Recents Results from BaBar

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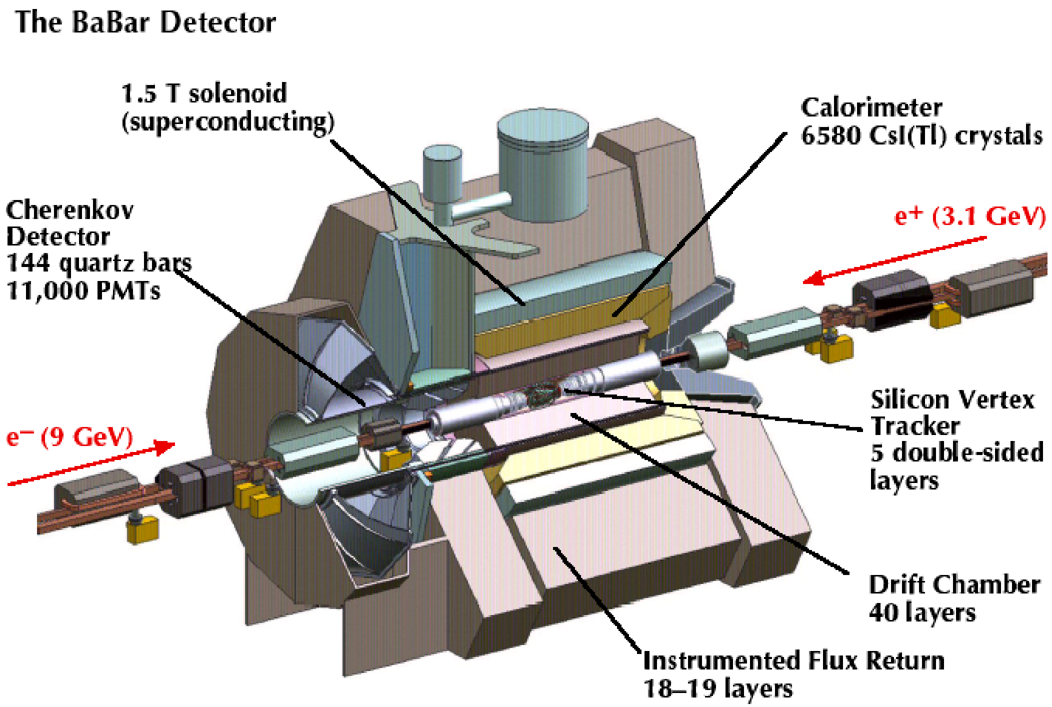
Outline

- Introduction:
  - general overview of the detector and data sample;
  - CKM matrix and Unitarity Triangle: the legacy of the B factories;
- Recent results:
  - Charm physics:
    - Search for T and CP violation; search for flavor-changing neutral current (FCNC) processes.
  - Spectroscopy:
    - Searches for $h_b(1P)$ state;
    - $\eta_c(1S,2S) \to K^+K^-\pi^+\pi^-\pi^0$.
  - Studies of B_s and B decays:
    - $BR(B_s \to X\, l\, \nu_l)$ & B_s fraction: f_s
    - $B \to \Phi\Phi K$; $B^- \to D^0K^-$;
- Conclusions

Introduction

The BaBar experiment

PEP-II is an asymmetric-energy B factory at SLAC running mostly at the $\Upsilon(4S)$ (10.58 GeV) with a center-of-mass boost with $\beta\gamma$=0.55



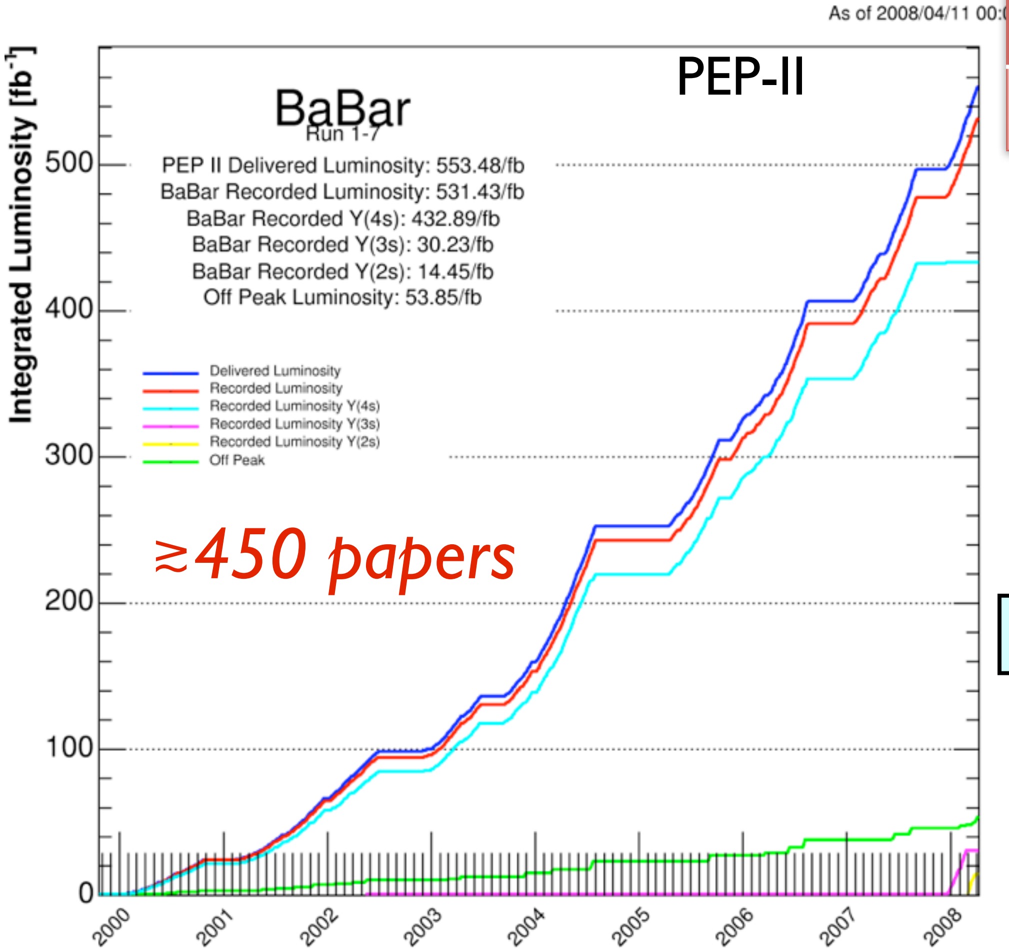
SVT: 97% efficiency, 15 μm z hit resolution (inner layers, perp. tracks)

SVT+DCH: $\sigma(p_T)/p_T$ = 0.13 % $\times$ p_T + 0.45 %, $\sigma(z_0)$=65 μm@ 1GeV/c

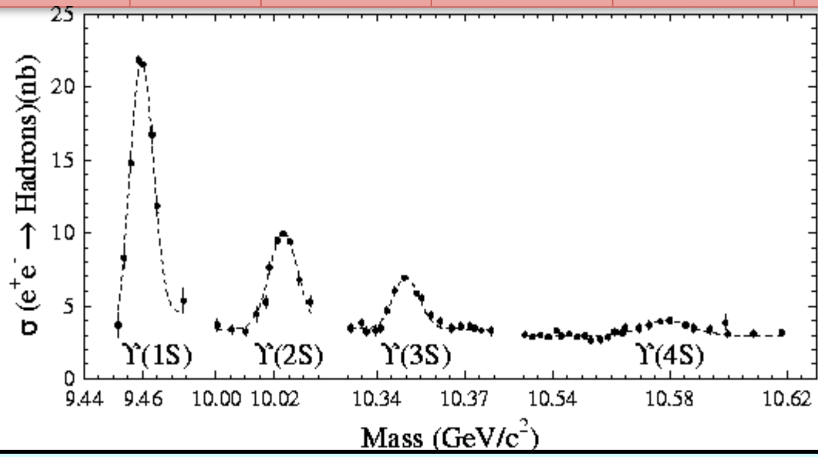
DIRC: K-π separation 4.2 σ @ 3.0 GeV/c → 2.5 σ @ 4.0 GeV/c

EMC: $\sigma_E/E = 2.3\,\% \cdot E^{-1/4} \oplus 1.9\,\%$

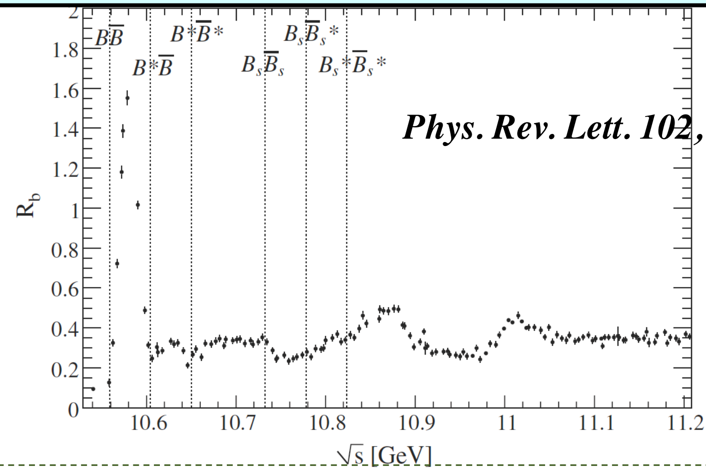
The BaBar dataset



	Υ(1S)	Υ(2S)	Υ(3S)	Υ(4S)	Υ(5S)
BaBar	-	14 fb^{-1}	30 fb^{-1}	433 fb^{-1}	-



Offpeak (10.54GeV) + Scan above Y(4S): 53.9 fb^{-1}



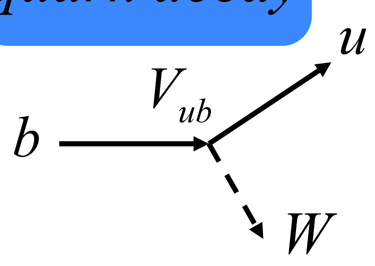
Phys. Rev. Lett. 102, 012001 (2009)

Recorded luminosity ~530 fb^{-1}
Peak luminosity ~12×10^{33} $cm^{-2}s^{-1}$

Main goal of the B factories

- *Verify the Cabibbo-Kobayashi-Maskawa (CKM) mechanism of quark mixing and CP violation with 3 generations of quarks.*

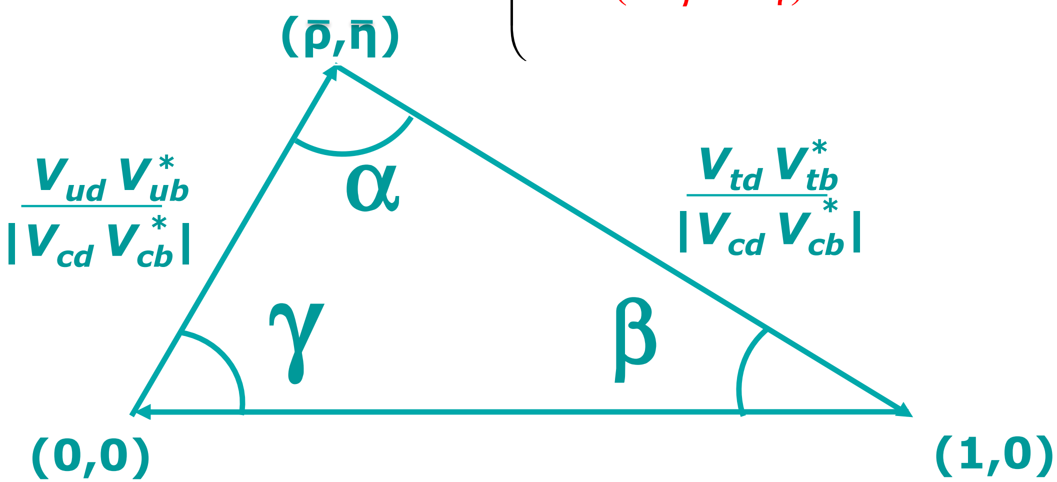
quark decay



CKM matrix

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}.$$

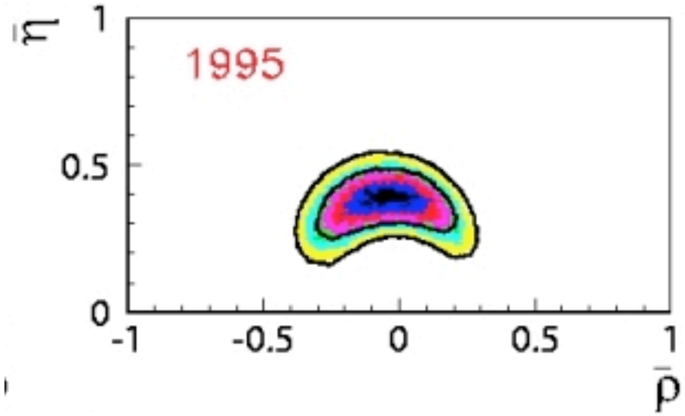
Unitarity Triangle



$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

The legacy of the B factories, *in one slide*

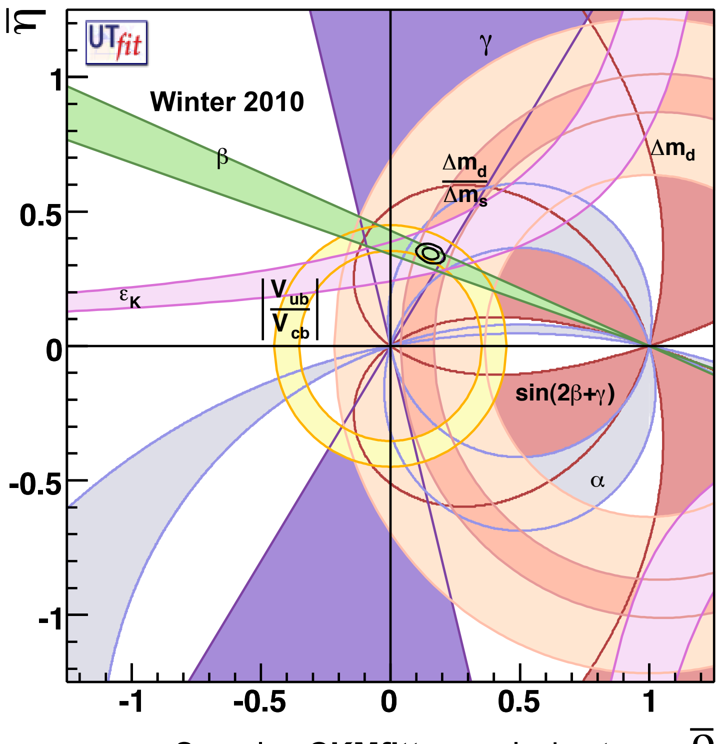
Before the B factories (BaBar and Belle)



Constraints on the Unitarity Triangle

see *http://www.utfit.org/*

...and after the B factories (+other measurements)

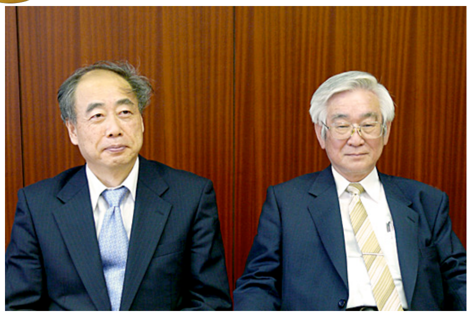


See also **CKMfitter** analysis at
http://ckmfitter.in2p3.fr/

The CKM mechanism is confirmed

Nicola Cabibbo
awarded of 2010 Dirac Medal

Kobayashi and Maskawa
awarded of 2008 Nobel Prize



Recent results: Charm physics

CP violation in D decays with a K_S in final state

- Standard Model: *CP* violation from *KM* phase in *CKM* quark mixing matrix:

$$\begin{bmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta + \frac{i}{2}\eta\lambda^2) \\ -\lambda & 1-\frac{\lambda^2}{2} - \boxed{i\eta A^2\lambda^4} & A\lambda^2(1+i\eta\lambda^2) \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$

- Charmed Mesons:
  - *CP* violation is *CKM* suppressed $\mathcal{O}(10^{-3})$ or less
  - The presence of a K^0_S introduces *CPV* of (0.332±0.006)% from CP violation K^0-$\overline{K}^0$ mixing
  - Experimental Sensitivity $\mathcal{O}(10^{-3})$

1% Signal = New Physics

Search for CP violation in $D^{\pm} \to K_S \pi^{\pm}$

$$A_{CP} = \frac{\Gamma(D^+ \to K_S^0\pi^+) - \Gamma(D^- \to K_S^0\pi^-)}{\Gamma(D^+ \to K_S^0\pi^+) + \Gamma(D^- \to K_S^0\pi^-)}$$

Direct CP asymmetry from K_S mixing: **-0.332**±0.006%

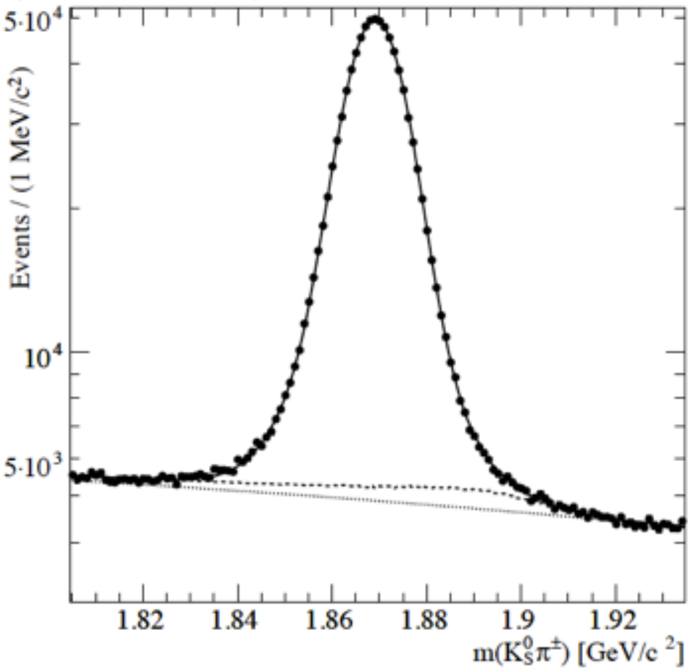
New Physics affecting doubly Cabibbo-suppressed Feynman diagram could cancel or enhance it to % level

Phys.Rev.D 83:071103,2011 469 fb^{-1}

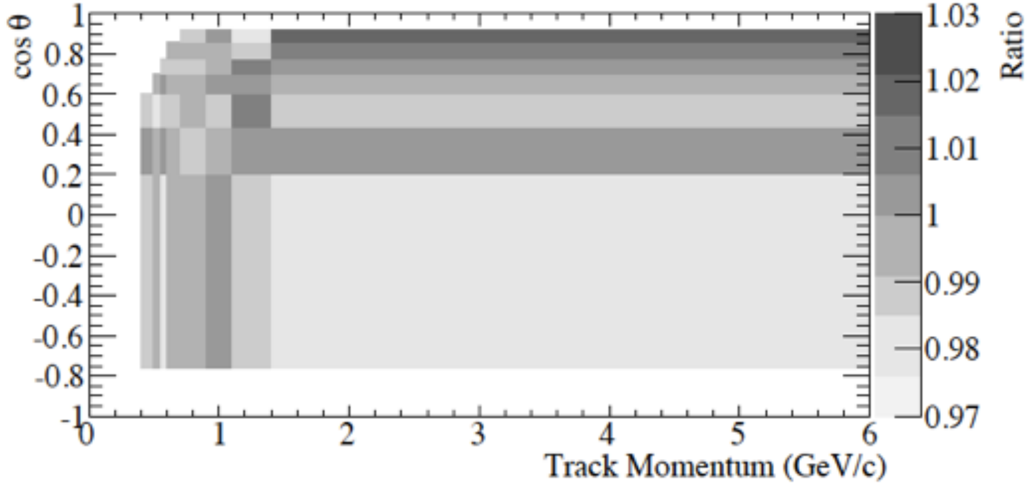
New Idea

Fit: Signal, reflection bkg and combinatorial bkg

$(807.4 \pm 0.1) \times 10^3$ signal events.



New data-driven method to determine charge asymmetry in track reconstruction.
Use tracks from $e^+e^- \to \Upsilon(4S) \to B\overline{B}$ *process, free of any physics-induced charge asymmetry.*

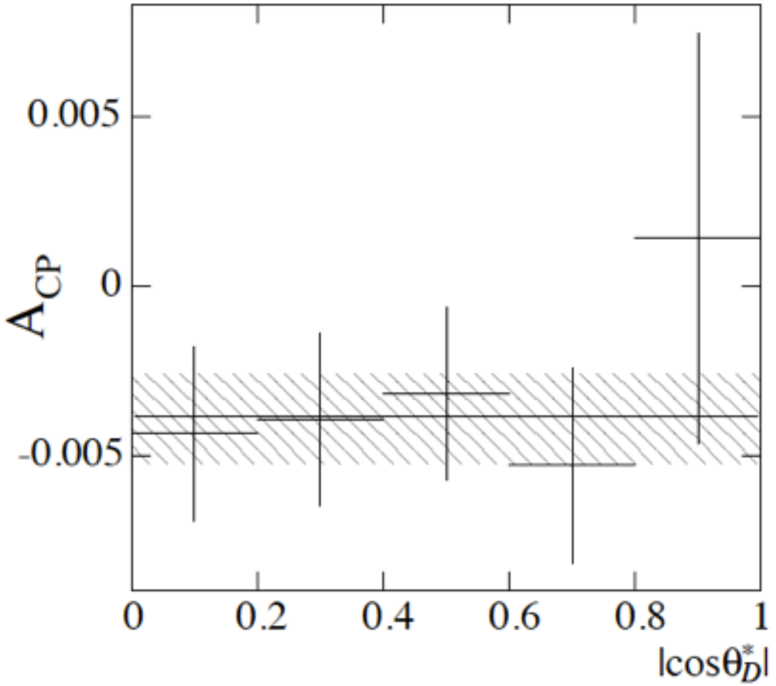


Ratio of detection efficiency: π^+/π^-

Search for CP violation in $D^{\pm} \to K^0_S \pi^{\pm}$

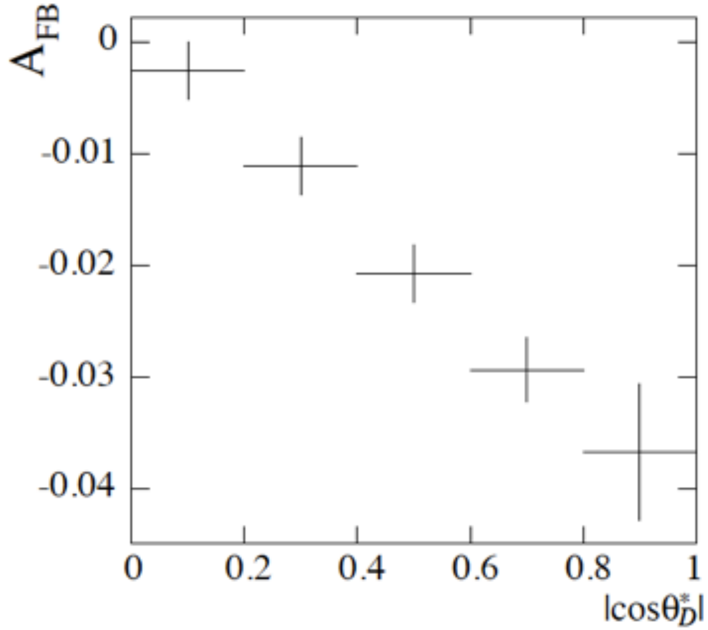
CP violation asymmetry

$$A_{CP}(|\cos\theta^*_D|) = \frac{A(+|\cos\theta^*_D|) + A(-|\cos\theta^*_D|)}{2}$$



FW-BW asymmetry due to γ-Z interference and to detector efficiency asymmetry

$$A_{FB}(|\cos\theta^*_D|) = \frac{A(+|\cos\theta^*_D|) - A(-|\cos\theta^*_D|)}{2}$$



$$A_{CP} = (-0.44 \pm 0.13 \pm 0.10)\,\%$$

Phys.Rev.D 83:071103,2011 469 fb^{-1}

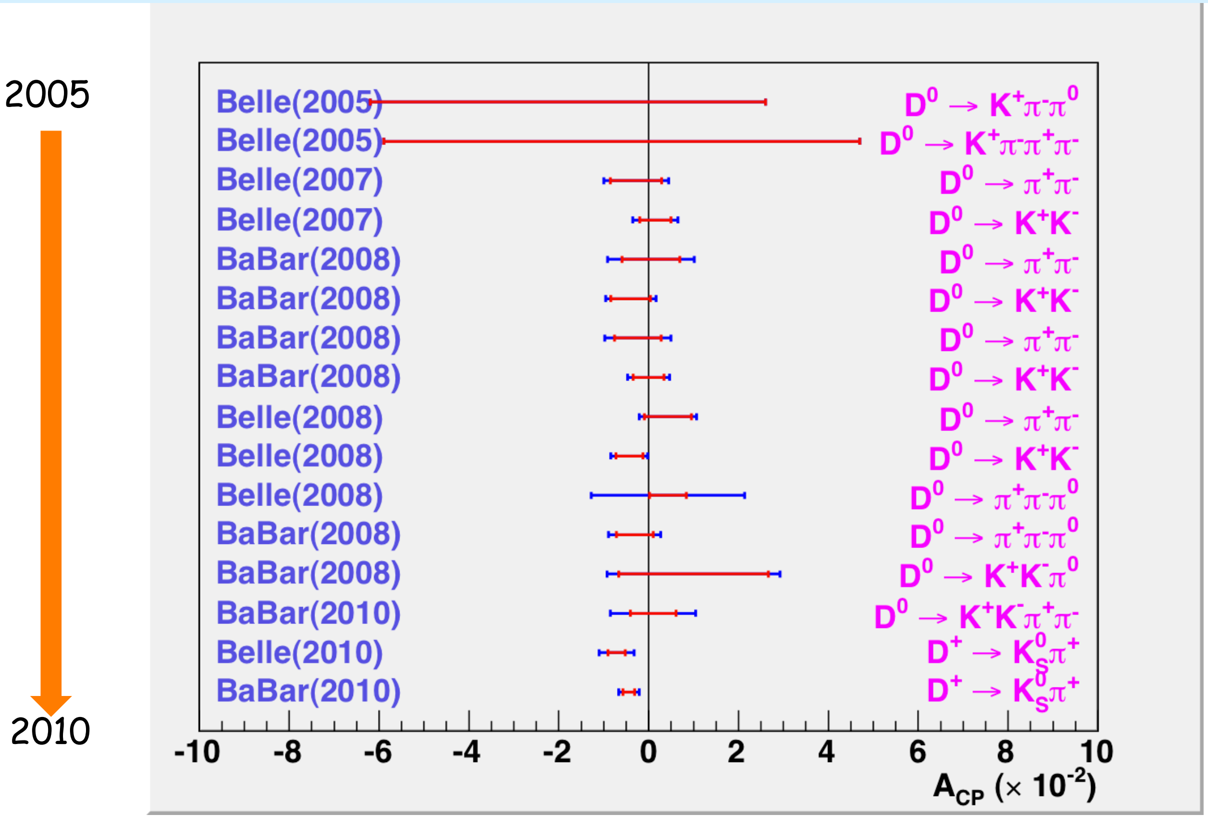
Consistent with SM prediction $(-0.332 \pm 0.006)\%$

Time-integrated CPV measurements

$D^+ \to K_s^0 \pi^+$

A_{CP}=[-0.44±0.13(stat)±0.10(sys)]% (BaBar 470fb^{-1})

A_{CP}=[-0.71±0.19(stat)±0.20(sys)]% (Belle 673fb^{-1})



Also CDF recently provided a very competitive result in $D^0 \to \pi^+\pi^-$

$$A_{CP}(D^0 \to \pi^+\pi^-) = [0.22 \pm 0.24\ (stat.) \pm 0.11\ (syst.)]\%$$

***arXiv:1012.2415** [hep-ex]*

5.94 fb^{-1} of data

Search for CPV using T-odd correlations in $D_{(s)}^+ \to K^+ K_S \pi^+ \pi^-$ decays

I.I. Bigi hep-ph/0107102 (2001)

W. Bensalem, A. Datta and D. London, Phys. Rev. D66, 094004 (2002)
W. Bensalem and D. London, Phys. Rev. D64, 116003 (2001)
W. Bensalem, A. Datta and D. London, Phys. Lett. B538, 309 (2002)

- It is a measurement of T violation and of CP violation assuming CPT is conserved.
- T-odd observable: $C_T = \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$

$$A_T = \frac{\Gamma(D_{(s)}^+, C_T > 0) - \Gamma(D_{(s)}^+, C_T < 0)}{\Gamma(D_{(s)}^+, C_T > 0) + \Gamma(D_{(s)}^+, C_T < 0)}$$

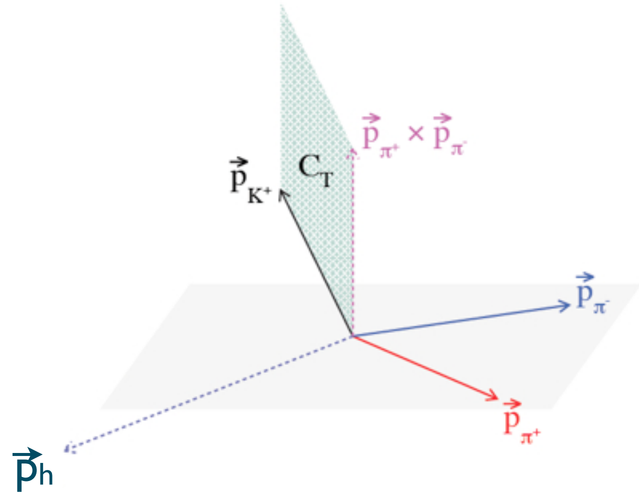
measured on D^+

- Final state interaction (FSI) could introduce fake T-odd asymmetries $A_T \neq 0$.
- T-violating observable, removes FSI effects:

$$\mathcal{A}_T = \frac{1}{2}(A_T - \bar{A}_T)$$

measured on D^-

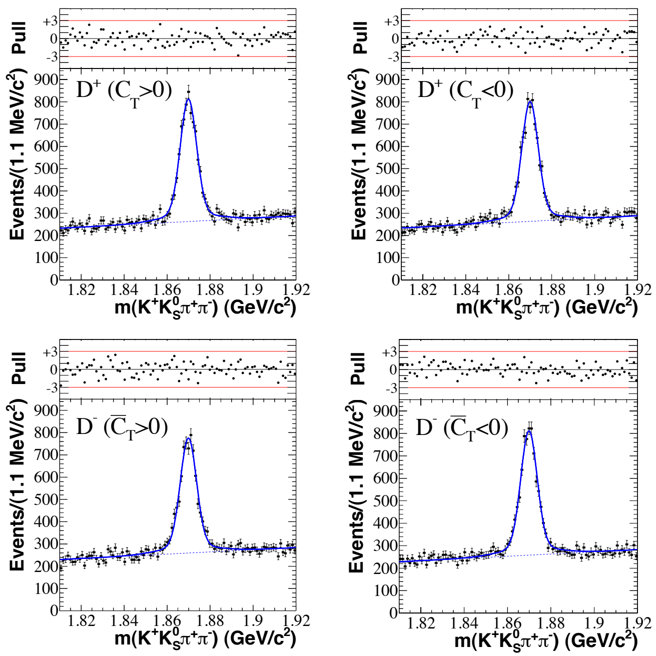
$D_{(s)}^+$ rest frame



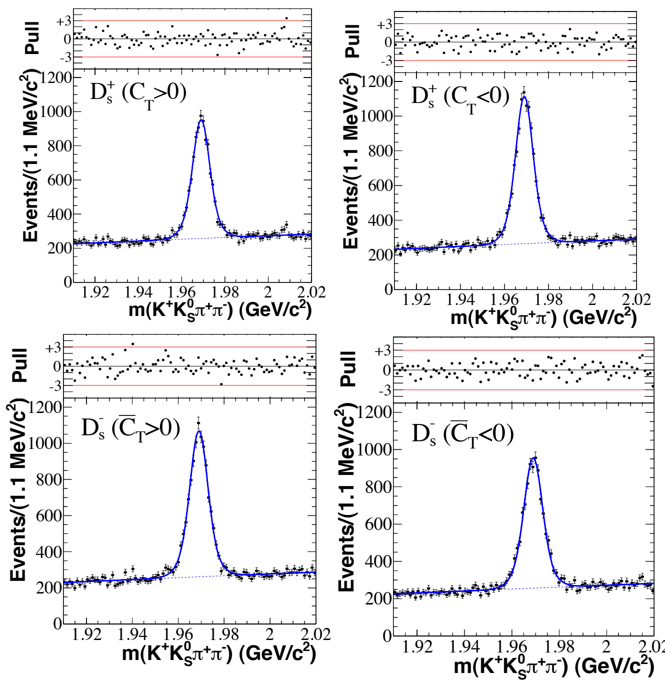
$D^+ \to K^+ K_S \pi^+ \pi^-$ and $D_s^+ \to K^+ K_S \pi^+ \pi^-$ events

520 fb^{-1}

D^+ Fit projections in signal region



D_s^+



Submitted to PRD (RC)
***arXiv:1105.4410** [hep-ex]*

- Inclusive $D_{(s)}^+$ reconstruction;
- $p^*(D) > 2.5$ GeV/c;
- use data sidebands for bkg parameterization;
- 20,000 D^+ Cabibbo suppressed and 30,000 D_s^+ Cabibbo favored decays;

Systematic errors

x 10^{-3}

	$\mathcal{A}_T(D^+)$	$A_T(D^+)$	$\bar{A}_T(D^-)$	$\mathcal{A}_T(D_s^+)$	$A_T(D_s^+)$	$\bar{A}_T(D_s^-)$
1) Reconstruction	2.05	2.84	1.26	1.00	1.00	1.27
2) Likelihood Ratio	1.08	3.41	5.58	2.46	7.77	8.16
3) Fit Model	1.30	1.14	1.46	0.10	0.78	0.70
4) Particle Identification	3.70	3.33	4.08	2.22	2.47	6.73
Total	4.56	5.66	7.18	3.43	8.25	10.67

Final results

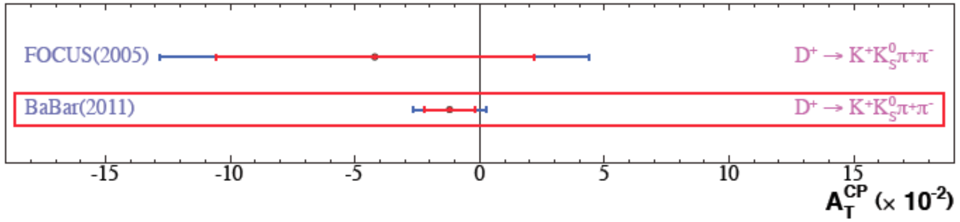
Submitted to PRD (RC) ***arXiv:1105.4410*** *[hep-ex]* 520 fb^{-1}

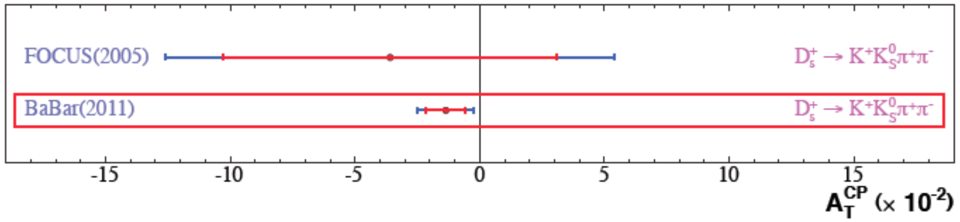
$$A_T(D^+) = (+11.2 \pm 14.1_{\text{stat}} \pm 5.7_{\text{syst}}) \times 10^{-3}$$
$$\bar{A}_T(D^-) = (+35.1 \pm 14.3_{\text{stat}} \pm 7.2_{\text{syst}}) \times 10^{-3}$$
$$A_T(D_s^+) = (-99.2 \pm 10.7_{\text{stat}} \pm 8.3_{\text{syst}}) \times 10^{-3}$$
$$\bar{A}_T(D_s^-) = (-72.1 \pm 10.9_{\text{stat}} \pm 10.7_{\text{syst}}) \times 10^{-3}$$

Final state interaction effects seem to be larger in D_s^+ than D^+ decays

$$\mathcal{A}_T(D^+) = (-12.0 \pm 10.0_{\text{stat}} \pm 4.6_{\text{syst}}) \times 10^{-3}$$
$$\mathcal{A}_T(D_s^+) = (-13.6 \pm 7.7_{\text{stat}} \pm 3.4_{\text{syst}}) \times 10^{-3}$$

T violation parameter consistent to 0. Factor 10 better than previous result.





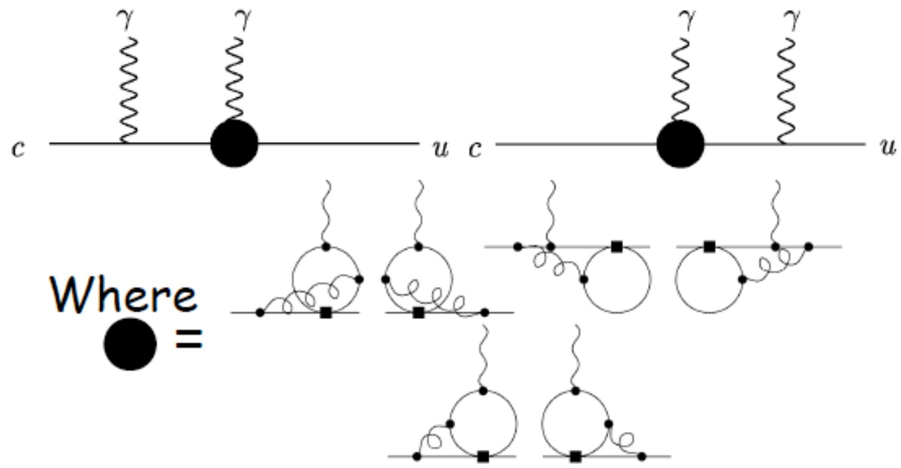
Physics motivations for studying $D^0 \to \gamma\gamma$ decay

- FCNC Decay
  - Forbidden at the tree-level
  - 1-loop GIM suppressed

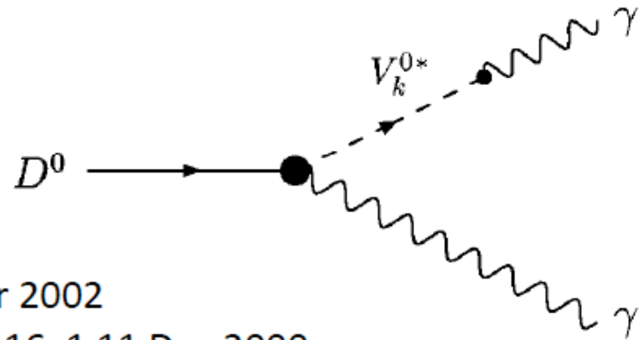
- Dominated by long distance effects [1]
  - Short-range (2-loop dominate):
    $B(D^0 \to \gamma\gamma) \approx 3 \times 10^{-11}$
  - Long-range (VMD contribution dominates):
    $B(D^0 \to \gamma\gamma) \approx 3.5 \times 10^{-8}$

- However, possible 10^2 enhancement from new physics (gluino-exchange of MSSM) [2]
- Within the range of BaBar sensitivity.
- Excellent (but difficult) mode to search for new physics

Short Distance

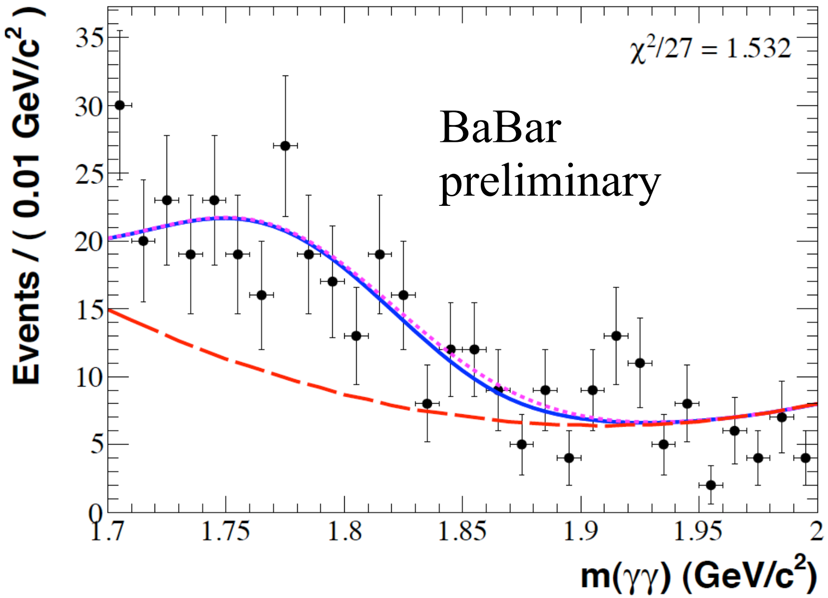


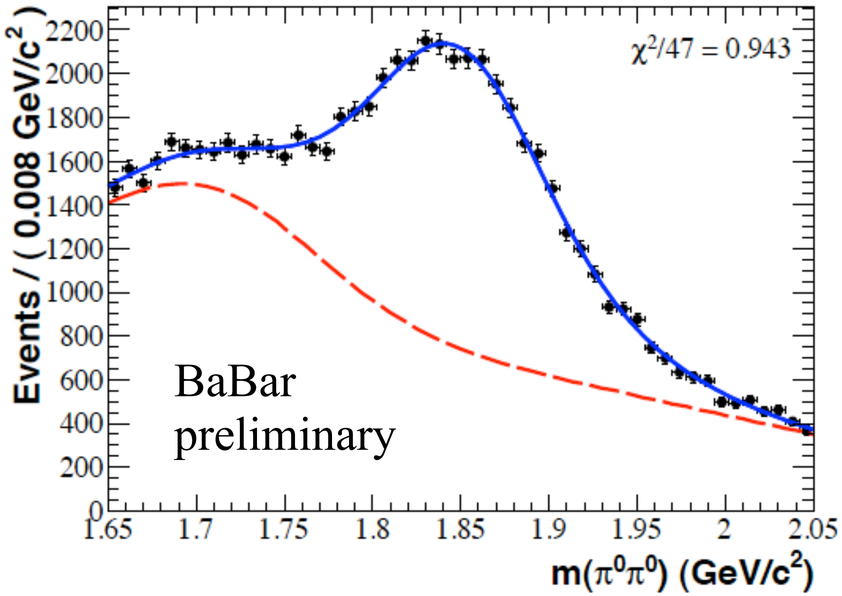
Long Distance



[1] Burdman et al. hep-ph/0112235v2 1 Mar 2002
[2] S. Prelovsek and D. Wyler, hep-ph/0012116v1 11 Dec 2000

Search for $D^0 \to \gamma\gamma$ and BR measurement of the $D^0 \to \pi^0\pi^0$ decay





Use $D^0 \to K^0{}_S\pi^0$ as BR normalizing mode

Systematic	$\sigma(D^0 \to \gamma\gamma)$ (%)	$\sigma(D^0 \to \pi^0\pi^0)$ (%)
Tracking (K^0_S) and Vertexing	0.96	0.96
Photon Reconstruction	0.60	3.00
π^0 Veto	1.80	-
D^{*+} Fragmentation	0.02	0.03
Signal Shape	*	0.20
Background Shape	*	0.80
Cut selection	*	2.50
$D^0 \to K^0_s\pi^0$ Signal Shape	0.53	0.17
$D^0 \to K^0_s\pi^0$ Background Shape	0.01	0.63
$D^0 \to K^0_s\pi^0$ Cut selection	0.76	0.76
Total Systematic Uncertainty	*	4.23

$$B(D^0 \to \pi^0\pi^0) = (8.4 \pm 0.1 \pm 0.4 \pm 0.3) \times 10^{-4}$$

comparable precision with CLEO measurement

$$B(D^0 \to \gamma\gamma) < 2.4 \times 10^{-6}$$

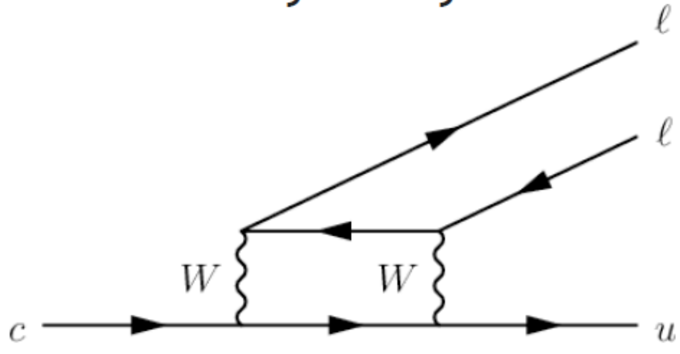
at the 90% confidence level.

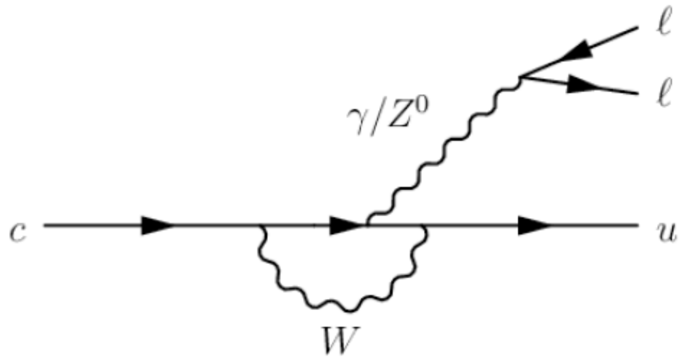
- About factor of 10 improvement on previous CLEO measurement

Physics interest in searching for FCNC decays

Search for Flavor-Changing Neutral-Current (FCNC) decays

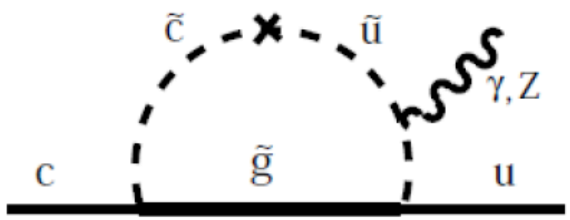
FCNC decays only occur in loop diagrams in SM:





Charm decays heavily GIM suppressed in SM: BF($c \to ull$)~10^{-8}

New physics can introduce new particles into loop



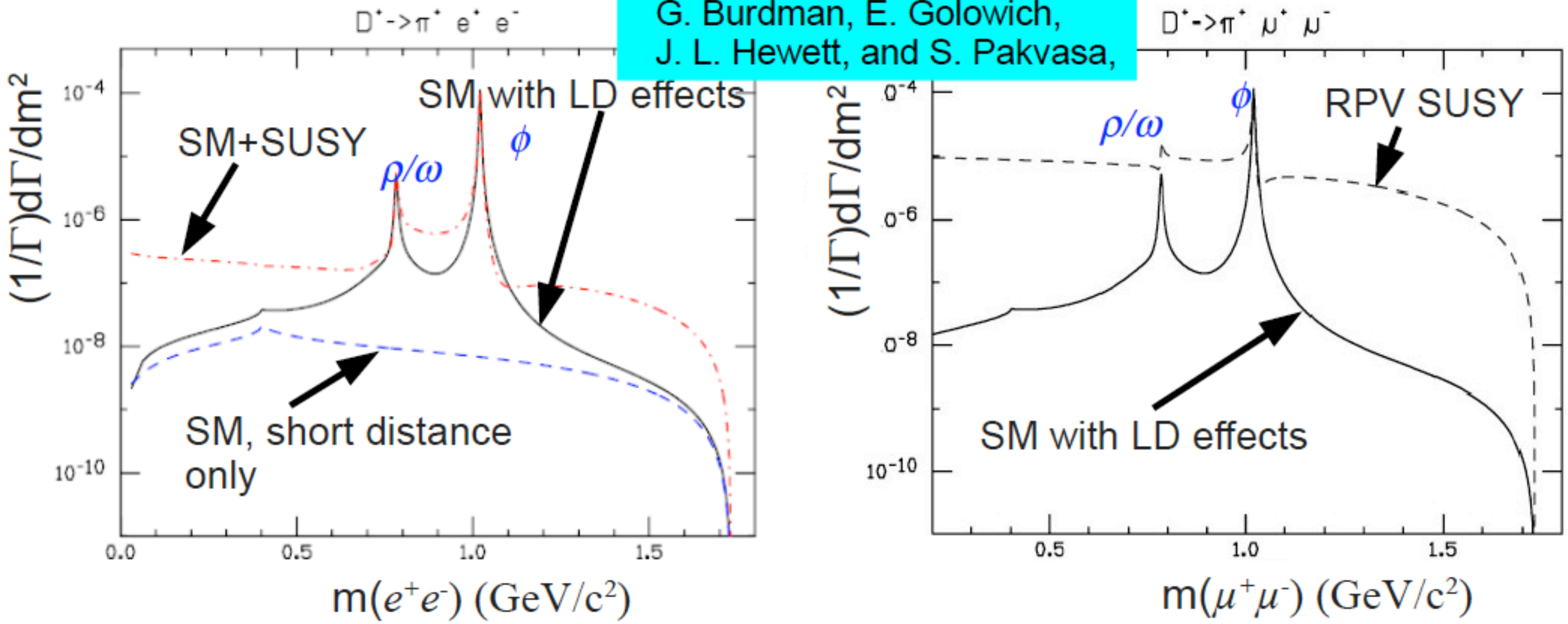
Some models increase BF($c \to ull$) to 10^{-6}–10^{-5}

Also look for exotic decays violating lepton flavor and/or lepton number

Standard Model predictions for signal and bkg

- While FCNC predicted to be low in SM, do have contribution from leptonic decays of intermediate resonances in $D_{(s)}^+ \to h^+ V,\ V \to l^+ l^-$

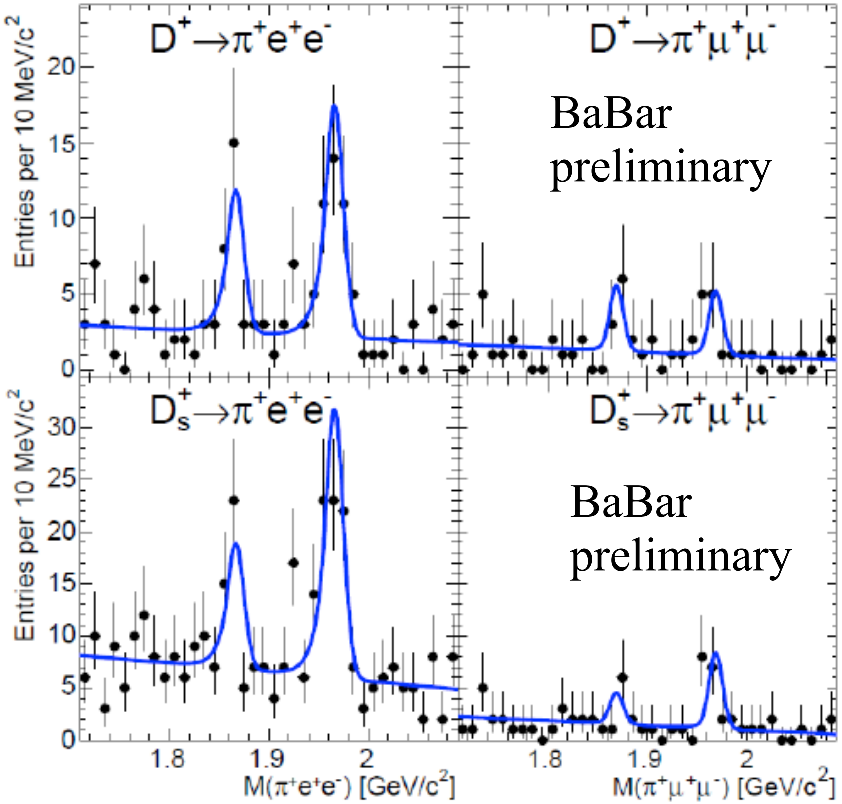
PRD 66, 014009 (2002)
G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa,



At current sensitivity, only ϕ resonance contributes
Can be removed by cut on l^+l^- invariant mass

Validating the analysis using control modes

- Before unblinding, checked procedure using ϕ resonance
  - Reverse l^+l^- mass cut:
    $0.995 < m(e^+e^-) < 1.030$ GeV/c^2
    $1.005 < m(\mu^+\mu^-) < 1.030$ GeV/c^2
- Significant signal seen in 3 of 4 modes
- Yield is about as expected
  - 1.5σ low in $D_s^+ \to \pi\phi$, $\phi \to e^+e^-$



388 fb^{-1}

Decay mode	Yield (events)	Efficiency (%)	Expected yield (events)
$D^+ \to \pi^+\phi_{e^+e^-}$	$21.8 \pm 5.8 \pm 1.5$	5.65	22.2 ± 1.1
$D^+ \to \pi^+\phi_{\mu^+\mu^-}$	$7.5 \pm 3.4 \pm 1.4$	1.11	4.5 ± 0.4
$D_s^+ \to \pi^+\phi_{e^+e^-}$	$62.8 \pm 9.9 \pm 3.0$	6.46	79 ± 3
$D_s^+ \to \pi^+\phi_{\mu^+\mu^-}$	$12.7 \pm 4.3 \pm 2.6$	1.07	13.1 ± 1.2

Fit results and comparison with previous limits

- Most channels improve upon previous limits
  - Many modes by more than order of magnitude
  - Dimuon modes have the worst limits (lowest efficiency)

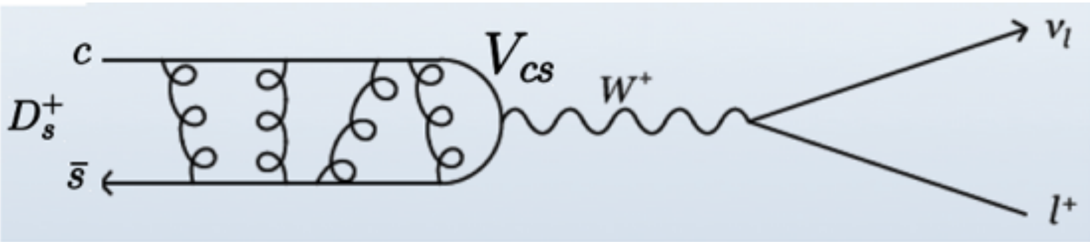
Decay mode	BF UL (10^{-6}) 90% CL		
$D^+ \to \pi^+ e^+ e^-$	1.1	5.9	CLEO-c
$D^+ \to \pi^+ \mu^+ \mu^-$	6.5	3.9	D0
$D^+ \to \pi^+ e^+ \mu^-$	2.9	34	E791
$D^+ \to \pi^+ \mu^+ e^-$	3.6	34	E791
$D_s^+ \to \pi^+ e^+ e^-$	13	22	CLEO-c
$D_s^+ \to \pi^+ \mu^+ \mu^-$	43	26	FOCUS
$D_s^+ \to \pi^+ e^+ \mu^-$	12	610	E791
$D_s^+ \to \pi^+ \mu^+ e^-$	20	610	E791
$D^+ \to K^+ e^+ e^-$	1.0	3.0	CLEO-c
$D^+ \to K^+ \mu^+ \mu^-$	4.3	9.2	FOCUS
$D^+ \to K^+ e^+ \mu^-$	1.2	68	E791
$D^+ \to K^+ \mu^+ e^-$	2.8	68	E791
$D_s^+ \to K^+ e^+ e^-$	3.7	52	CLEO-c
$D_s^+ \to K^+ \mu^+ \mu^-$	21	36	FOCUS
$D_s^+ \to K^+ e^+ \mu^-$	14	630	E791
$D_s^+ \to K^+ \mu^+ e^-$	9.7	630	E791
$\Lambda_c^+ \to p e^+ e^-$	5.5	340	E653
$\Lambda_c^+ \to p \mu^+ \mu^-$	44	New results	
$\Lambda_c^+ \to p e^+ \mu^-$	9.9		
$\Lambda_c^+ \to p \mu^+ e^-$	19		

Decay mode	BF UL (10^{-6}) 90% CL		
$D^+ \to \pi^- e^+ e^+$	1.9	1.1	CLEO-c
$D^+ \to \pi^- \mu^+ \mu^+$	2.0	4.8	FOCUS
$D^+ \to \pi^- \mu^+ e^+$	2.0	50	E791
$D_s^+ \to \pi^- e^+ e^+$	4.1	18	CLEO-c
$D_s^+ \to \pi^- \mu^+ \mu^+$	14	29	FOCUS
$D_s^+ \to \pi^- \mu^+ e^+$	8.4	730	E791
$D^+ \to K^- e^+ e^+$	0.9	3.5	CLEO-c
$D^+ \to K^- \mu^+ \mu^+$	10	13	FOCUS
$D^+ \to K^- \mu^+ e^+$	1.9	130	E687
$D_s^+ \to K^- e^+ e^+$	5.2	17	CLEO-c
$D_s^+ \to K^- \mu^+ \mu^+$	13	13	FOCUS
$D_s^+ \to K^- \mu^+ e^+$	6.1	680	E791
$\Lambda_c^+ \to \overline{p} e^+ e^+$	2.7	New results	
$\Lambda_c^+ \to \overline{p} \mu^+ \mu^+$	9.4		
$\Lambda_c^+ \to \overline{p} \mu^+ e^+$	16		

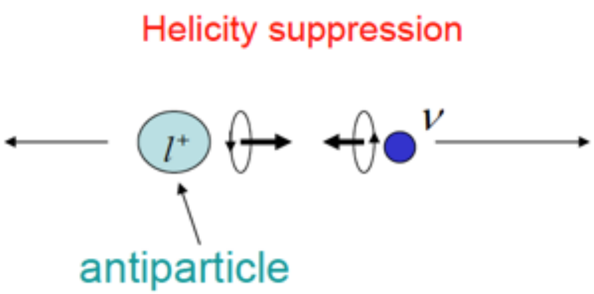
BaBar preliminary 388 fb^{-1}

New Limits approach theoretically interesting region

Measurement of the decay constant f_{D_s} with $D_s^+ \to l^+ \nu$ decays



$$\Gamma = \frac{G_F^2 M_{D_s^+}^3}{8\pi} \left(\frac{m_\ell}{M_{D_s^+}} \right)^2 \left(1 - \frac{m_\ell^2}{M_{D_s^+}^2} \right)^2 |V_{cs}|^2 f_{D_s}^2$$



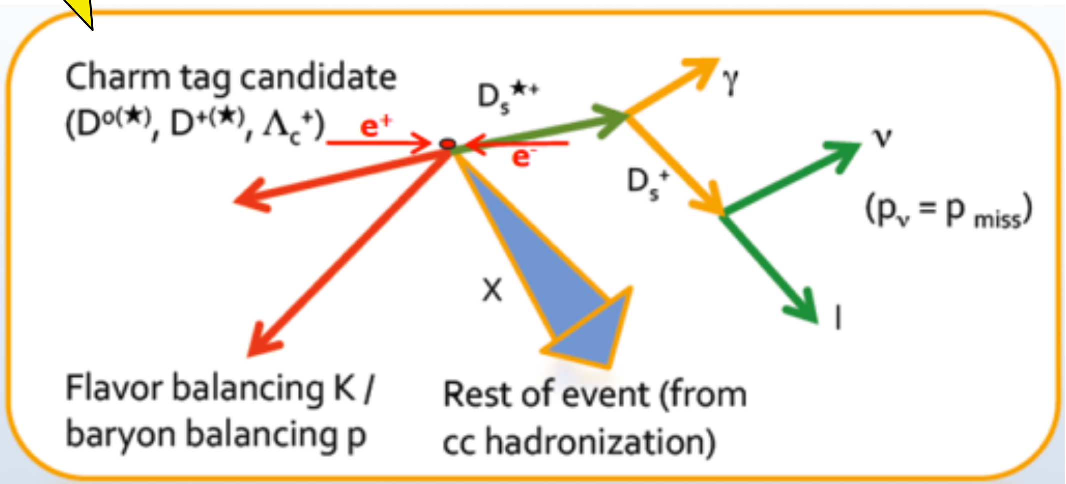
- Clean measurement of the decay constant f_{D_s};
- Test of LQCD predictions;
- Test of New Physics models.

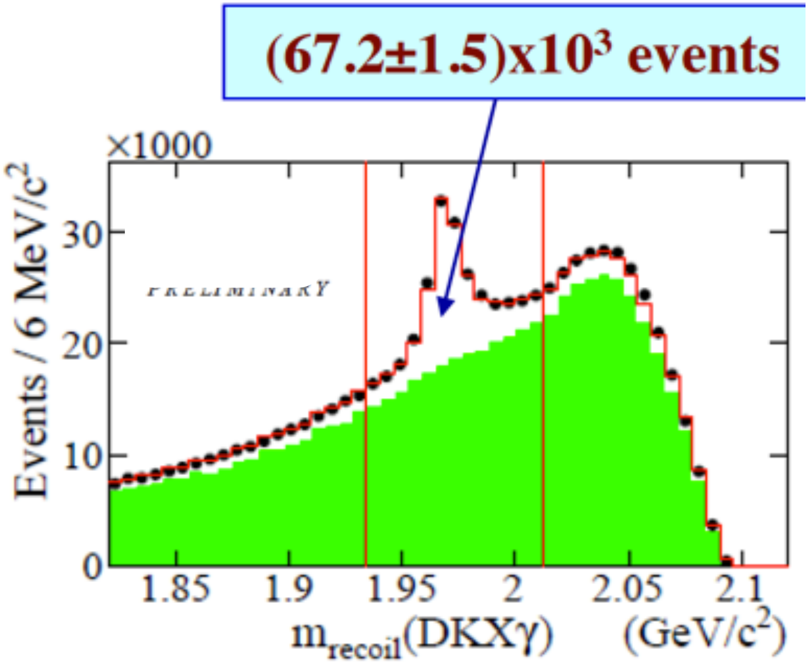
Measurement of $D_s^+ \to l^+ \nu$ and f_{Ds}

Phys. Rev. D 82, 091103(R) (2010) 521 fb^{-1}

New Technique

Absolute decay rate measurement with full reconstruction of the event





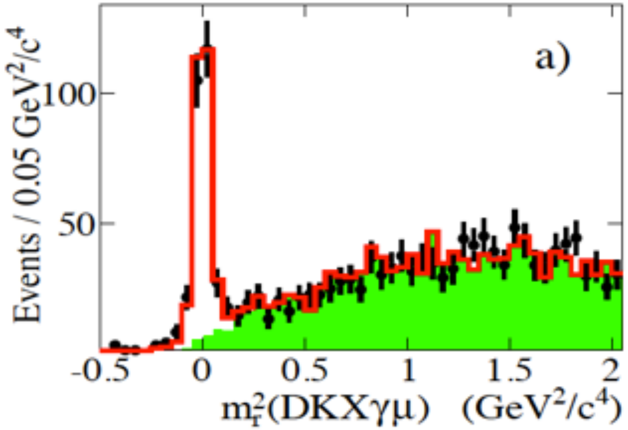
- **Inclusive D_s candidates**
  - **The signal consists of D_s* candidates decaying to $D_s\gamma$**
  - **The D_s candidate is reconstructed from the four-momentum recoiling against the DKXγ ($D = D^{0(*)}, D^{+(*)}, \Lambda_c^+$; $K = K_s, K^+$,(p); $X = \pi^+, \pi^0$)**
- **Within this sample, the $D_s^+ \to \ell^+ \nu_\ell$ ($\ell = e, \mu, \tau$) events are selected**
  - **One more track, identified as e/μ, is required**

Measurement of $D_s^+ \to l^+\nu$ and f_{D_s}

Phys. Rev. D 82, 091103(R) (2010) 521 fb^{-1}

$D_s^- \to \mu^- \bar{\nu}_\mu$

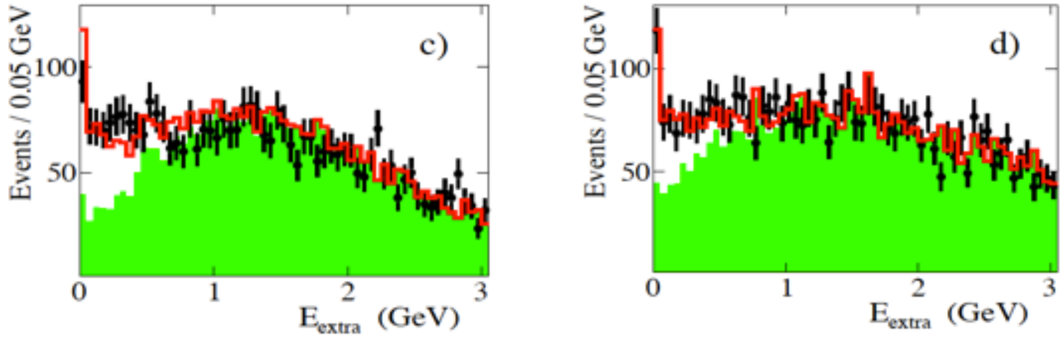
275 ± 17 events



neutrino missing mass squared

$D_s^- \to \tau^- \bar{\nu}_\tau \ (\tau^- \to e^- \bar{\nu}_e \nu_\tau)$ $\quad$ $D_s^- \to \tau^- \bar{\nu}_\tau \ (\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)$

408 ± 42 events $\quad$ 340 ± 32 events



Extra energy in the EM calorimeter has to be compatible with neutrino deposit

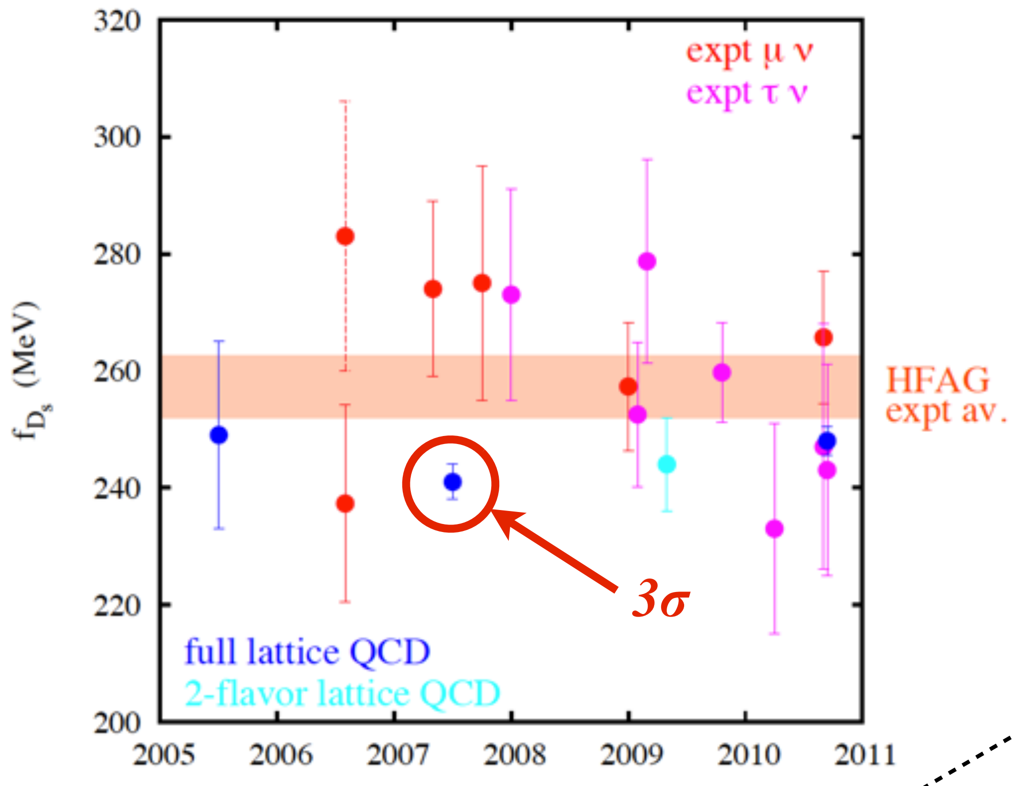
$$f_{D_s} = (258.6 \pm 6.4(stat) \pm 7.5(syst))\ \text{MeV}$$

By-product of the analysis $BR(D_s^- \to K^- K^+ \pi^-) = (5.78 \pm 0.20 \pm 0.30)\%$

Consistent with CLEO-c result $(5.50 \pm 0.23 \pm 0.16)\%$ ***Phys. Rev. Lett. 100, 161804 (2008)***

f(D_s) puzzle solved!

History of f(D_s) determination

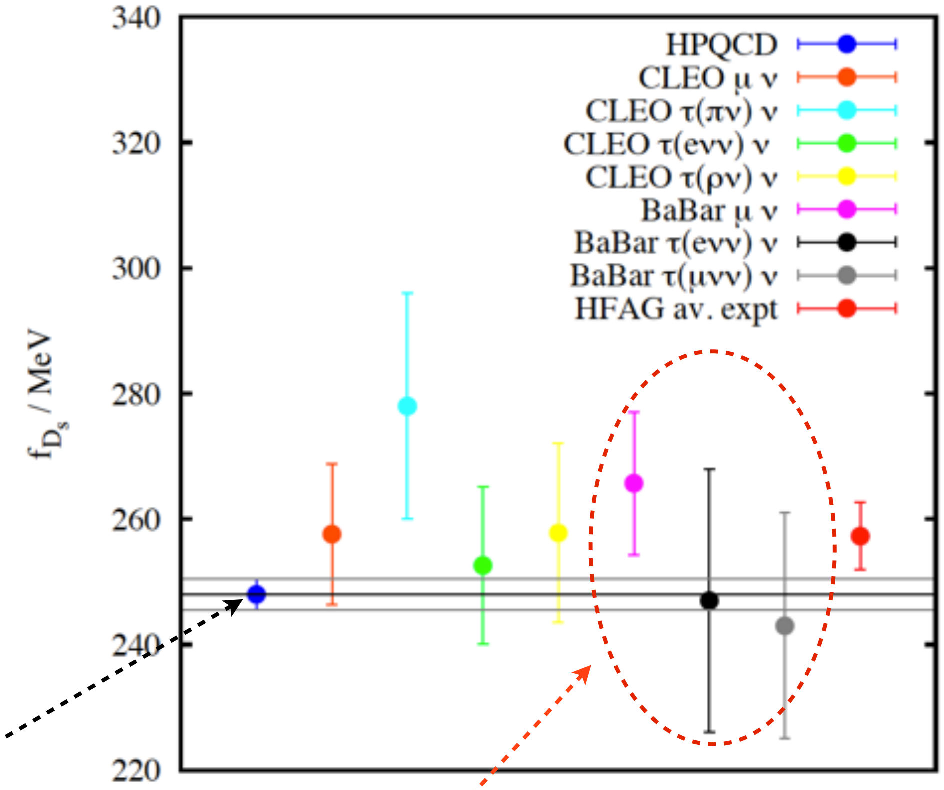


HPQCD f(D_s) = 248.0±2.5 MeV

Phys.Rev.D82:114504,2010

LQCD and experiments now agree!

1.6σ difference

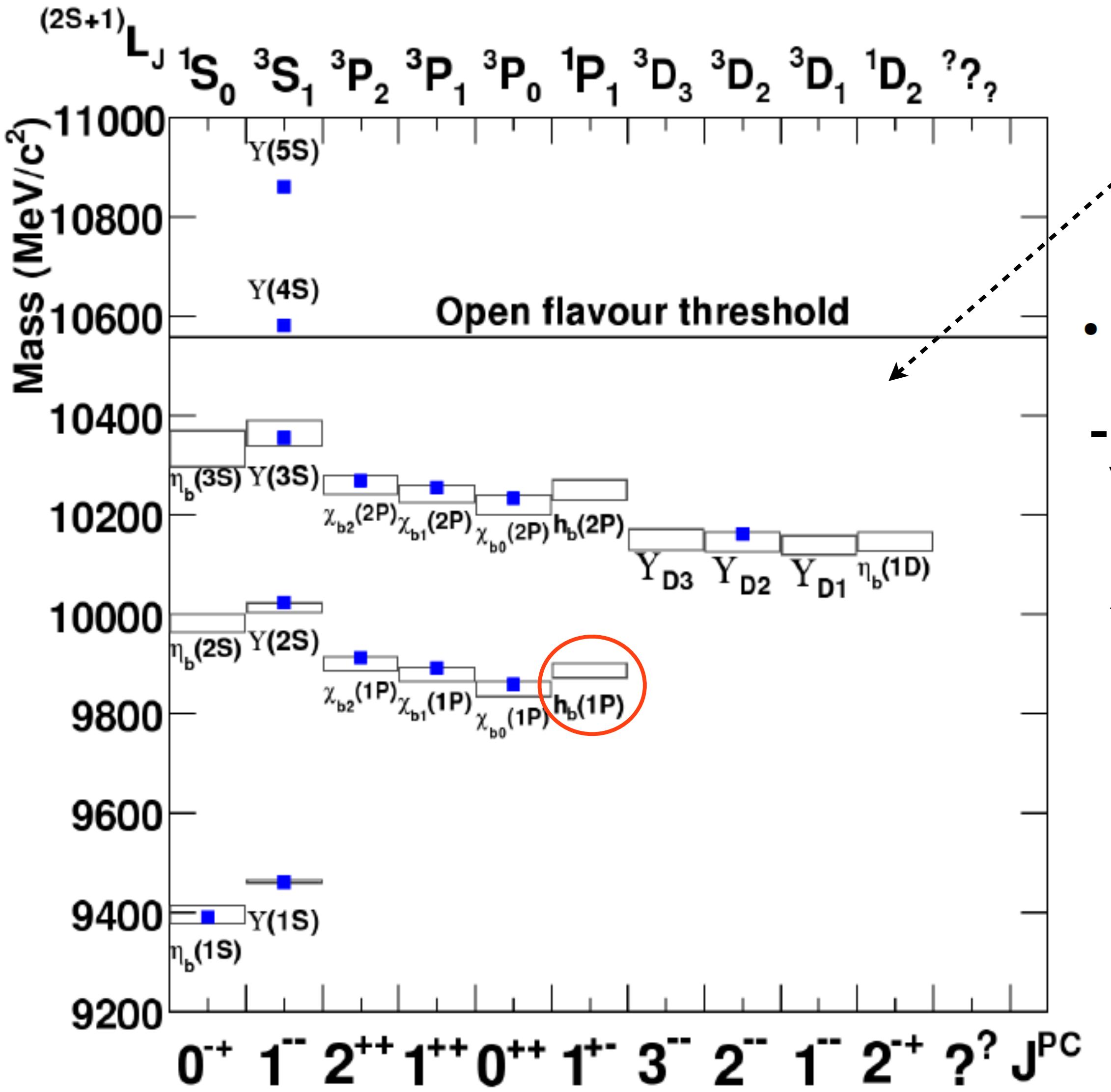


HFAG f(D_s) = 257.3±5.3 MeV
BaBar f(D_s) = 258.6±6.4±7.5 MeV

Phys.Rev.D82:091103,2010.

Recent results: Spectroscopy

Bottomonium: search for $h_b(1P)$



established states

- Searched by CLEO in $\Upsilon(3S) \to \pi^0/\pi^+\pi^- h_b$

-Discriminate among potential models
Validate LQCD and pNRQCD calculations

Spin singlet partner of $\chi_{bJ}(1P)$

Narrow state (0.1 MeV)

$M_{th} \sim \chi_{bJ}(1P)$

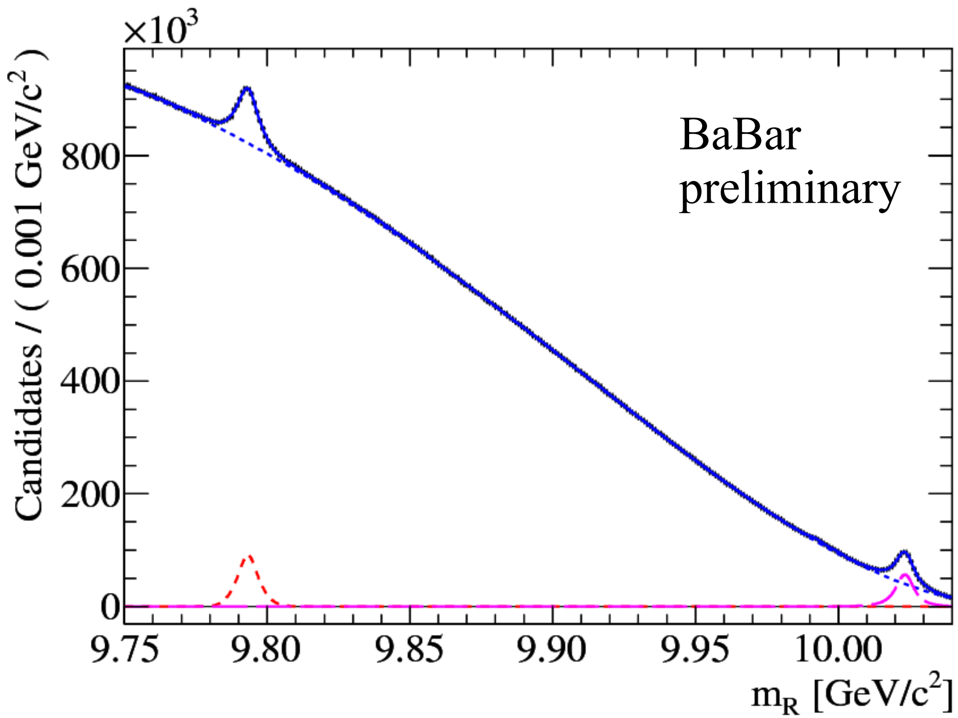
center of gravity = 9900 MeV/c^2

splitting < O(3MeV)

Dipion Recoil in $\Upsilon(3S)$

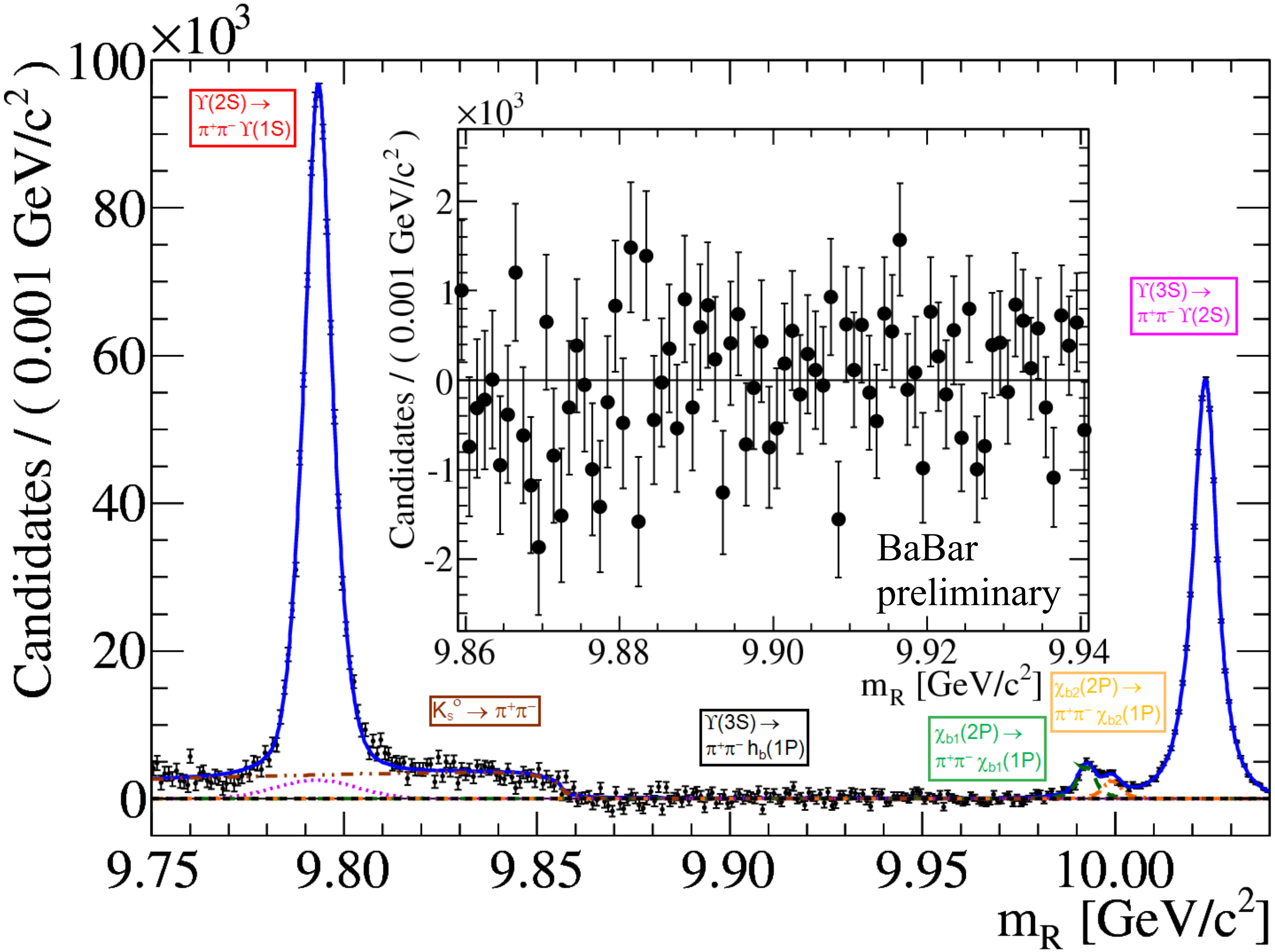
arXiv:1105.4234 [hep-ex]
Submitted to PRD (RC)
108 M $\Upsilon(3S)$ events

- Analysis goal: search for $Y(3S) \rightarrow \pi^+\pi^- h_b(1P)$
- Procedure
  - Reconstruct pair of oppositely charged tracks
  - Cuts on E_{total}, R_2, N_{tracks}, K_S^o veto (flight length, cos α)
  - Define $\pi^+\pi^-$ recoil mass: $m_R^2 = (m_{\Upsilon(3S)} - E^*_{\pi^+\pi^-})^2 - |P^*_{\pi^+\pi^-}|^2$
  - χ^2 fit to m_R
- Peaking components
  - $\Upsilon(3S) \rightarrow \pi^+\pi^- h_b$ signal
  - $\Upsilon(3S) \rightarrow \pi^+\pi^- \Upsilon(2S)$
  - $\Upsilon(2S) \rightarrow \pi^+\pi^- \Upsilon(1S)$
  - $\chi_{b1,2}(2P) \rightarrow \pi^+\pi^- \chi_{b1,2}(1P)$
- Smooth backgrounds
  - $K_S^o \rightarrow \pi^+\pi^-$
  - Non-peaking background



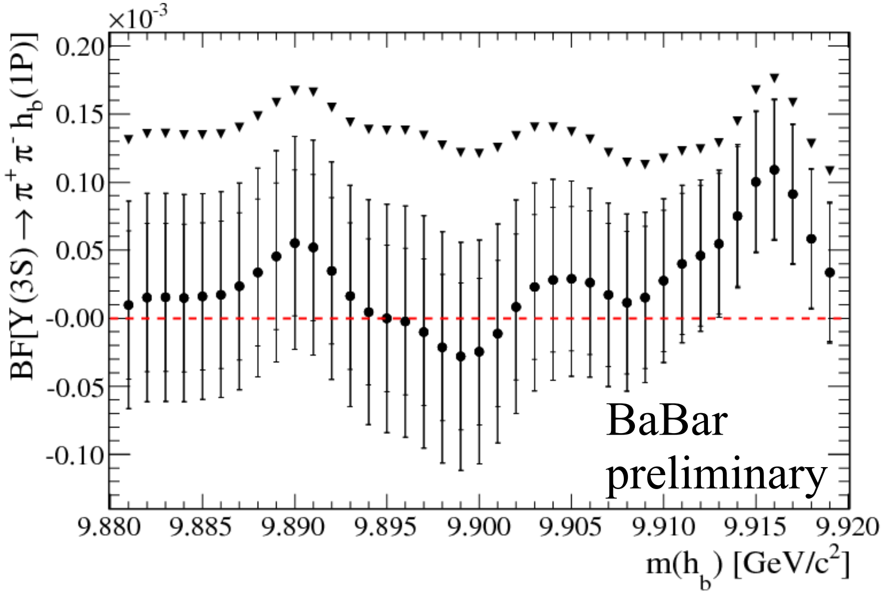
Dipion Recoil Fit Result

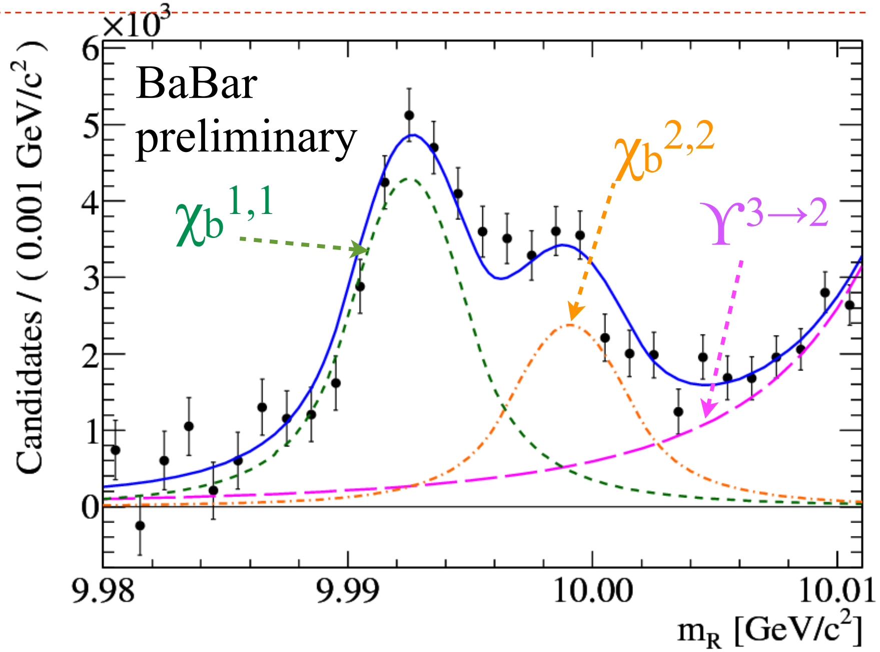
arXiv:1105.4234 [hep-ex]
Submitted to PRD (RC)
108 M Υ(3S) events



Dipion Recoil Summary

arXiv:1105.4234 [hep-ex]
Submitted to PRD (RC)
108 M $\Upsilon(3S)$ events





- No evidence for h_b: $B(\Upsilon(3S) \to \pi^+\pi^- h_b(1P)) < 1.8 \times 10^{-4}$
- Precision measurements

arXiv:1105.4234 [hep-ex]
Submitted to PRD (RC)
108 M $\Upsilon(3S)$ events

$$\mathcal{B}[\Upsilon(3S) \to \pi^+\pi^-\Upsilon(2S)] = (3.00 \pm 0.02(\text{stat.}) \pm 0.14(\text{syst.}))\%$$

$$\mathcal{B}[\chi_{b1}(2P) \to \pi^+\pi^-\chi_{b1}] = (9.2 \pm 0.6 \pm 0.9) \times 10^{-3}$$

$$\mathcal{B}[\chi_{b2}(2P) \to \pi^+\pi^-\chi_{b2}] = (4.9 \pm 0.4 \pm 0.6) \times 10^{-3}$$

$$\mathcal{B}[\Upsilon(3S) \to X\Upsilon(2S)] \times \mathcal{B}[\Upsilon(2S) \to \pi^+\pi^-\Upsilon] = (1.78 \pm 0.02 \pm 0.11)\%$$

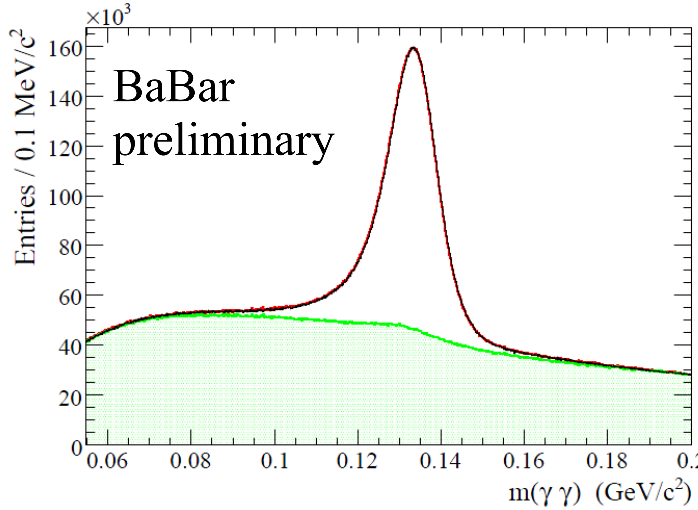
$$\Delta m[\Upsilon(3S)\text{-}\Upsilon(2S)] = 331.50 \pm 0.02(\text{stat.}) \pm 0.13(\text{syst.})\ \text{MeV}/c^2$$

Search for $h_b(1P)$ in $\Upsilon(3S)\rightarrow\pi^0 h_b(1P)(\gamma\,\eta_b(1S))$ decays

arXiv:1102.4565 [hep-ex]
Submitted to PRD (RC)
122 M $\Upsilon(3S)$ events

- Analysis Strategy
- Reconstruct $\pi^0(\gamma_1\gamma_2) + \gamma$
- Require E_γ consistent with $h_b(1P) \rightarrow \gamma\eta_b(1S)$
- Cuts on N_{tracks}, R_2, π^0 veto (all γ candidates), π^0 $\cos\theta_h$

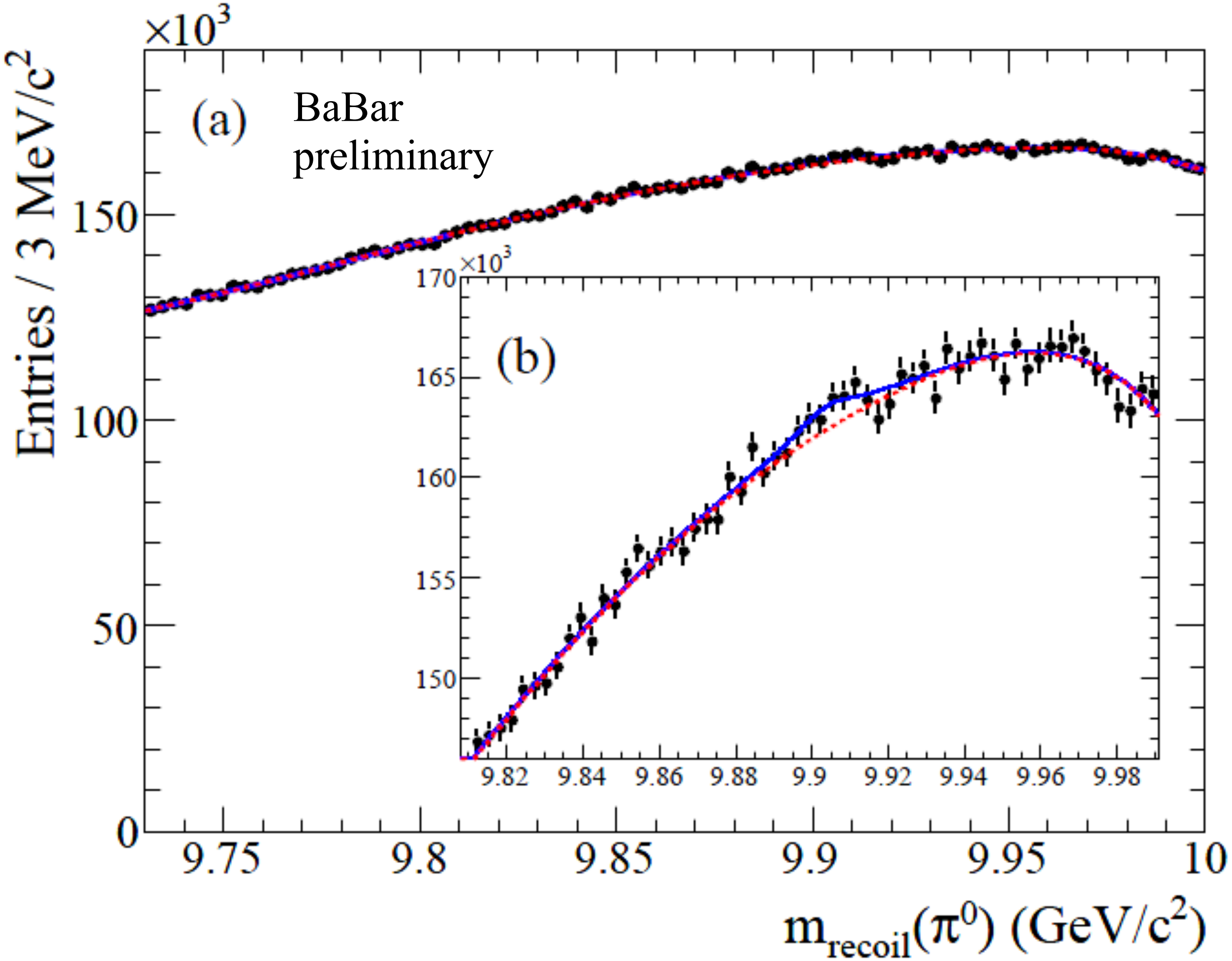
- Define π^0 missing mass: $m_{recoil}(\pi^0)^2 = \sqrt{[(m_{\Upsilon(3S)} - E^*_{\pi^0})^2 - P^{*2}_{\pi^0}]}$
- Constrain m_{π^0} to improve resolution
- N_{π^0} from $m_{\gamma_1\gamma_2}$ fit in each $m_{recoil}(\pi^0)$ bin



- χ^2 fit of $m_{recoil}(\pi^0)$ distribution
- $h_b(1P)$ signal: Double Crystal Ball
- Background: 6^{th} order polynomial, from reweighted MC

$\Upsilon(3S)\to\pi^0 h_b(1P)(\gamma\,\eta_b(1S))$ Results

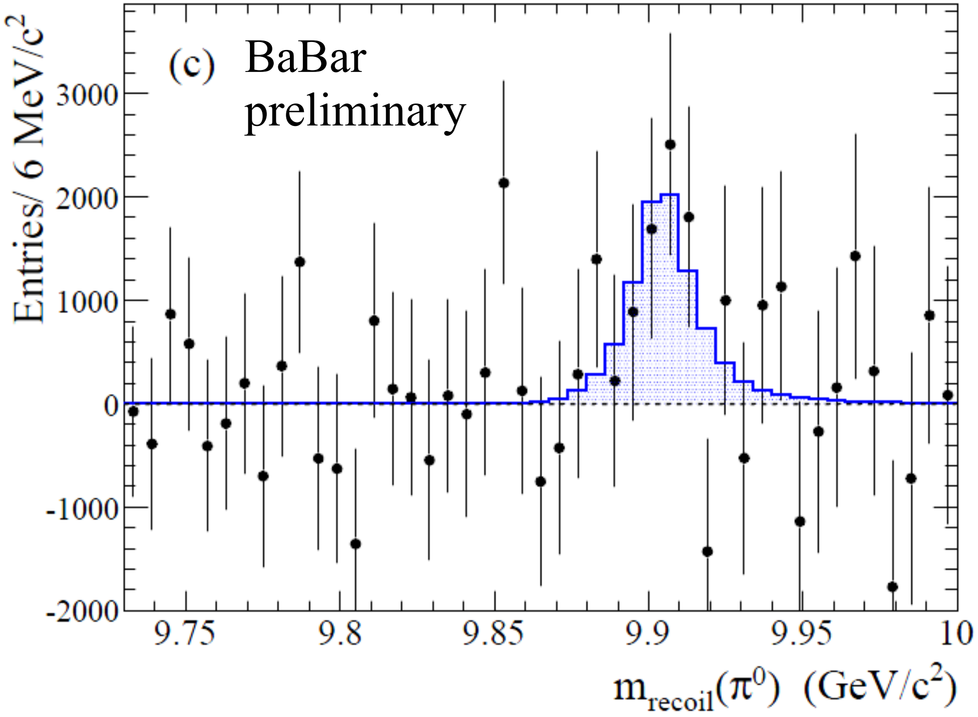
***arXiv:1102.4565** [hep-ex]*
Submitted to PRD (RC)
122 M $\Upsilon(3S)$ events



Evidence for $h_b(1P)$

arXiv:1102.4565 [hep-ex]
Submitted to PRD (RC)
122 M $\Upsilon(3S)$ events

Quantity	Value
Yield	9145±2804±1082 evts.
Significance	3.0 σ
M [$h_b(1P)$]	9902±4±1 MeV/c^2
BF($Y(3S)\to\pi^0 h_b$) x BF($h_b\to\gamma\eta_b$)	(3.7±1.1±0.7) x 10^{-4}



- Measured mass agrees with expectation
  - $m_{h_b(1P)} = (m_{\chi_{b0}(1P)} + 3m_{\chi_{b1}(1P)} + 5m_{\chi_{b2}(1P)}) / 9 \approx 9900$ MeV/c^2

Spin weighted average value.

- Branching fraction consistent with theory

- First evidence for $h_b(1P)$, confirmed by Belle

Study of $\gamma\gamma \to K^+K^-\pi^+\pi^-\pi^0$ and $\gamma\gamma \to K^0_S K\pi$ decays

- Search for $\eta_c(2S) \to K^+K^-\pi^+\pi^-\pi^0$, $K^0_S K\pi$ in two-photon "no tag" events.
- Precision measurement of $\eta_c(2S)$ mass.
- World average width measurement has 50% uncertainty.

($520\ fb^{-1}$)

arXiv:1103.3971
Accepted by PRD

Undetected electron and positron: quasi-real photons (q^2~0) allows:

$J^P = 0^+, 0^-, 2^+, 2^-, 3^+, 4^-, 4^+ \ldots$

[Yang, Phys. Rev. 77, 242 (1950)]

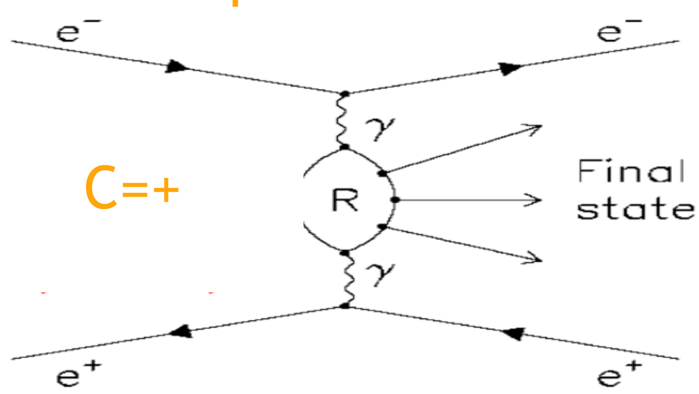
$J > 2$ is phase space suppressed.

Clear experimental signatures:

- Few charged-particle tracks in each event;
- Limited activity in the calorimeter.

Two-photon Fusion

C=+



Analysis technique

- Main background sources:

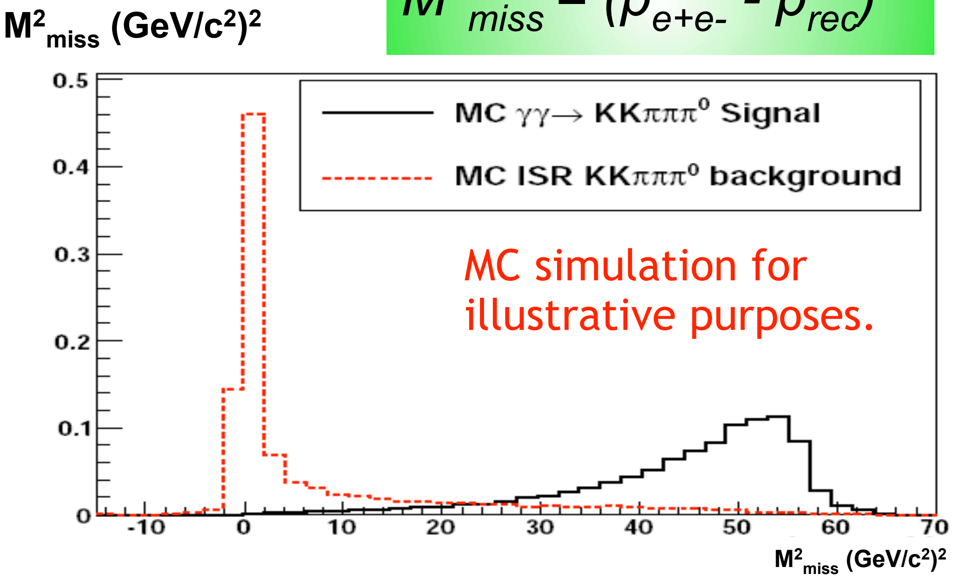
(1) $e^+e^- \rightarrow qq$ ($q = u, d, s, c$), $e^+e^- \rightarrow \Upsilon(nS)$:
suppressed requiring total final state transverse momentum $p_T < 0.15$ GeV/c;

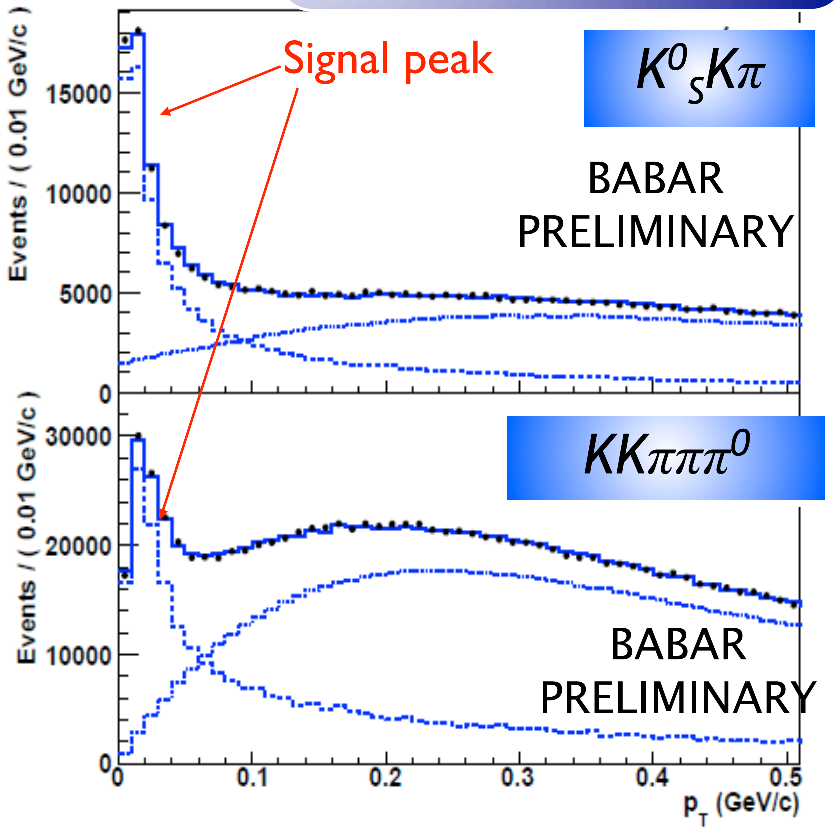
(2) ISR events with J/ψ or $\psi(2S)$ production:
suppressed requiring high missing mass M^2_{miss}.

(520 fb^{-1})

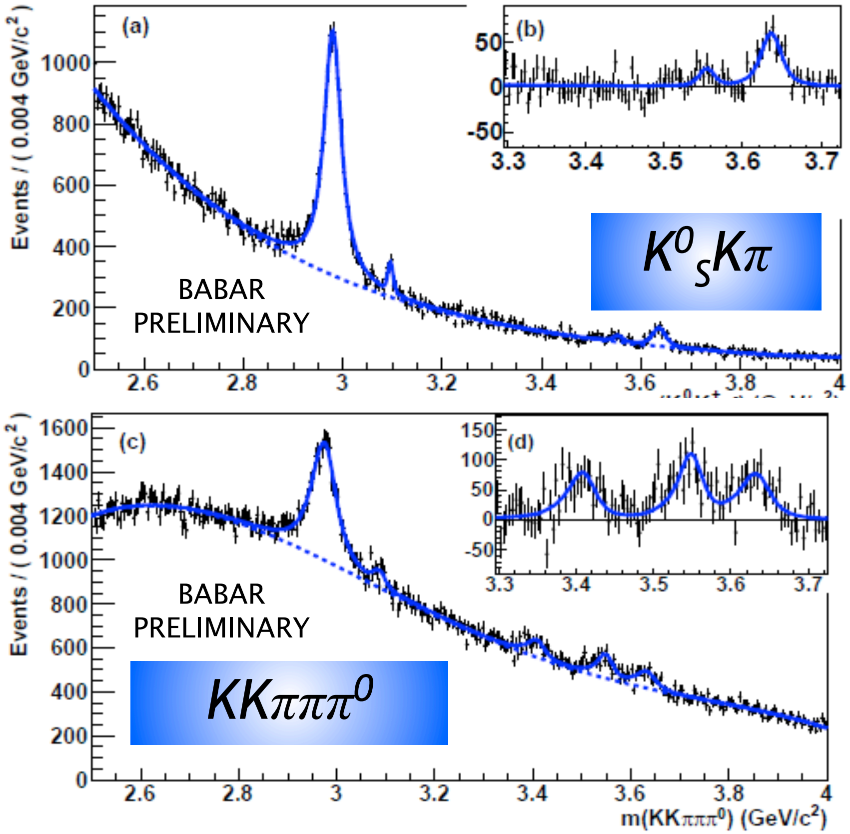
arXiv:1103.3971
Accepted by PRD

$$M^2_{miss} = (p_{e+e-} - p_{rec})^2$$





Results



arXiv:1103.3971
Accepted by PRD

(520 fb^{-1})

$$m(\eta_c(2S)) = 3638.5 \pm 1.5 \pm 0.8 \text{ MeV}/c^2$$

$$\Gamma(\eta_c(2S)) = 13.4 \pm 4.6 \pm 3.2 \text{ MeV}$$

Measurement more precise than the world average

Process	$\Gamma_{\gamma\gamma} \times \mathcal{B}$ (keV)
$\eta_c(1S) \to K\overline{K}\pi$	$0.386 \pm 0.008 \pm 0.021$
$\chi_{c2}(1P) \to K\overline{K}\pi$	$(1.8 \pm 0.5 \pm 0.2) \times 10^{-3}$
$\eta_c(2S) \to K\overline{K}\pi$	$0.041 \pm 0.004 \pm 0.006$
$\chi_{c2}(2P) \to K\overline{K}\pi$	$< 2.1 \times 10^{-3}$
$\eta_c(1S) \to K^+K^-\pi^+\pi^-\pi^0$	$0.190 \pm 0.006 \pm 0.028$
$\chi_{c0}(1P) \to K^+K^-\pi^+\pi^-\pi^0$	$0.026 \pm 0.004 \pm 0.004$
$\chi_{c2}(1P) \to K^+K^-\pi^+\pi^-\pi^0$	$(6.5 \pm 0.9 \pm 1.5) \times 10^{-3}$
$\eta_c(2S) \to K^+K^-\pi^+\pi^-\pi^0$	$0.030 \pm 0.006 \pm 0.005$
$\chi_{c2}(2P) \to K^+K^-\pi^+\pi^-\pi^0$	$< 3.4 \times 10^{-3}$

$\eta_c(2S) \to KK\pi\pi\pi^0$ observed with 5.3σ significance

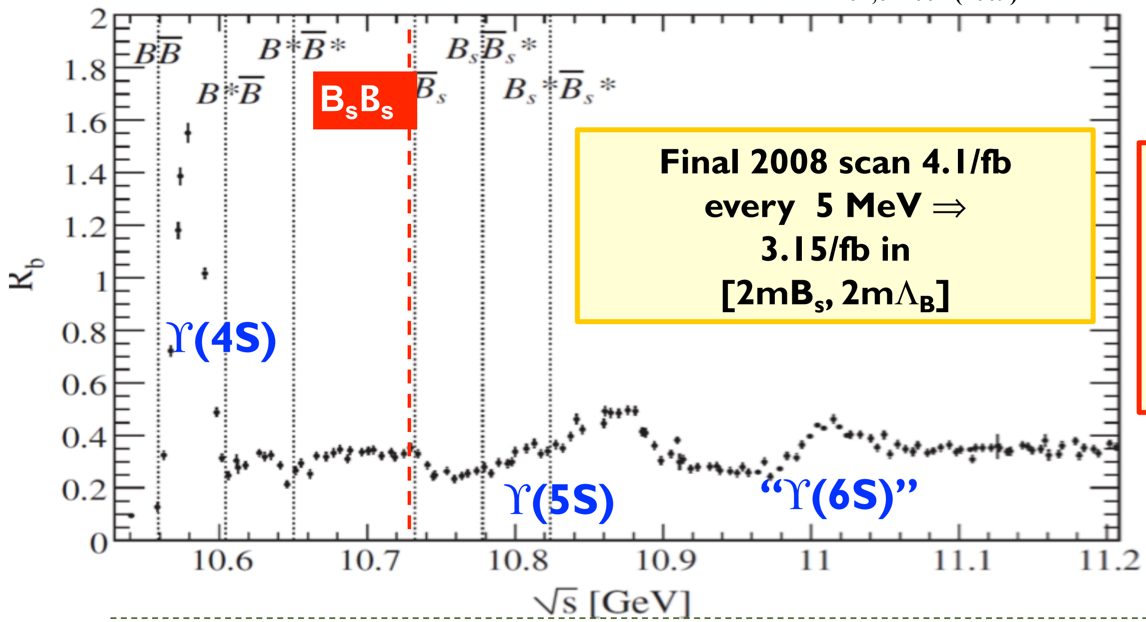
Recent results:
Studies of B_s and B decays

BR($B_s \to X\, l\, \nu_l$) & B_s fraction: f_s above $\Upsilon(4S)$

- **semi-leptonic $B_{u,d}$: BR($B_{u,d} \to X\, l\, \nu_l$)=(10.99-10.33±0.28)% well-known**
- **Semi-leptonic B_s: BR($B_s \to X\, l\, \nu_l$) not well-known**
  - **(7.9±2.4)%** (PDG from LEP@Z^0 includes P($b \to B_s$)=(10.5±0.9)%)
  - **(10.2±0.8±0.9)%** (Belle unpublished arXiv:0710.2548)
  - **LHCb measures ratios** of semi-exclusive decays to total inclusive (arXiv:1102.0348): BR($B_s \to (D_{s2}^*/D_{s1})^+ X\mu\nu_\mu$) / BR($B_s \to X\mu\nu_\mu$)

⇒**Use the 4.1 fb^{-1} scan above $\Upsilon(4S)$ ((25.500±6200) $B_s^{(*)}B_s^{(*)}$) to measure both the inclusive semi-leptonic BR_{sl} and the B_s production rate f_s**

PRL 102,012001 (2009)



➔Inclusive yields of ϕ mesons & ϕ+lepton are more abundant in B_s decays : used here to measure B_{sl} and f_s.

**Here results only (details in Lake Louise Winter Institute 2011 talk by B. Hamiton)*

BR($B_s \to X\, l\, \nu_l$) & B_s fraction: f_s above $\Upsilon(4S)$

➔ **Measure number of events as a function of CM energy:**

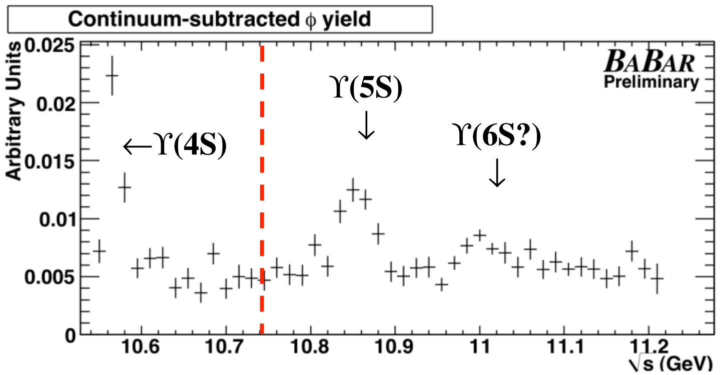
- **B-Hadron events =** $R_b\left[f_s\epsilon_{1s} + (1-f_s)\epsilon_1\right]$
- **Inclusive ϕ rate =** $R_b\left[f_s P(B_s\bar{B}_s \to \phi X)\epsilon_{2s} + (1-f_s)P(B\bar{B} \to \phi X)\epsilon_2\right]$
- **ϕ rate in correlation with a high-momentum lepton =**

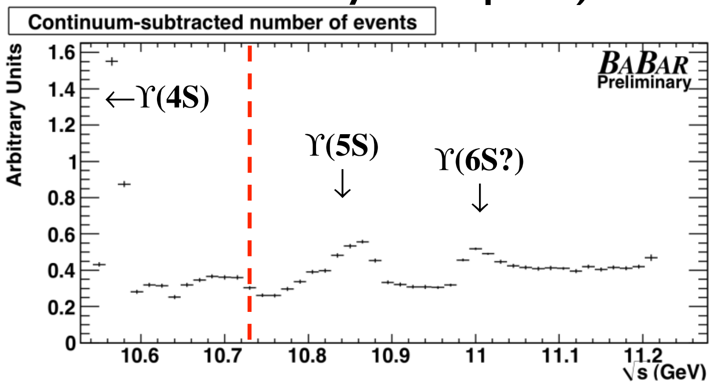
$$R_b\left[f_s P(B_s\bar{B}_s \to \phi\ell\nu X)\epsilon_{3s} + (1-f_s)P(B\bar{B} \to \phi\ell\nu X)\epsilon_3\right]$$

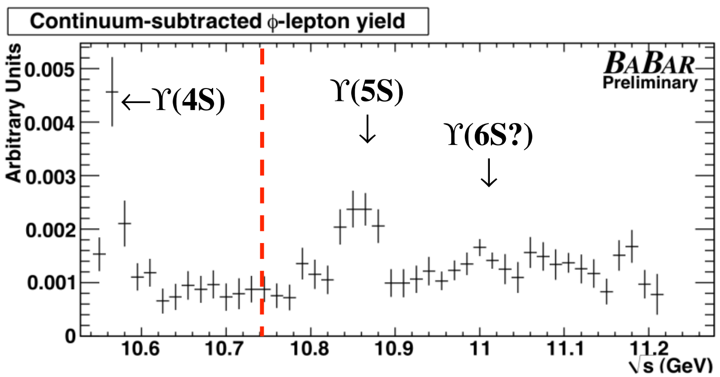
➔ **Subtract light $q\bar{q}$** (q=u,d,s,c) **continuum from off-peak Υ(4S) and account for $B_{u,d}$ contributions from Υ(4S) data**

➔ **B_s contributions depend on:**

BR($B_s \to D_s X_i$) (PDG BR=(93±25)%), BR($B_s \to l\nu_l X_j$),
BR($D_s \to l\nu_l X_k$) (PDG), BR($D_s \to \phi X_l$) (PDG),
BR($D_s \to \phi l\nu_l X_m$) (PDG) and others…
(⇒account for semi-leptonic AND secondary/fake leptons)



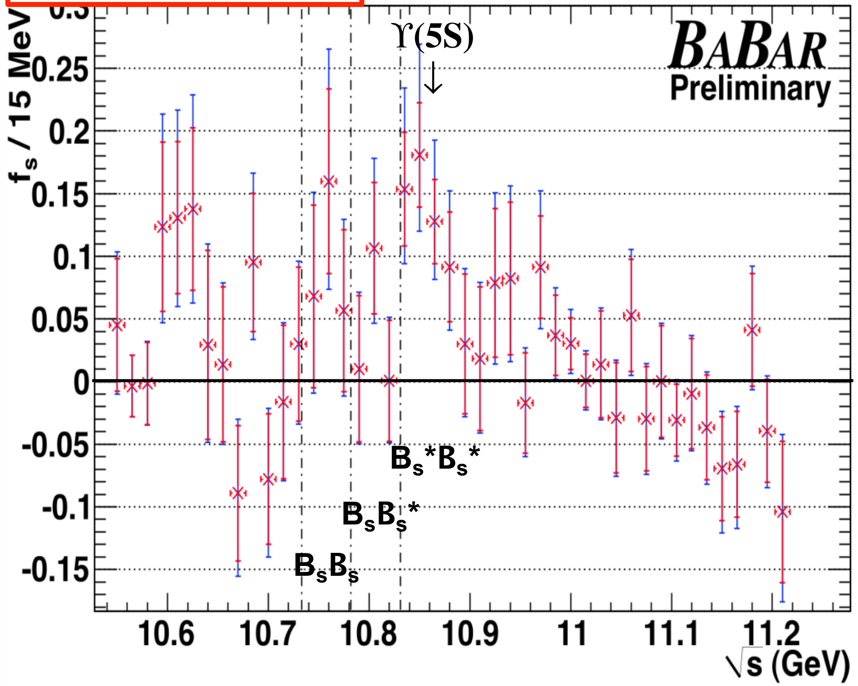




events yields/15 MeV bins

➔ extract B_s production fraction f_s at each CM energy point and perform a global χ^2 fit to the various yields to extract the semi-leptonic $BR(B_s \to X\, l\, \nu_l)$

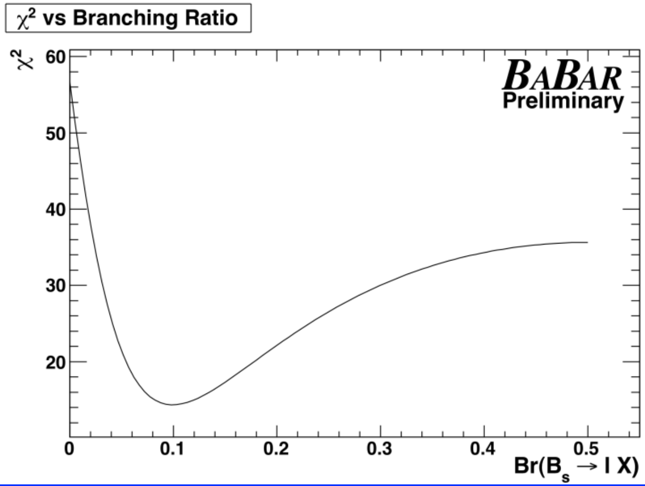
f_s / 15 MeV bins



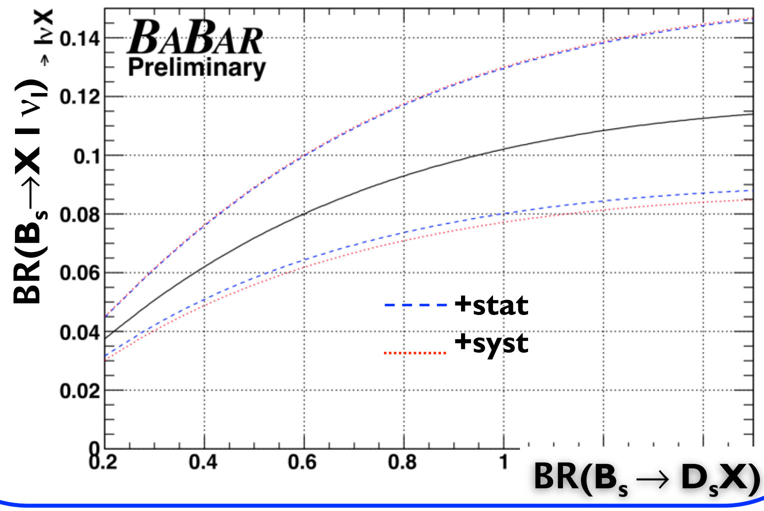
⇒ Bins near Υ(5S) consistent/previous ON peak results:

- **Belle: (19.3 ±2.9)%** PRD 76, 012002 (2007)
- **CLEO: (16.8 ±2.6)%** PRD 75, 012002 (2007)

+see theory : N.A. Törnqvist, PRL 53, 878 (1984)

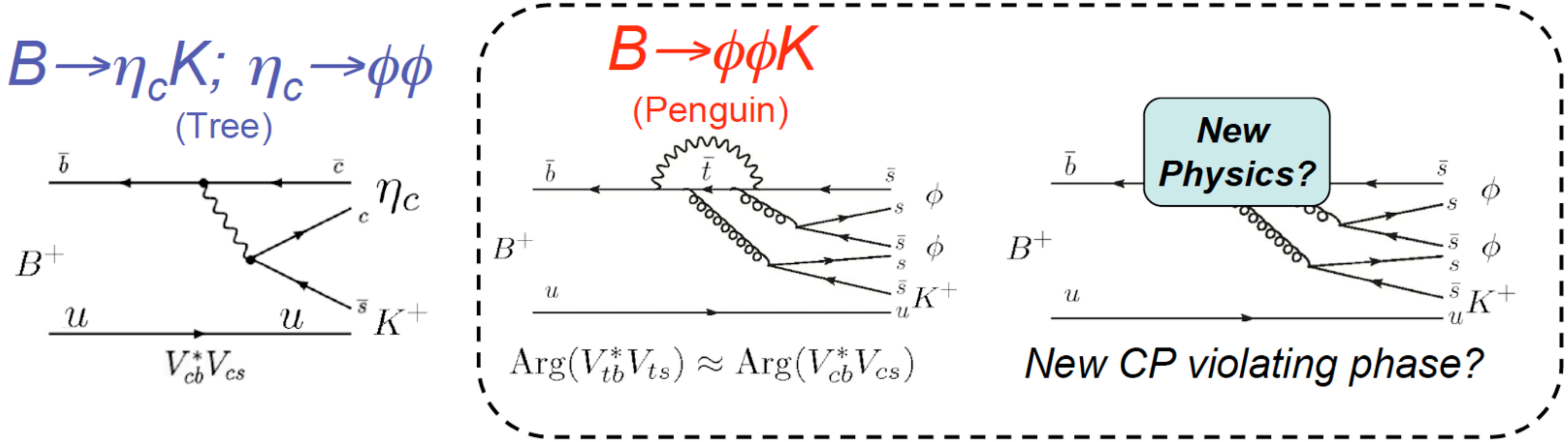


$$BR(B_s \to X\, l\, \nu_l) = (9.9^{+2.6}_{-2.1}\,(stat)^{+1.3}_{-2.0}\,(syst))\%$$



Search for CPV in B→φφK decays

- In the Standard Model, the tree and penguin amplitudes have the same weak phase, so *no direct CPV is expected*.



- Non-zero direct CP asymmetry would be a smoking gun for New Physics.
  - Could be as large as 40%! *(Haizumi, Phys. Lett.* ***B 583****, 285 (2004))*.

- Results based on 464M $B\bar{B}$ events Accepted for publication by PRD

⇒ Supersedes previous BABAR measurement PRL 97, 261803 (2006).

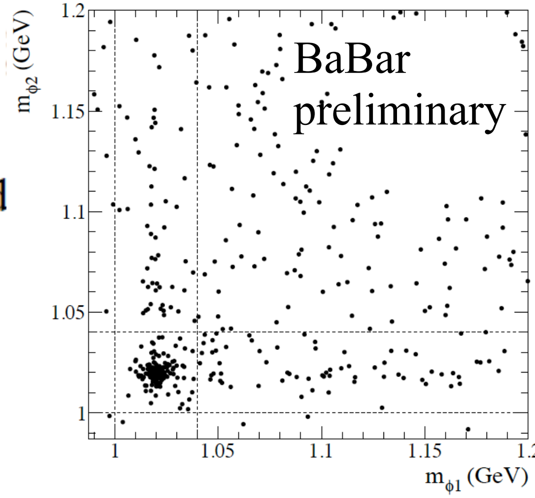
$B \to \phi\phi K$ results

Accepted by PRD

- Maximum likelihood (ML) fits using m_{ES}, ΔE, Fisher (and the 2 ϕ masses for BF)

- Use 5 zones in the $m_{\phi 2}$ vs. $m_{\phi 1}$ plane to distinguish final states with 5 kaons
  - $B \to 5K$ fits in the different zones
  - Use cross-zone fractions from MC to estimate peaking background

Signal-enhanced plot: cuts on m_{ES}, ΔE and F



- Branching fractions for $m_{\phi\phi} < 2.85$ GeV/c²:
  - **BF**$(B^+ \to \phi\phi K^+) = (5.6 \pm 0.5 \pm 0.3)\ 10^{-6}$
  - **BF**$(B^0 \to \phi\phi K^0) = (4.5 \pm 0.8 \pm 0.3)\ 10^{-6}$

First observation (>5σ)!

- Direct CPV
  - Below the η_c: $m_{\phi\phi} < 2.85$ GeV/c²

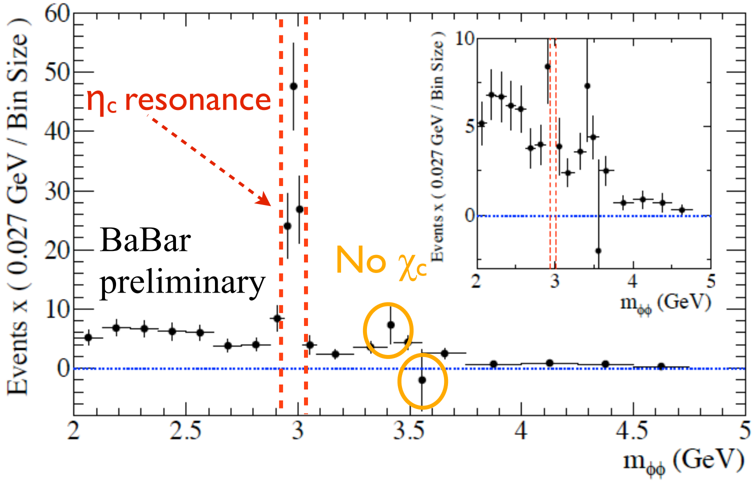
$A_{CP}(B^+ \to \phi\phi K^+) = -0.10 \pm 0.08 \pm 0.02$

  - In the η_c region: $2.94 < m_{\phi\phi} < 3.02$ GeV/c²

$A_{CP}(B^+ \to \phi\phi K^+) = -0.09 \pm 0.10 \pm 0.02$

$\Rightarrow$ *Both A_{CP} consistent with 0 & SM*

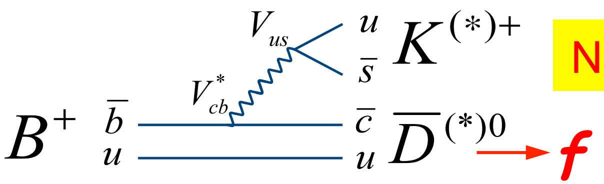
$B^+ \to \phi\phi K^+$ yield vs. $m_{\phi\phi}$



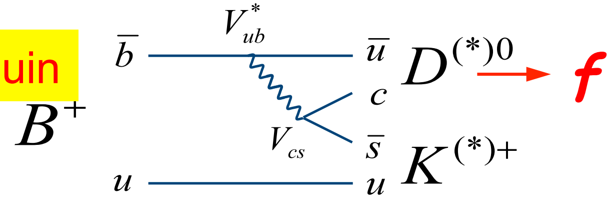
Search for b→u transitions in $B^- \to [K^+\pi^-\pi^0]_D K^-$ decays

arXiv:1104.4472 [hep-ex]
Accepted for publication by PRD
Results based on 474 M $B\overline{B}$ pairs

Extraction of γ from the interference of the decay amplitudes $b \to u\bar{c}s \ (\propto V_{ub})$ and $b \to c\bar{u}s$



No penguin



Color **favorite amplitude** b→c   Color **suppressed amplitude** b→u

$A \propto \lambda^3$
$\lambda = |V_{us}|$

$$a = A(B^+ \to \overline{D}^0 K^+) \propto V^*_{cb} V_{us}$$

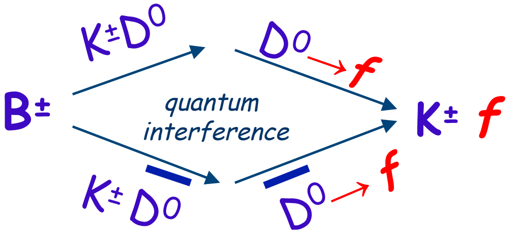
$$A(B^+ \to D^0 K^+) \propto V^*_{ub} V_{cs} = a r_B e^{i\delta_B} e^{i\gamma}$$

γ is here

δ_B: relative strong phase

Crucial parameter for sensitivity to γ:
(not precisely measured)

$$r_B = \frac{|A(B^+ \to D^0 K^+)|}{|A(B^+ \to \overline{D}^0 K^+)|} \approx \frac{|V_{ub}||V_{cs}|}{|V_{cb}||V_{us}|} \cdot f_{COL} \approx 0.10$$



f = *Three-body (Dalitz plot fit)*

f = *CP modes* ***$KK, \pi\pi, K_S\pi^0, K_S\omega, K_S\phi$*** *(GLW)*

f = *DCS* ***doubly-Cabibbo-suppressed decays*** *(ADS)*

ADS method

- The "ADS*" technique equalizes the magnitude of the interfering amplitudes

$B^- \to D^0 K^-$ favored $(b \to c)$	followed by	$D^0 \to K^+\pi^-\pi^0$ suppressed $(c \to d)$

interferes with

$B^- \to \bar{D}^0 K^-$ suppressed $(b \to u)$	followed by	$\bar{D}^0 \to K^+\pi^-\pi^0$ favored $(\bar{c} \to \bar{s})$

Opposite Sign event (OS) related to K charge. Suppressed transition.

- CP asymmetry can be *very* large.
- Very sensitive to r_B.

$B^- \to D^0 K^-$
$\hookrightarrow K^-\pi^+\pi^0$

Same Sign event (SS). Favored transition.

ADS stands for D. Atwood, I. Dunietz, A. Soni, PRL 78, 3257 (1997); PRD 63, 036005 (2001).

Search for b→u transitions in $B^- \to [K^+\pi^-\pi^0]_D K^-$ decays

arXiv:1104.4472 [hep-ex]
Accepted for publication by PRD
Results based on 474 M $B\bar{B}$ pairs

- Extract ratio of *OS* wrt *SS* events, mainly sensitive to parameter r_B which drives sensitivity to CKM phase γ

$$R^+ = \frac{\Gamma(B^+ \to [\bar{f}]_D K^+)}{\Gamma(B^+ \to [f]_D K^+)} = \frac{\#\,OS}{\#\,SS}$$

$$R^- = \frac{\Gamma(B^- \to [f]_D K^-)}{\Gamma(B^- \to [\bar{f}]_D K^-)} = \frac{\#\,OS}{\#\,SS}$$

$$R^+ = r_B^2 + r_D^2 + 2 r_B r_D k_D \cos(\gamma + \delta)$$

$$R^- = r_B^2 + r_D^2 + 2 r_B r_D k_D \cos(\gamma - \delta)$$

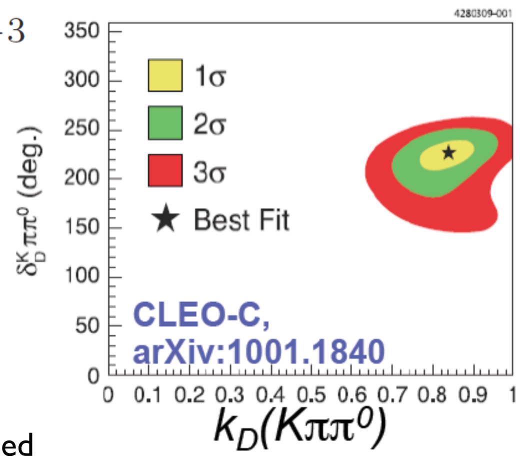
k_D and δ_D can be measured at charm factories using the Quantum-Correlated Measurements

Accounting for 3-body $D^0 \to K^\pm \pi^\mp \pi^0$ decay amplitudes:

$$r_D^2 \equiv \frac{\Gamma(D^0 \to f)}{\Gamma(D^0 \to \bar{f})} = \frac{\int d\vec{m}\, A_{DCS}^2(\vec{m})}{\int d\vec{m}\, A_{CF}^2(\vec{m})} = (2.2 \pm 0.1) \times 10^{-3}$$

PDG 2010 value

$$k_D e^{i\delta_D} \equiv \frac{\int d\vec{m}\, A_{DCS}(\vec{m}) A_{CF}(\vec{m}) e^{i\delta(\vec{m})}}{\sqrt{\int d\vec{m}\, A_{DCS}^2(\vec{m}) \int d\vec{m}\, A_{CF}^2(\vec{m})}}$$



k_D coherence factor $0 < k_D < 1$, the larger the better!
δ(m) relative A_{CF}, A_{DCS} strong phase

CF = Cabibbo favored
DCS = Double Cabibbo suppressed

Search for b→u transitions in $B^- \to [K^+\pi^-\pi^0]_D K^-$ decays

arXiv:1104.4472 [hep-ex]
Accepted for publication by PRD
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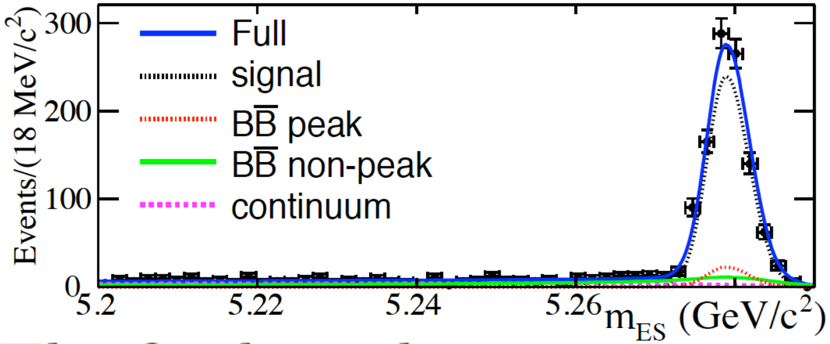
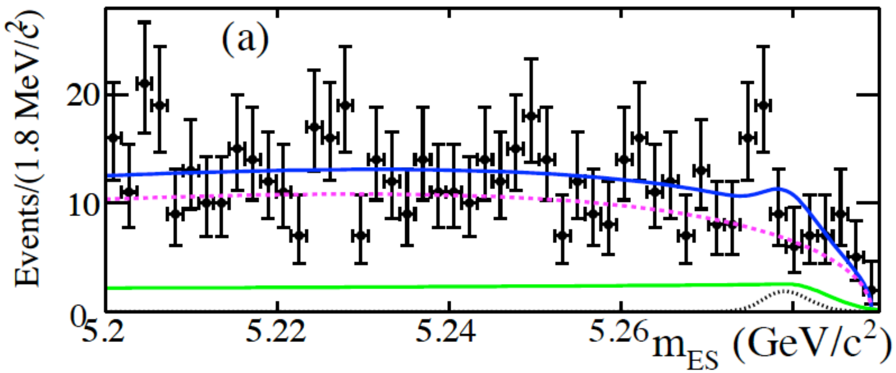
m_{ES} distribution for *SS* events



m_{ES} distribution for *OS* events



The final results are:

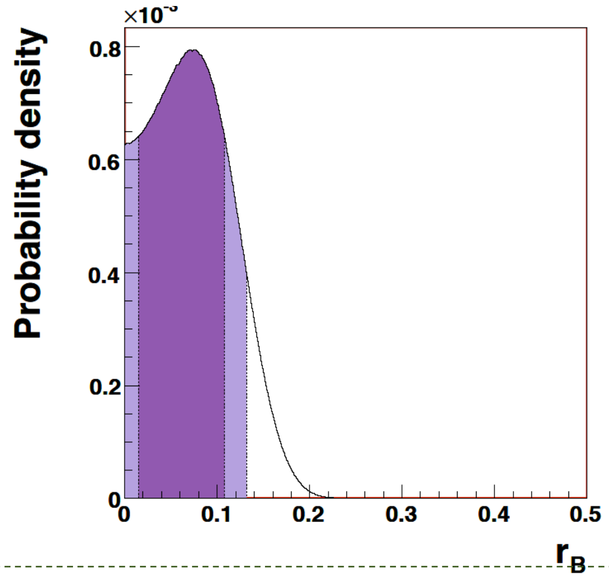
Sample	B^+	B^-	B^+ and B^-
R, 10^{-3}	5^{+12}_{-10}	12^{+12}_{-10}	$9.1^{+8.2}_{-7.6}$
$N_{B^\pm,\mathrm{tot}}$	1032 ± 41	946 ± 39	1981 ± 57

$$R^+ = \left(5^{+12}_{-10}(\mathrm{stat})^{+1}_{-4}(\mathrm{syst})\right) \times 10^{-3}$$

$$R^- = \left(12^{+12}_{-10}(\mathrm{stat})^{+2}_{-4}(\mathrm{syst})\right) \times 10^{-3}$$

larger systematic error due to *OS* peaking bkg.

$r_B < 0.13$ at 90% probability.



Conclusions

- An overview of the recent BaBar results has been presented covering several topics: Charm physics, spectroscopy, studies of B_s and B decays.
- Present results are in agreement with Standard Model expectations within the uncertainties.
- Flavor physics provides an alternative and complementary path for searching for physics beyond the Standard Model with respect to direct searches at LHC.
- A larger data sample, compared to the BaBar one, is required in order to perform a stringent test of the present theory by looking for unpredicted effects.
- Present and future experiments will tell us:

Backup slides

CKM matrix and Unitarity Triangle determination

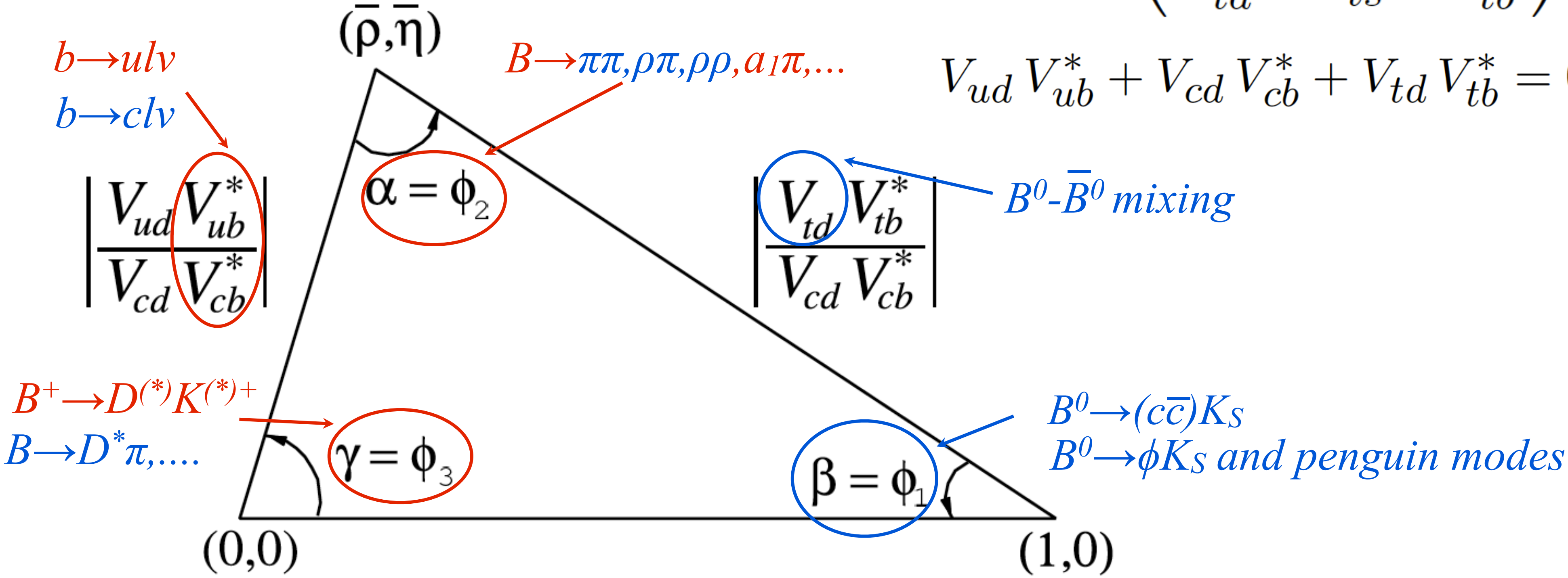
- measurements of the angles: α, β, γ
- measurements of the sides trough $|V_{ub}|$, $|V_{cb}|$, $|V_{td}|$

not updated in 2010
updated in 2010

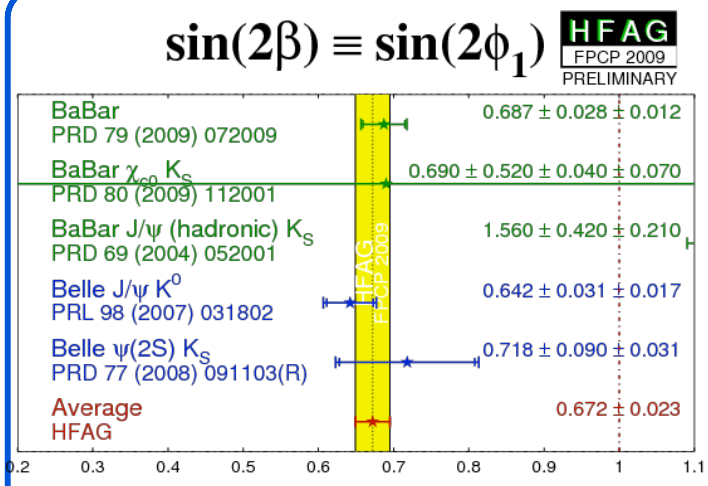
$$V_{\mathrm{CKM}} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

CKM quark-mixing matrix

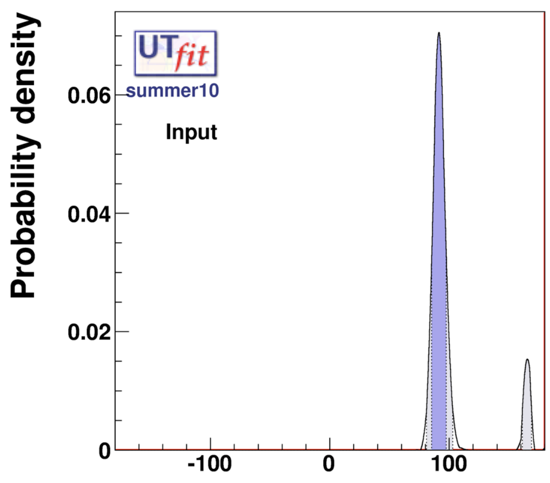
$$V_{ud}\,V_{ub}^{*} + V_{cd}\,V_{cb}^{*} + V_{td}\,V_{tb}^{*} = 0$$



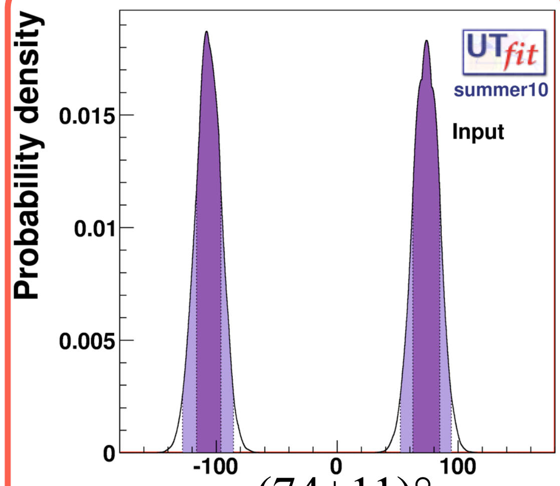
Status of art



$\beta=(21.1\pm0.9)^\circ$

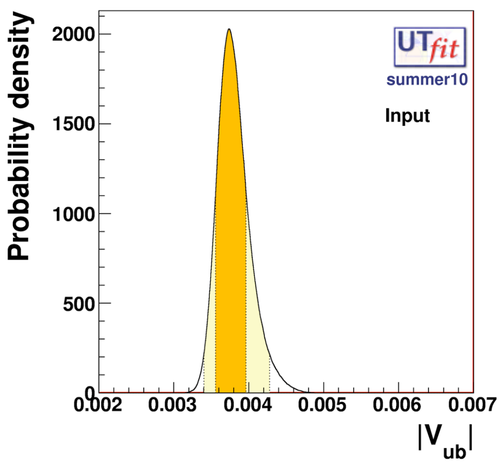


$\alpha=(91.4\pm6.1)^\circ$ α,[°]

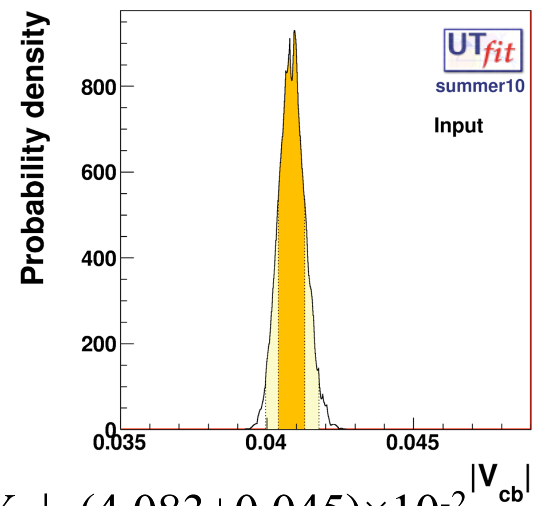


$\gamma=(74\pm11)^\circ$ γ,[°]

$\gamma=(-106\pm11)^\circ$



$|V_{ub}|=(3.76\pm0.20)\times10^{-3}$



$|V_{cb}|=(4.083\pm0.045)\times10^{-2}$

not updated in 2010

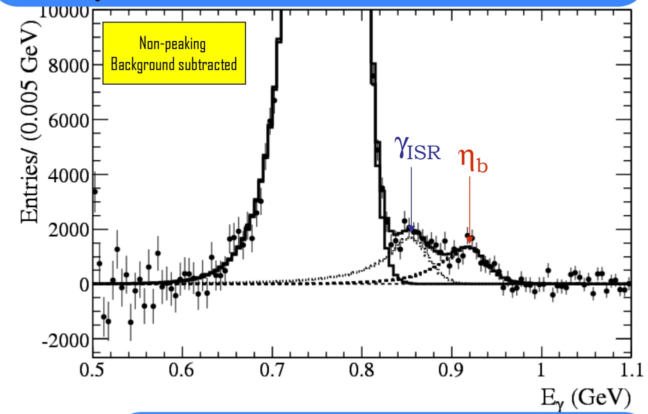
updated in 2010

- *sin2β HFAG average;*
- *Input values for UT_{fit}: "world averages" for α, γ, $|V_{ub}|$, $|V_{cb}|$.*

BaBar results *well beyond the original goal*

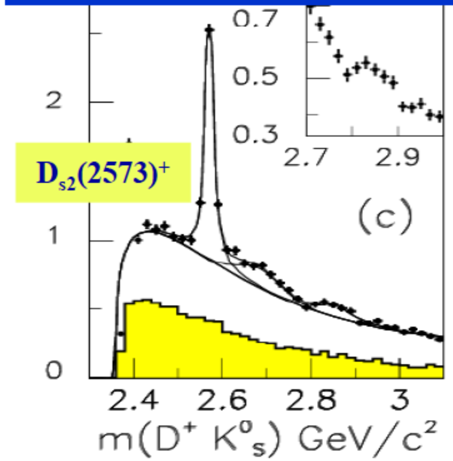
η_b discovery $\Upsilon(3S)\to\gamma\eta_b(1S)$

Phys.Rev.Lett. 101 (2008) 071801

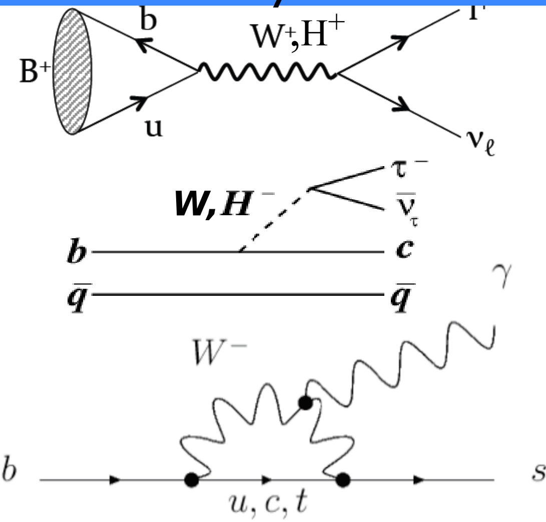


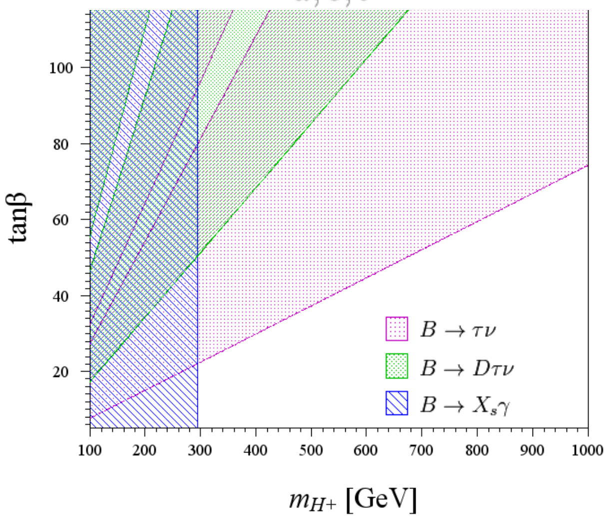
Phys.Rev.Lett.97:222001, 2006

New DK state(s) at 2.86GeV/c²



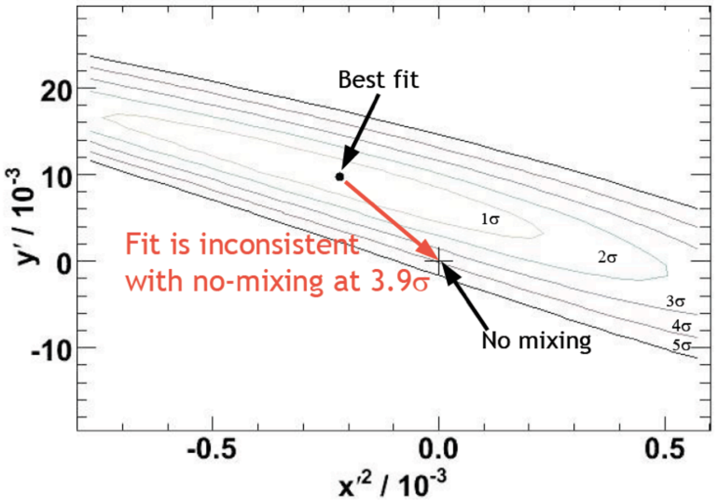
Limits on New Physics (2HDM-II) from B rare decays





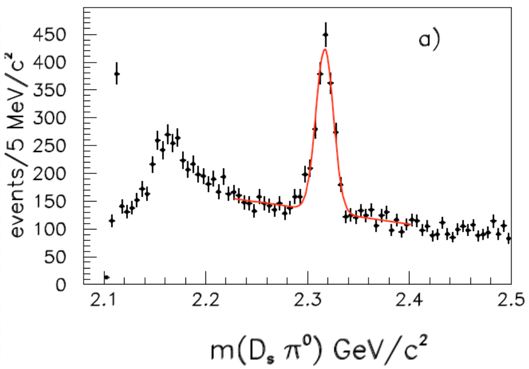
Evidence of D^0 mixing

Phys.Rev.Lett.98:211802, 2007

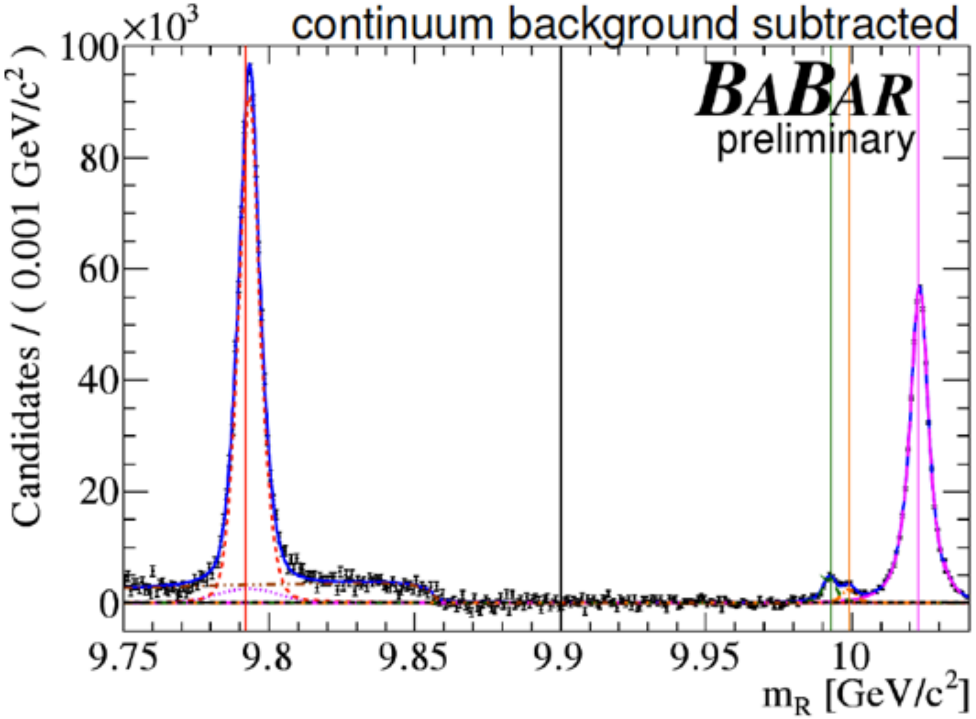


Discovery of $D_{s0}^*(2317)$

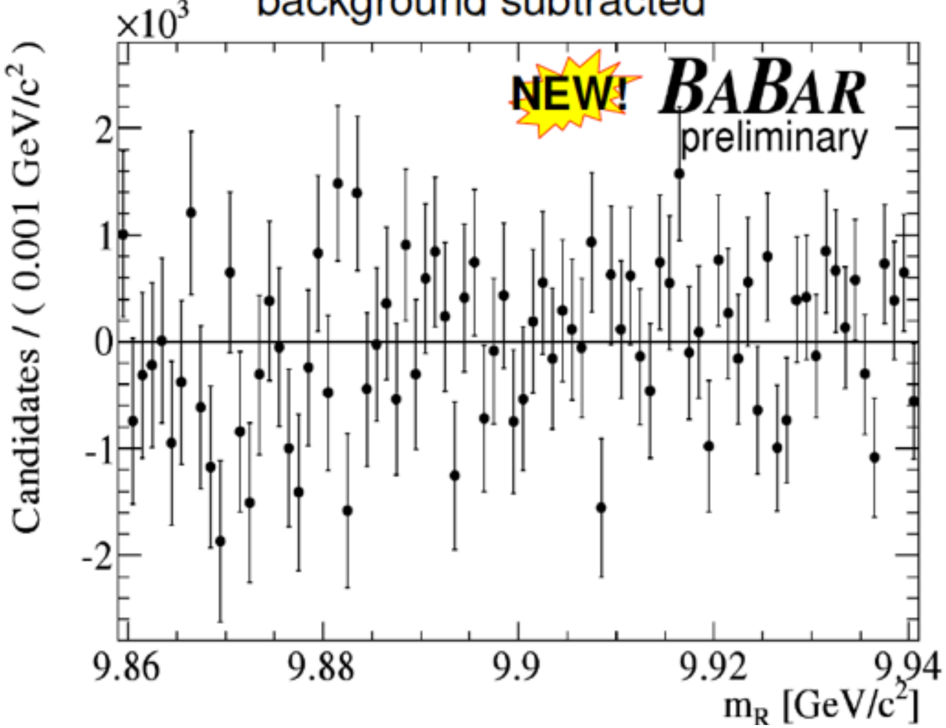
Phys.Rev.Lett.90:242001,2003



$h_b(1P)$ results



Zoom around signal region
background subtracted



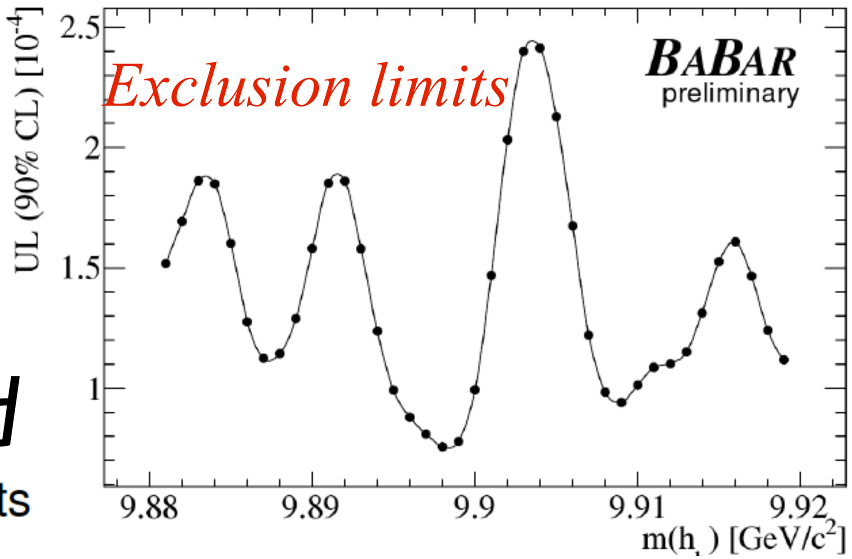
$\Upsilon(3S) \to X\, \Upsilon(2S), \Upsilon(2S) \to \Upsilon(1S)\, \pi\, \pi$

$K^0_S \to \pi^+ \pi^-$ (fixed)

$\Upsilon(3S) \to \gamma\, \chi_{b1}(2P),\ \chi_{b1}(2P) \to \pi^+ \pi^- \chi_{b1}(1P)$

$\Upsilon(3S) \to \gamma\, \chi_{b2}(2P),\ \chi_{b2}(2P) \to \pi^+ \pi^- \chi_{b2}(1P)$

$\Upsilon(3S) \to \Upsilon(2S)\, \pi\, \pi$



No h_b signal found

– O(10x) improvement on BF upper limits

$\eta_c(1S)$ & $\eta_c(2S)$ current status

$\eta_c(1S)$

Discovered by Crystal Ball 1980

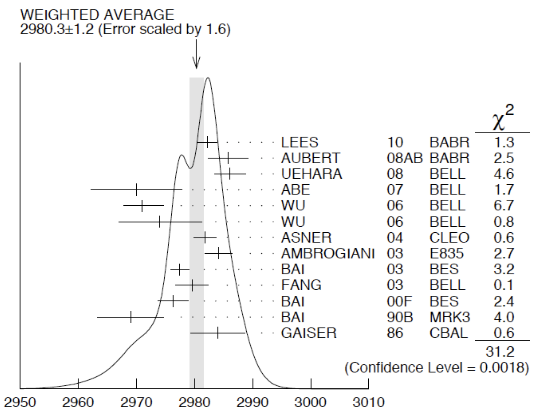
Phys. Rev. Lett. 45, 1150-1153 (1980)

$\eta_c(2S)$

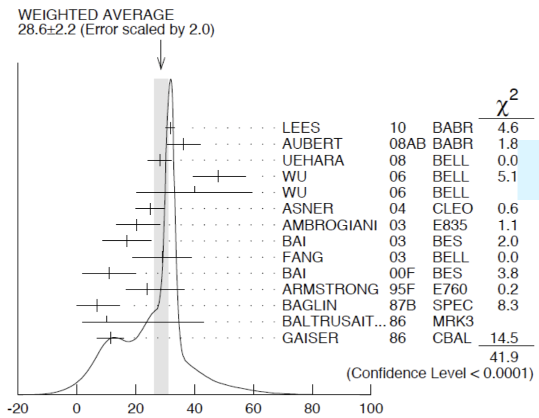
Discovered by BELLE 2002

Phys. Rev. Lett. 89 102001 (2002)

$M(\eta_c(1S))$

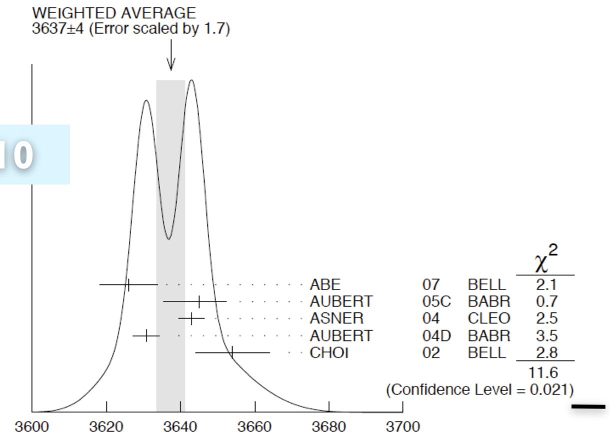


$\Gamma(\eta_c(1S))$



PDG 2010

$M(\eta_c(2S))$



$\eta_c(1S)$ observed by several experiments but there is a large spread in mass and width measurements

$\Gamma(\eta_c(1S))$~15 MeV (J/ψ and $\psi(2S)$) radiative decays

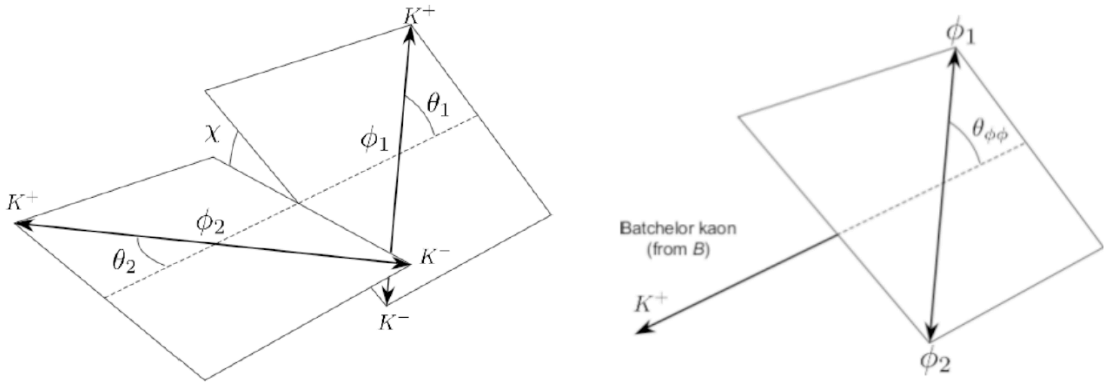
$\Gamma(\eta_c(1S))$~30 MeV (B-decays and $\gamma\gamma$ production)

Until recently has only been observed in exclusive decay to $KK\pi$

Precise measurement of $m(\eta_c(2S))$ will help discriminate among different charmonium models

B→ϕϕK angular analysis

Accepted by PRD



We project the $J^P = 0^-$ component by making a histogram of $m_{\phi\phi}$ weighting each event by

$$P_2(\cos\theta_1)\ \mathrm{Re}\left[Y_2^2(\theta_2,\chi)\right] = \frac{25}{4}\left\{3\cos^2\theta_1 - 1\right\}\ \sin^2\theta_2\ \cos 2\chi, \qquad (2)$$

- Results for η_c region are consistent with expectation for η_c ($\phi\phi$ system is J^P=0$^-$).
- Below η_c region is not consistent with J^P=0$^-$ (based on χ distribution, not reported here) but consistent with J^P=0$^+$.