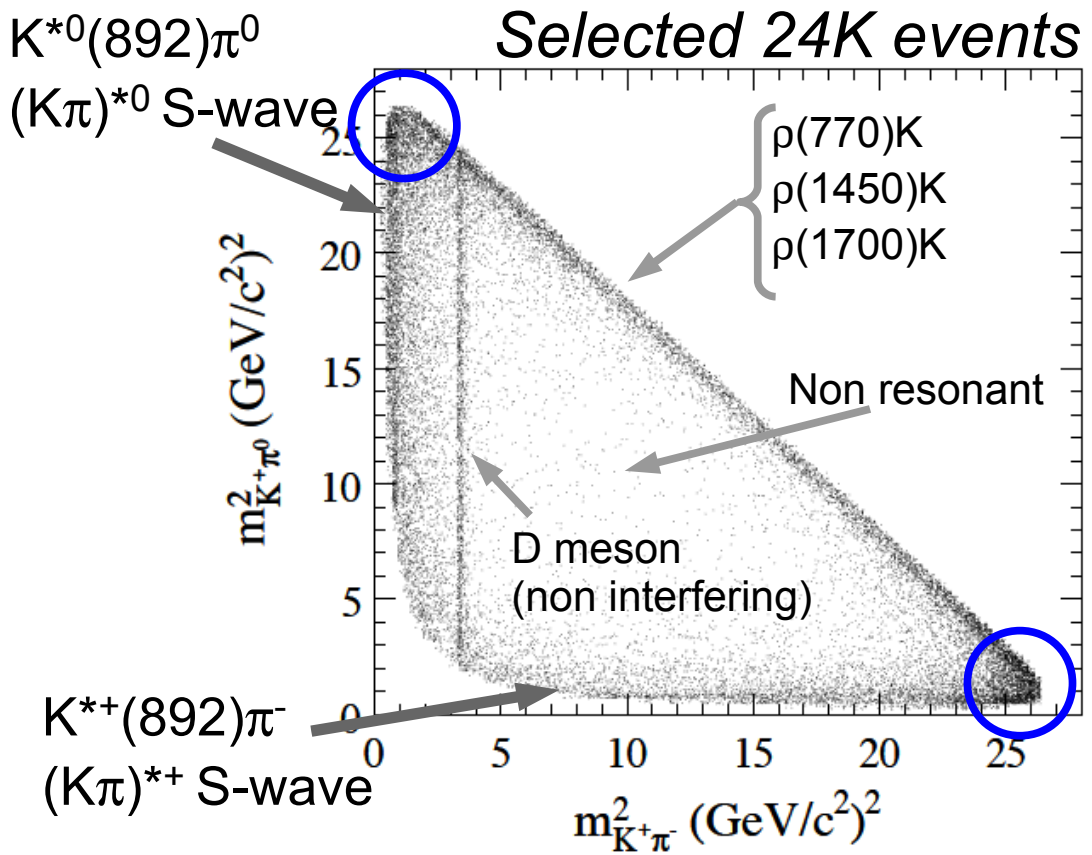
Interference with $K^{*+}\pi^-$

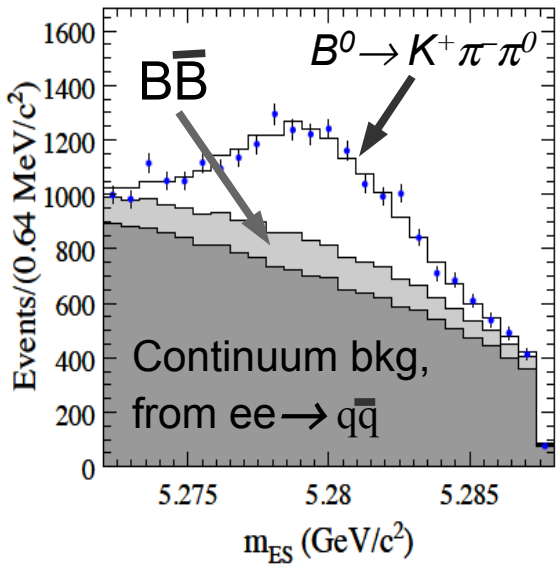
From $B^0 \to K_S\pi^+\pi^-$ DP

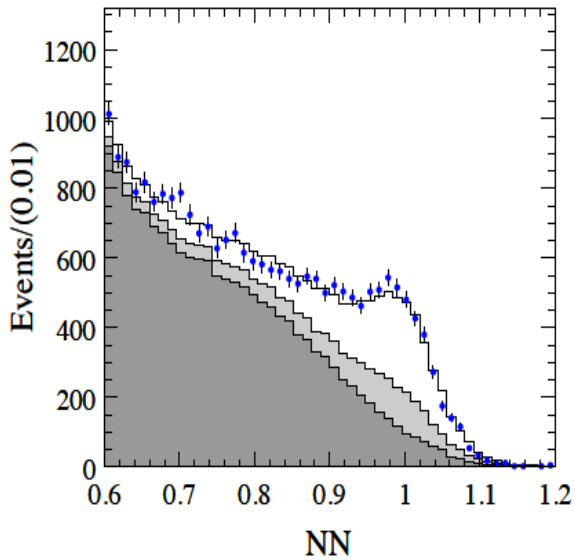
$B^0 \to K^+\pi^-\pi^0$ Dalitz Plot

- *Resonances populate the borders of the Dalitz Plot (DP)*
  - *Overlap region of resonances is small*
  - *Crucial understanding of backgrounds and efficiency in the corners*
- *ML fit with m_{ES}, ΔE, NN_{out} and DP*
  - *Maximize the signal-background separation*
  - *Signal category includes signal from misreconstructed events*
- *Charmless signal yield:*
  - $N(K^+\pi^-\pi^0)=3670 \pm 96_{stat} \pm 94_{syst}$
  - $B^0 \to D^0\pi^0$ and $B^0 \to D^-K^+$ consistent with expectations

Phys.Rev.D83:112010 (2011)







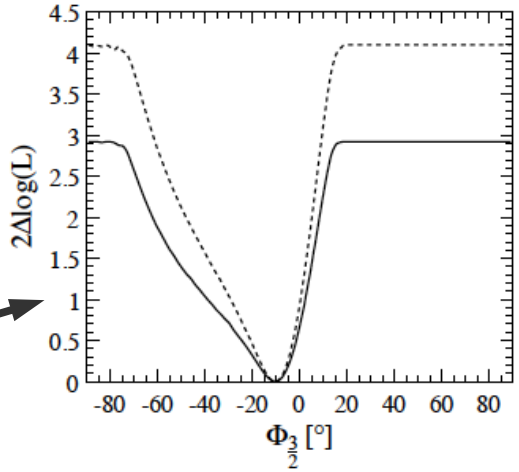
$B^0 \to K^+\pi^-\pi^0$ Results

- $BF(B^0 \to K^+\pi^-\pi^0) = (38.5 \pm 1.0 \pm 3.9)\times 10^{-6}$
- A_{CP} *combined with published results with* $B^0 \to K_s\pi^-\pi^+$

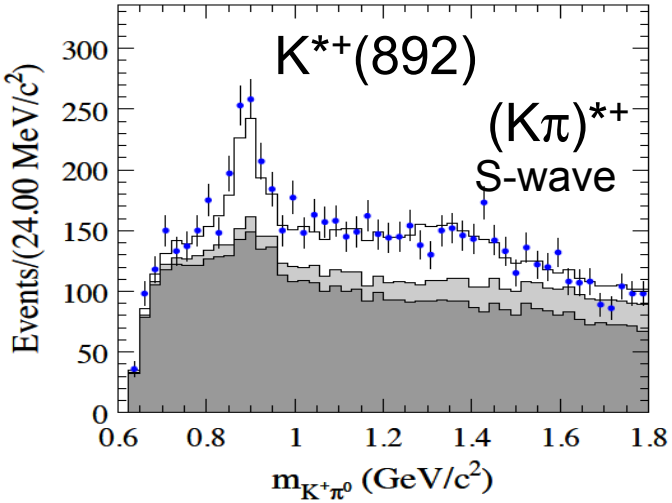
BaBar, PRD80,112001

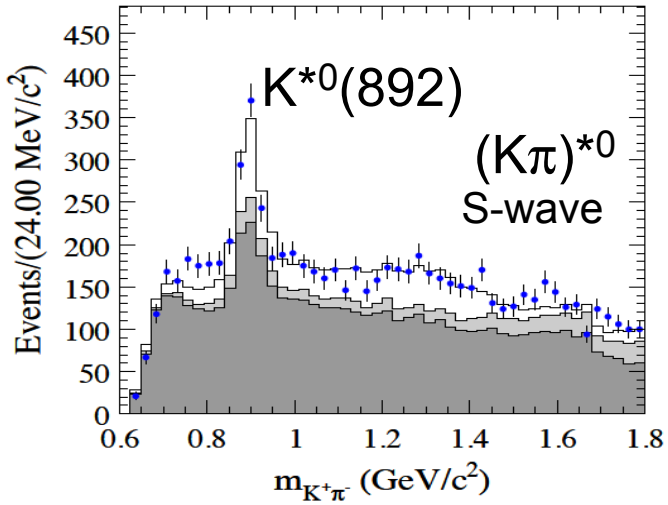
  - $A_{CP}(K^{*+}\pi^-) = -0.24 \pm 0.07 \pm 0.02$
  - *Evidence of direct CPV in* $B^0 \to K^{*+}\pi^-$ *(3.1 σ)*

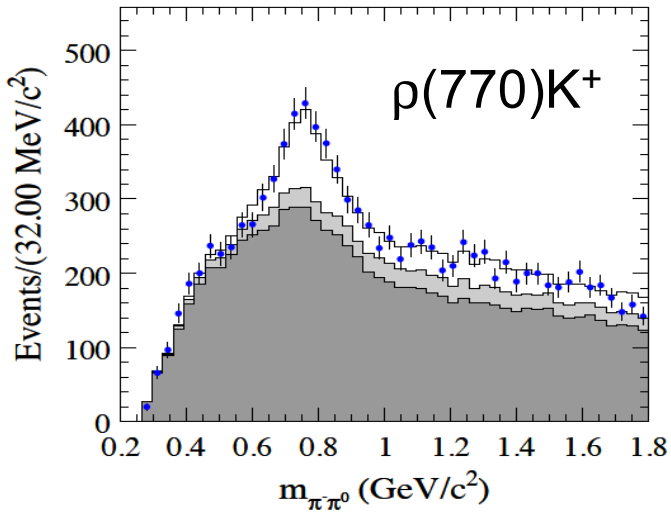
- *Destructive interference of the neutral and charged* $K^*\pi$ *amplitude:*
  - $\bar{A}_{3/2}(K^*\pi)$ *close to 0 → no sensitivity to* $\Phi_{3/2}$
- *Better possibilities from ρK:*
  - $\Phi_{3/2}(\rho K) = (-10^{+10}_{-20}{}^{+7}_{-22})^\circ$



Isobar	$\mathcal{B}$ ($\times 10^{-6}$)	$\bar{\Phi}$ [°]	Φ [°]	A_{CP}
$\rho(770)^- K^+$	$6.6 \pm 0.5 \pm 0.8$	0 (fixed)	0 (fixed)	$0.20 \pm 0.09 \pm 0.08$
$\rho(1450)^- K^+$	$2.4 \pm 1.0 \pm 0.6$	$75 \pm 19 \pm 9$	$126 \pm 25 \pm 26$	$-0.10 \pm 0.32 \pm 0.09$
$\rho(1700)^- K^+$	$0.6 \pm 0.6 \pm 0.4$	$18 \pm 36 \pm 16$	$50 \pm 38 \pm 20$	$-0.36 \pm 0.57 \pm 0.23$
$K^*(892)^+\pi^-$	$8.0 \pm 1.1 \pm 0.8$	$33 \pm 22 \pm 20$	$39 \pm 25 \pm 20$	$-0.29 \pm 0.11 \pm 0.02$
$K^*(892)^0\pi^0$	$3.3 \pm 0.5 \pm 0.4$	$29 \pm 18 \pm 6$	$17 \pm 20 \pm 8$	$-0.15 \pm 0.12 \pm 0.04$
$(K\pi)_0^{*+}\pi^-$	$34.2 \pm 2.4 \pm 4.1$	$-167 \pm 16 \pm 37$	$-130 \pm 22 \pm 22$	$0.07 \pm 0.14 \pm 0.01$
$(K\pi)_0^{*0}\pi^0$	$8.6 \pm 1.1 \pm 1.3$	$13 \pm 17 \pm 12$	$10 \pm 17 \pm 16$	$-0.15 \pm 0.10 \pm 0.04$
NR	$2.8 \pm 0.5 \pm 0.4$	$48 \pm 14 \pm 6$	$90 \pm 21 \pm 15$	$0.10 \pm 0.16 \pm 0.08$







$|V_{ub}|$ *from SL decays* $B \to \pi / X_u \ell \nu$

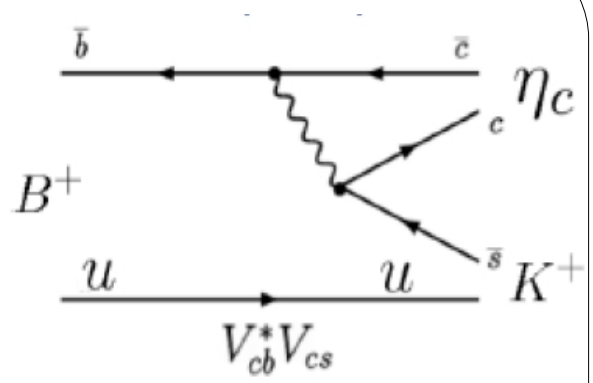
$B \to K\pi\pi^0$

$B \to \phi\phi K$

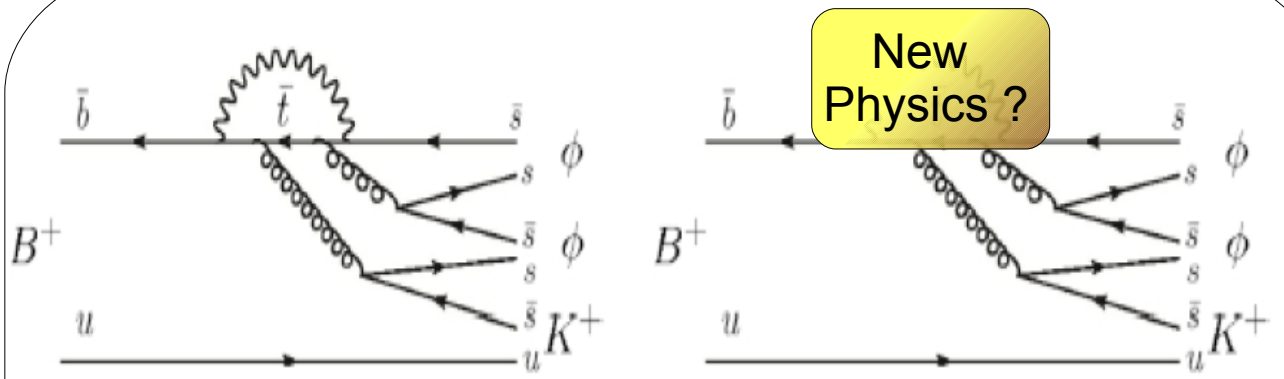
$B \to D^{(*)}\tau\nu$

$B \to \phi\phi K$

- *Interference between tree and penguin amplitudes under the η_c peak*



Tree $B \to \eta_c K$, $\eta_c \to \phi\phi$



$\mathrm{Arg}(V_{tb}^* V_{ts}) \approx \mathrm{Arg}(V_{cb}^* V_{cs})$

New CP-violating phase

Penguin $B \to \phi\phi K$

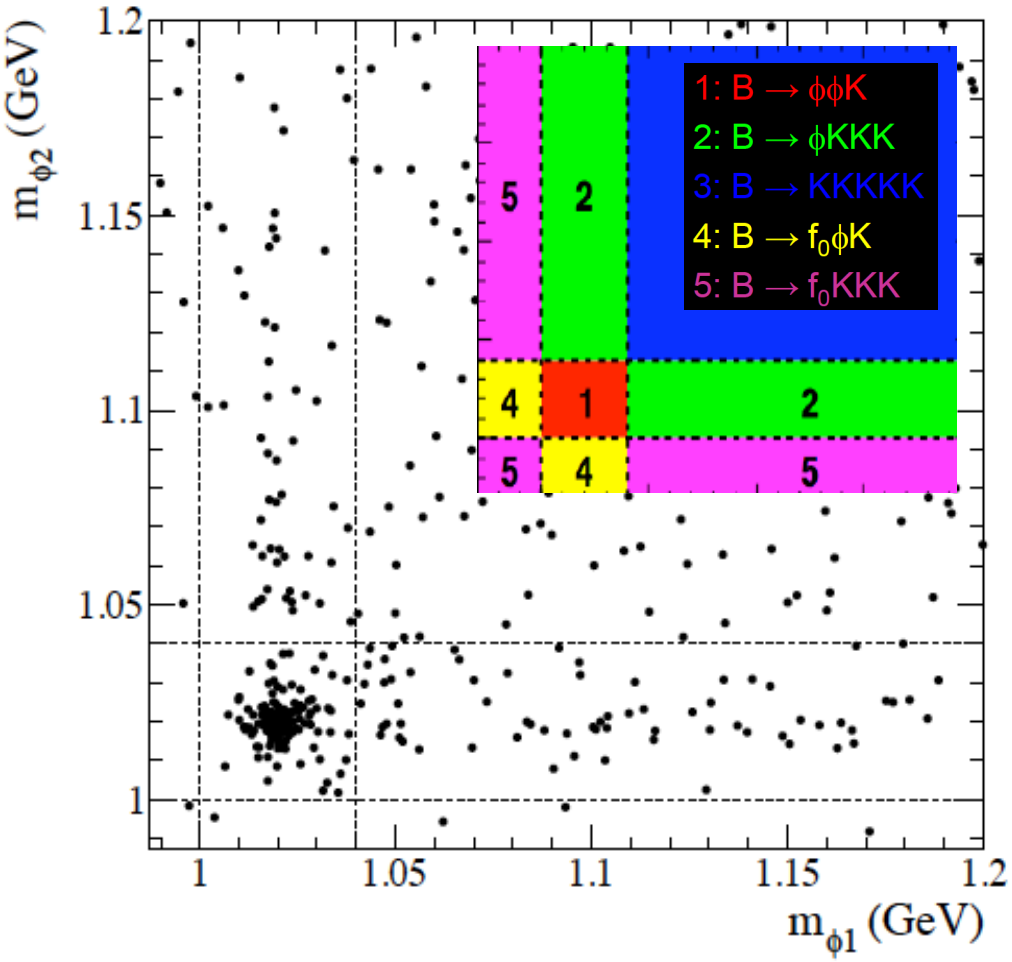
- *In the SM, T and P have same weak phase: expect no direct CP-Violation*
- *Any observation of direct CP asymmetry would indicate NP phase in P process*
  - *Could be at the ~40% level* (Hazumi, Phys. Lett B 583, 285 (2004))

$B^+ \to \phi\phi K$

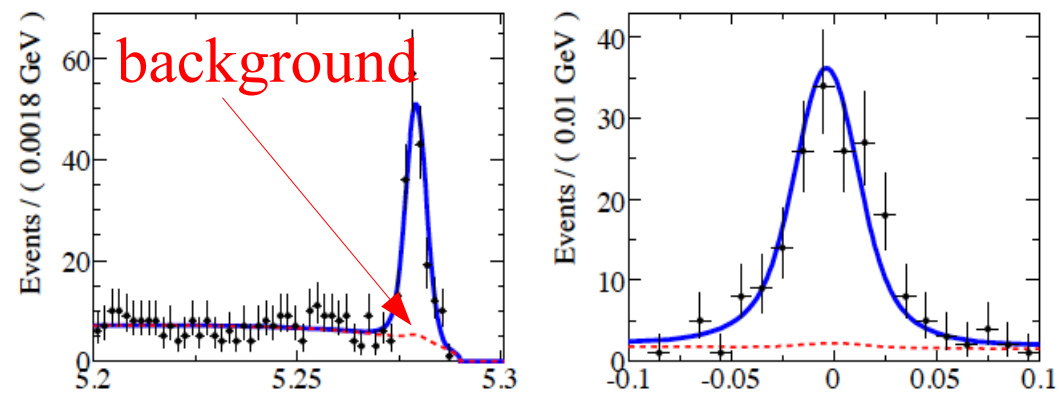
- *Use 5 regions in the m_ϕ-m_ϕ plane to distinguish final states with 5-Kaons*
  - *Fit in different regions*

- *Maximum likelihood fit to m_{ES}, ΔE, Fisher (to suppress continuum $e^+e^- \to qq_{bar}$), $m_{\phi 1}$,$m_{\phi 2}$*

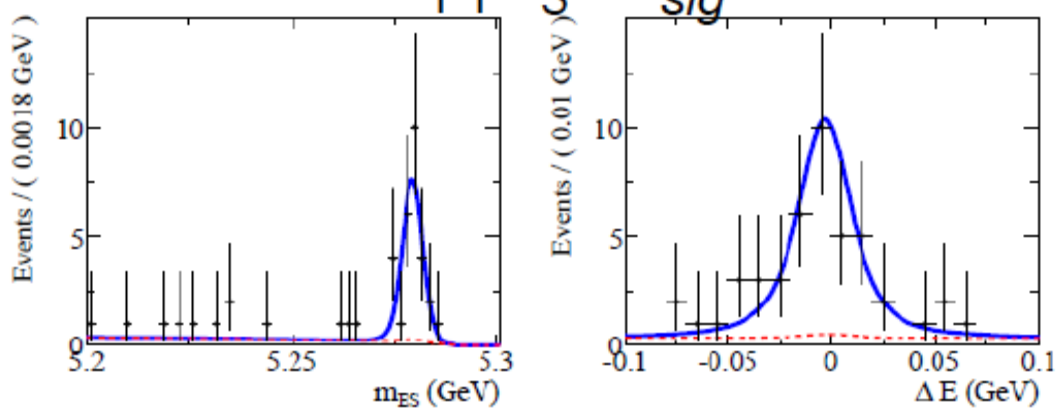
446 x 10^6 $B\bar{B}$



$B^+ \to \phi\phi K^+$ N_{sig}=178 ± 15



$B^0 \to \phi\phi K_S$ N_{sig}=40±7



- ***First Observation of K_s mode***

$B^+ \to \phi\phi K$: BR and A_{CP}

Partial BF ($m_{\phi\phi}$<2.84 GeV)

BF($B^+ \to \phi\phi K^+$) = $(5.6 \pm 0.5 \pm 0.3)\cdot 10^{-6}$

BF($B^0 \to \phi\phi K_s$) = $(4.5 \pm 0.8 \pm 0.3)\cdot 10^{-6}$

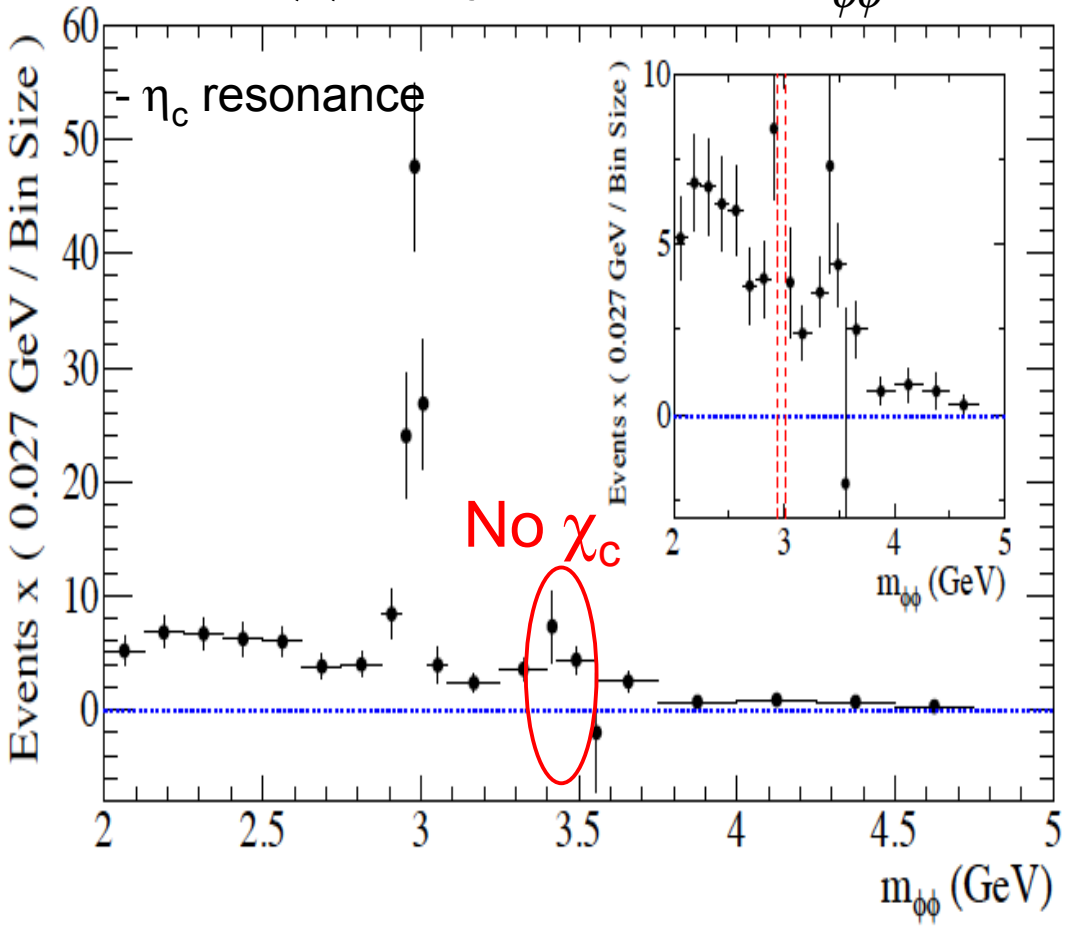
First measurement!

- *$A_{CP}(\phi\phi K^+)$ below and within the η_C region:*

M($\phi\phi$)<2.85 GeV	-0.10 ± 0.08 ± 0.02
M($\phi\phi$):2.94-2.98 GeV	-0.10 ± 0.15 ± 0.02
M($\phi\phi$):2.98-3.02 GeV	-0.08 ± 0.14 ± 0.02

- *consistent with 0 and SM*

$B^+ \to \phi\phi K^+$: yields vs. $m_{\phi\phi}$



Result submitted to PRD
ArXiv: 1105.5159

$|V_{ub}|$ *from SL decays* $B \to \pi / X_u \ell \nu$

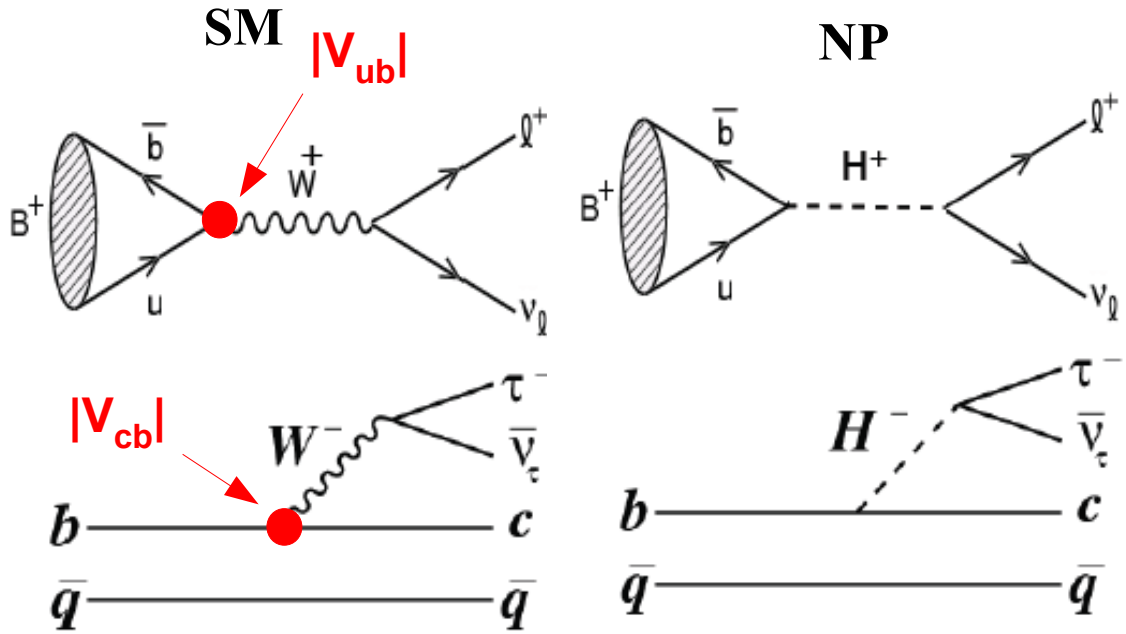
$B \to K\pi\pi^0$

$B \to \phi\phi K$

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

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

- *Similar to $B \to \tau\nu$, but:*
  - *From annihilation to exchange*
  - *From V_{ub} to V_{cb} : <u>not a rare decay!</u>*
  - *(tau mass no negligible): 2 form factor for tl D, 4 for the D*, but HQET relates the extra to the well measured FF in light leptons*
- *Look only at $\tau \to \ell\nu\nu$ ($\ell \to e$ or μ) 3ν i the final state $\to$ <u>signal signature: **larg missing mass**</u>*



Extract directly the ratio R

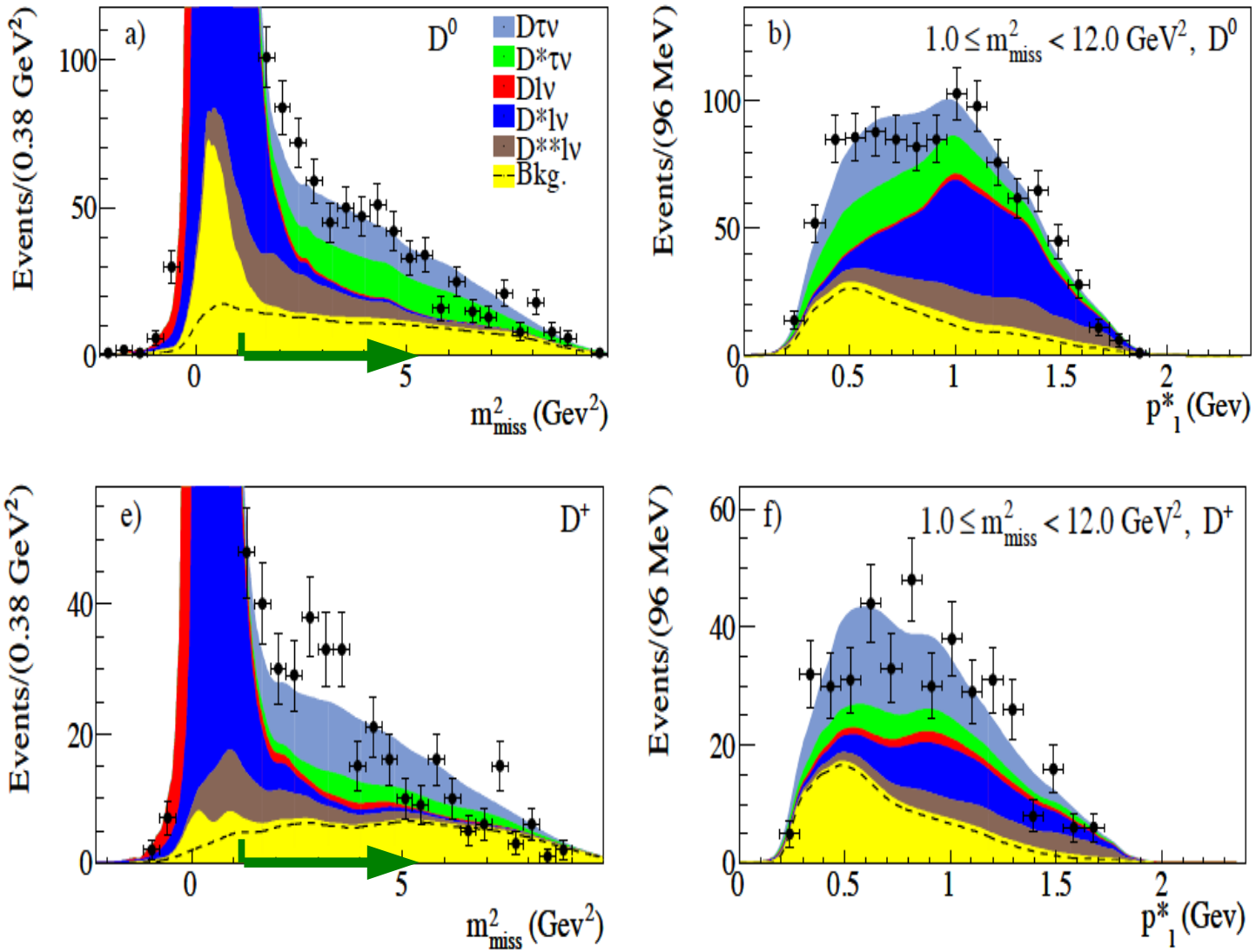
$$R(D^{(*)}) = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu_\tau\right)}$$

Reduce theoretical and experimental errors

- *Use the hadronic tag $B_{tag} \to D^{(*)}Y$*
  - *Y is a combination of π, π^0 and K*
  - *Reduce combinatoric*
- *Reconstruct 4 signal decay channels (fitted together):*
  - *D^0, D^{*0}, D^+, D^{*+}*

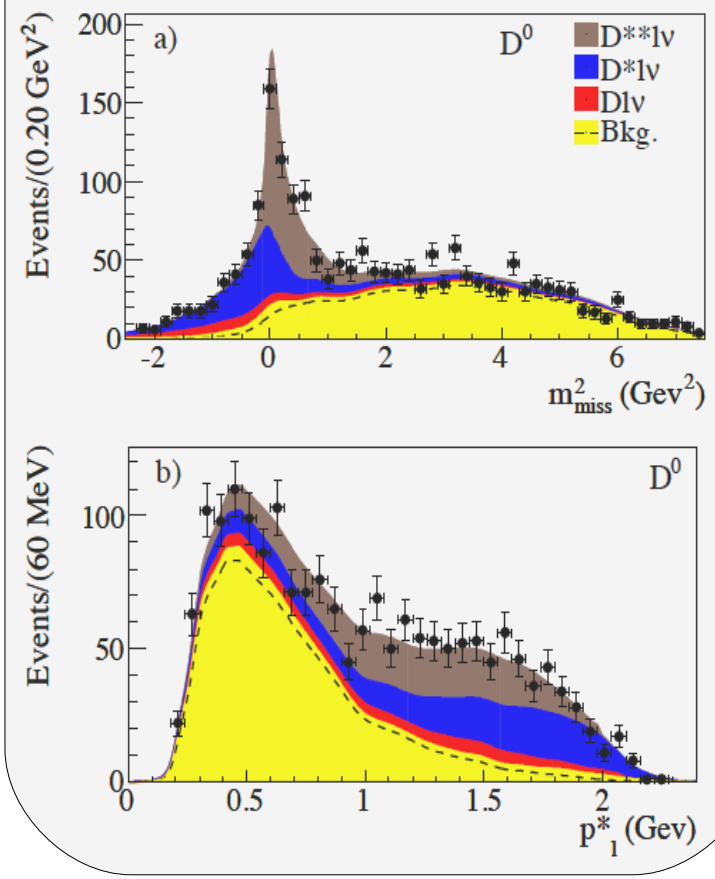
$B \to D(^*)\tau\nu$: fit

- *Simultaneous 2D un-binned ML-fit of missing mass m_{miss}^2 and P_ℓ to 4 signal samples and the D** control samples*



$B \to D^{**}\ell\nu$ poorly known

Select $D(^*)\pi^0$ candidates and fitted together with the signal sample



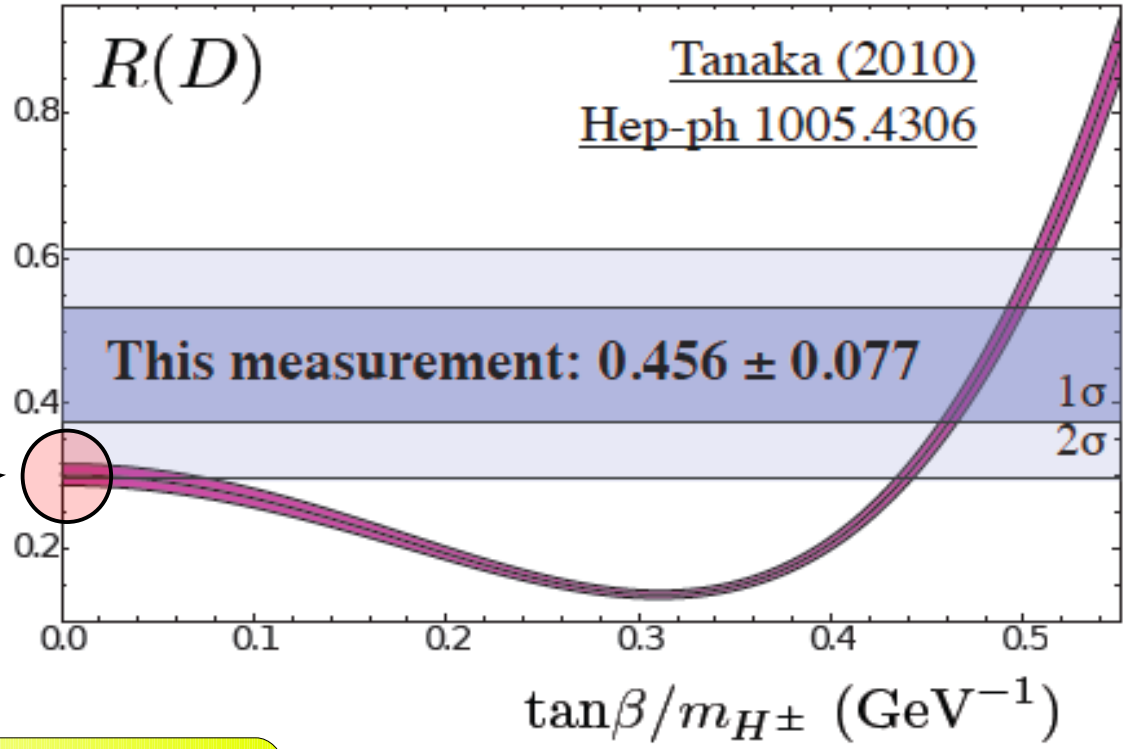
$B \to D(^*)\tau\nu$: preliminary results

Mode	N_{sig}	N_{norm}	$\varepsilon_{sig}/\varepsilon_{norm}$	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)(\%)$	Σ_{tot} (Σ_{stat})
$D^0\tau^-\overline{\nu}_\tau$	226 ± 39	1433 ± 46	2.13 ± 0.06	$0.422 \pm 0.074 \pm 0.059$	$0.96 \pm 0.17 \pm 0.14$	5.0 (6.2)
$D^{*0}\tau^-\overline{\nu}_\tau$	511 ± 48	6839 ± 90	1.36 ± 0.02	$0.314 \pm 0.030 \pm 0.028$	$1.73 \pm 0.17 \pm 0.18$	8.9 (11.9)
$D^+\tau^-\overline{\nu}_\tau$	139 ± 21	704 ± 29	2.19 ± 0.08	$0.513 \pm 0.081 \pm 0.067$	$1.08 \pm 0.19 \pm 0.15$	6.0 (7.5)
$D^{*+}\tau^-\overline{\nu}_\tau$	220 ± 23	2802 ± 56	1.25 ± 0.03	$0.356 \pm 0.038 \pm 0.032$	$1.82 \pm 0.19 \pm 0.17$	9.5 (12.1)
$D\tau^-\overline{\nu}_\tau$	368 ± 42	2140 ± 54	2.15 ± 0.05	$0.456 \pm 0.053 \pm 0.056$	$1.04 \pm 0.12 \pm 0.14$	6.9 (9.6)
$D^*\tau^-\overline{\nu}_\tau$	730 ± 50	9639 ± 107	1.33 ± 0.07	$0.325 \pm 0.023 \pm 0.027$	$1.79 \pm 0.13 \pm 0.17$	11.3 (17.1)

PRELIMINARY

Isospin constraints

- *Systematics are preliminary: expected to improve for the publication*
- *Results compatible with Belle latest results and previous BaBar one*
- *5σ in all channels*
- *1.8 σ from SM*
- *Results favors large tanβ*



More details: Manuel F Sevilla talk at EPS11

Conclusions

- *New results from Inclusive and Exclusive $|V_{ub}|$*
  - *Inclusive-Exclusive discrepancy still present: theoretical error in the inclusive ?*
- *Improvements on $B \to D(^*)\tau\nu$*
  - *Search for NP in CKM favored SL decays*
  - *All D channels observed*
- *Charmless B decays still source of many interesting results*
  - *News from $B \to K\pi\pi^0$, but weak limit on γ*
  - *$B \to \phi\phi K_s, K$: first observation of the K_s mode*
  - *Most of these results agree with SM prediction, but some puzzles remain (Polarization & $K\pi$ puzzle)*
- *More statistics is crucial to fully understand the tensions and puzzles*
  - ***LHCb: present !***
  - ***SuperB and Belle-II: next future!***