New Results from BaBar

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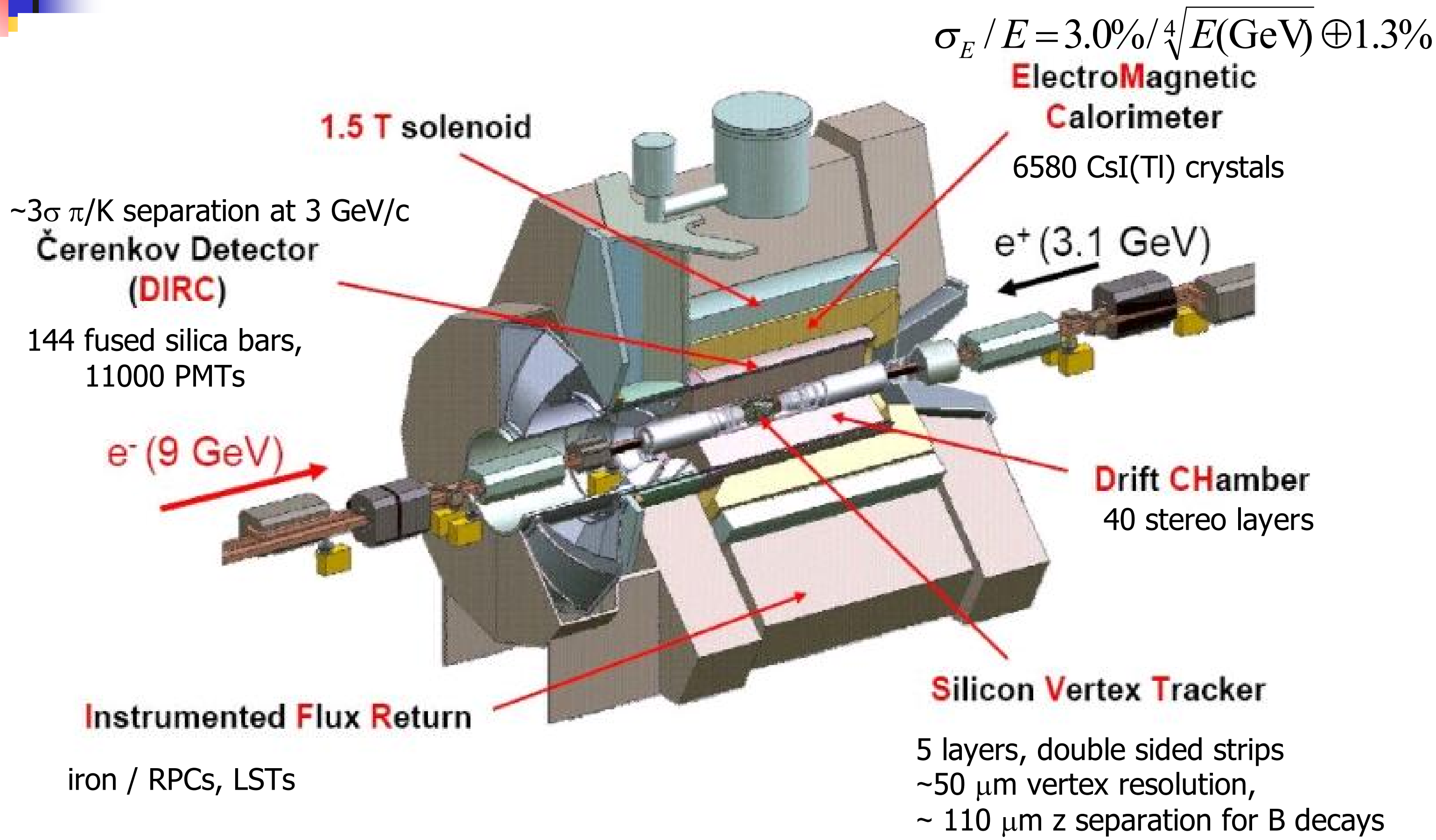
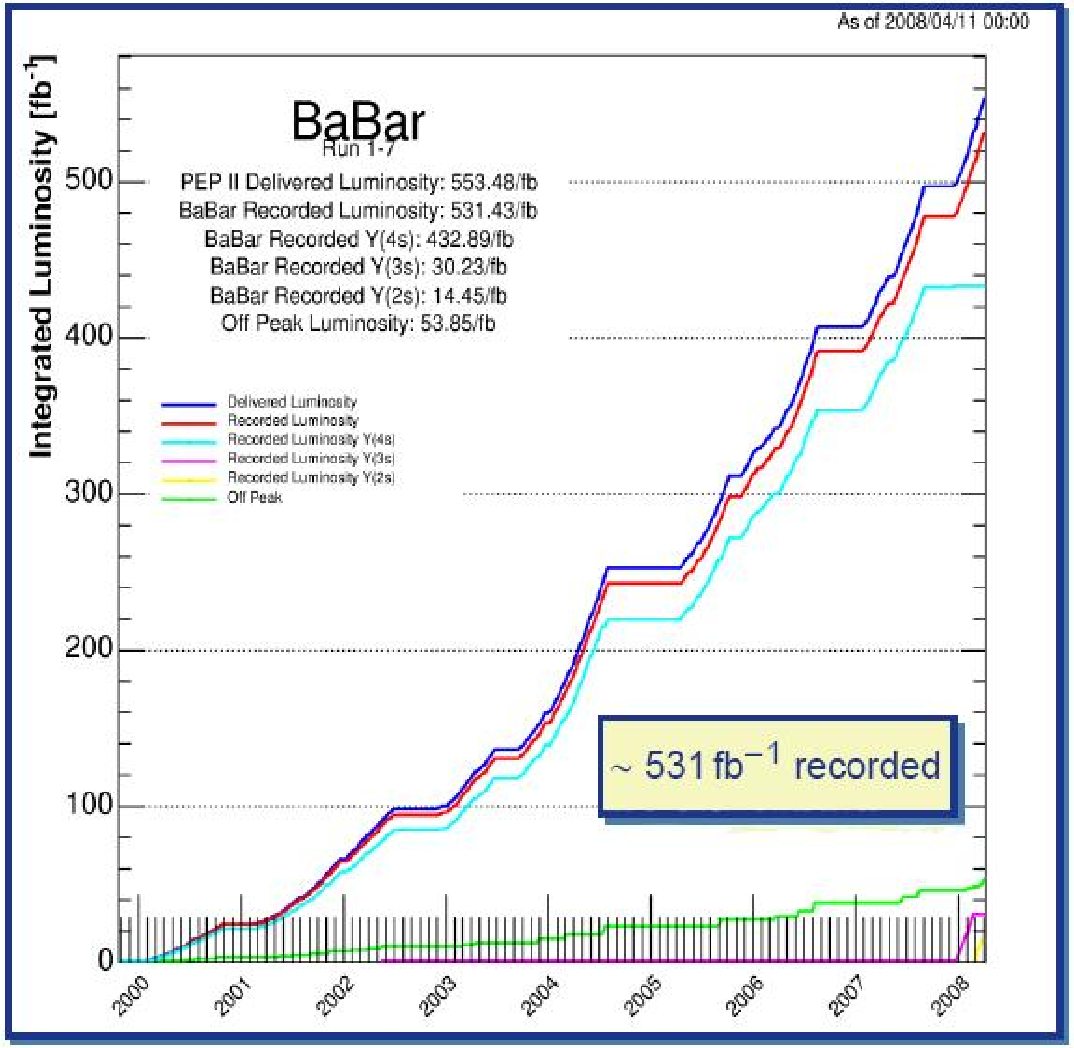
Outline

- BABAR detector
- Evidence for direct CP violation in the measurement of the CKM angle γ with $B^{\mp}\to D^{(*)}K^{(*)\mp}$ decays
- Semileptonic $b\to c\ell\nu$ decays
- Semileptonic $b\to u\ell\nu$ decays
- Measurement of $b\to d\gamma$, $b\to s\gamma$, and $|V_{td}/V_{ts}|$
- Study of two-photon production of pseudoscalar mesons

BABAR Detector



BABAR Detector



Final BABAR dataset:

$N(\Upsilon(4S) \rightarrow B\bar{B}) = 470 \times 10^6$

Off Peak Luminosity 53.85 fb^{-1}

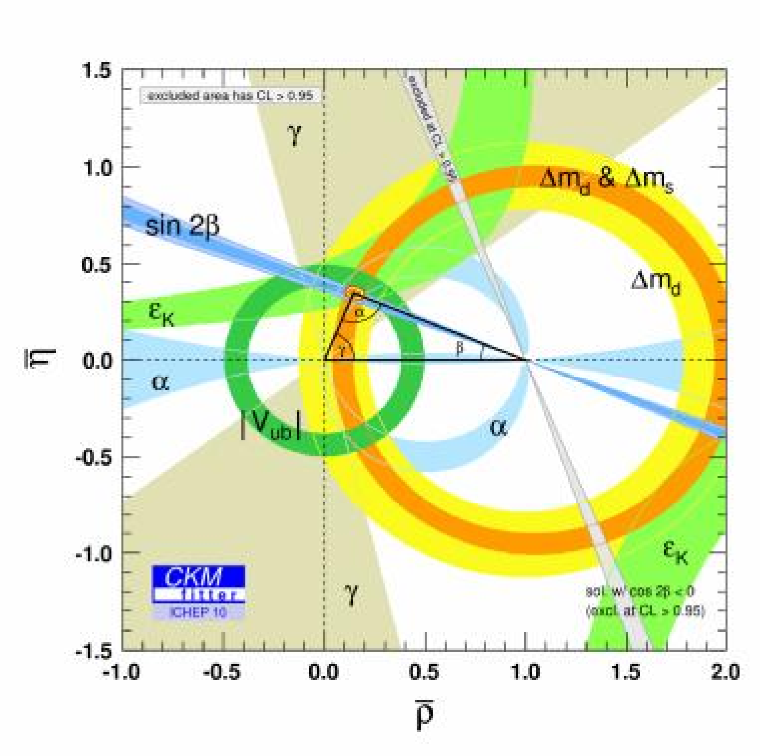
$N(\Upsilon(3S)) = 122 \times 10^6$

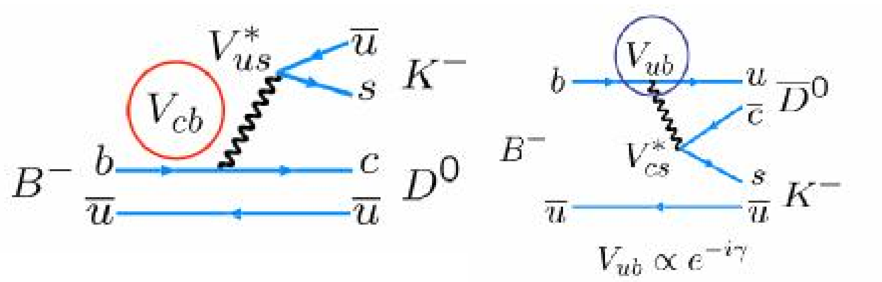
$N(\Upsilon(2S)) = 100 \times 10^6$

PEP-II peak luminosity

12.1 10^{33} $cm^{-2}s^{-1}$

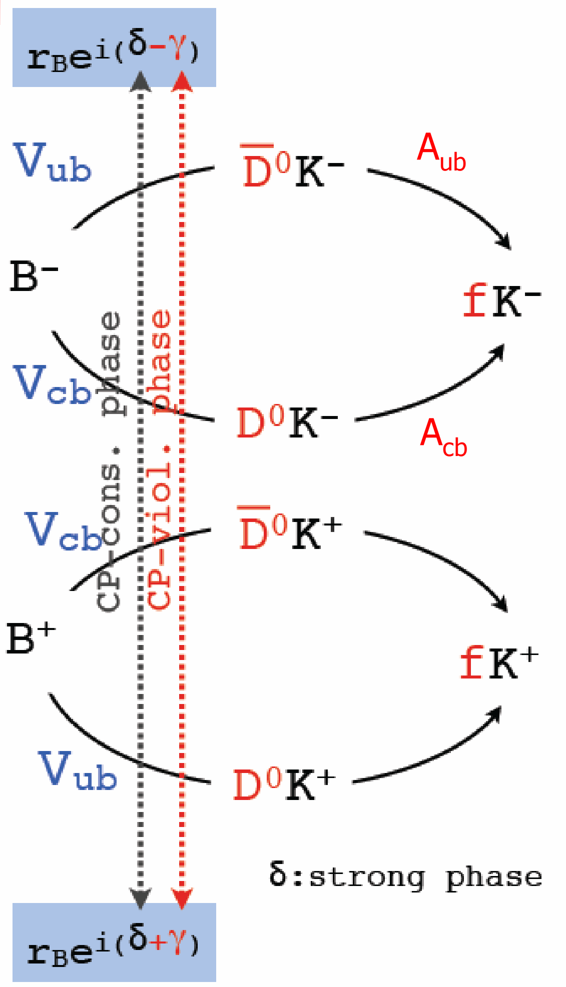
CKM angle γ

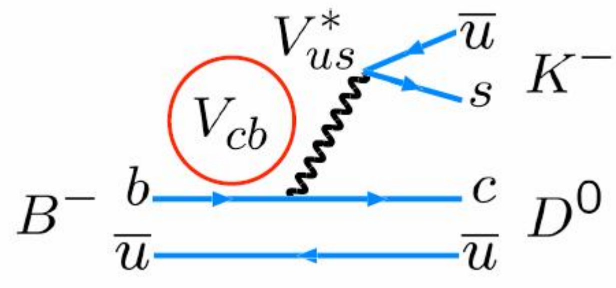


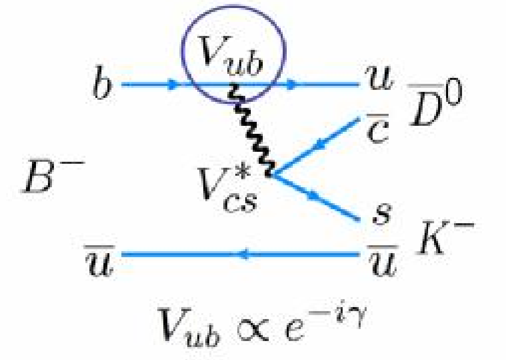


- The CKM angle γ is the only CP-violation parameter, which can be cleanly determined from tree-level *B*-meson decays. Its precise determination is an important goal of present and future experiments in flavor physics
- The γ angle can be determined using $B^{\mp}\to DK^{\mp}$ decays using interference between color-favored $B^-\to D^0K^-$ and color-suppressed $B^-\to \overline{D}{}^0K^-$ decays with D^0 and $\overline{D}{}^0$ decays to a common final state
- New BABAR results [arXiv:1005.1096] are based on Dalitz-plot analysis of eight decay modes for each *B*-meson sign: $B^{\pm}\to DK^{\pm}$, $B^{\pm}\to D^*[D\pi^0]K^{\pm}$, $B^{\pm}\to D^*[D\gamma]K^{\pm}$, and $B^{\pm}\to DK^{*\pm}$ final states with $D\to K_S\pi^+\pi^-$, $K_SK^+K^-$ full statistics of 468 million $B\overline{B}$ pares

CKM angle γ from $B \to DK$ decays







- Use common final states for D^0 and $\overline{D}^0$
- Largely unaffected by New Physics
- Clear theoretical interpretation of observables in terms of γ
- Difficulty: small BFs due to CKM suppresion (10^{-5}–10^{-7}, so not many events) and $r_B=|A_{ub}|/|A_{cb}|$ is small due to further CKM and color suppressions (small interference)
- All measurements are statistically limited

CKM angle γ from $B \to DK$ decays

Analysis methods for charged $B \to D^{(*)0} K^{(*)}$ (r_B~0.1)

- GLW [1]: D^0 decay final states: CP-even: K^+K^-, $\pi^+\pi^-$, and CP-odd: $K_S\,\pi^0$, $K_S\,\omega$, $K_S\phi$
- ADS [2]: D^0 decay final states: $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$ and CP-conj
- Dalitz-plot [3]: D^0 decay final states: $\pi^0\pi^+\pi^-$, $K_S\,\pi^+\pi^-$, $K_SK^+K^-$

[1] Gronau, London, Wyler, PLB 253, 483 (1991); PLB 265, 172 (1991)

[2] Atwood, Dunietz, Soni, PRL 78, 3357 (1997)

[3] Giri, Grossman, Soffer, Zupan, PRD 68, 054018 (2003);

γ from B→DK decays Dalitz-plot method

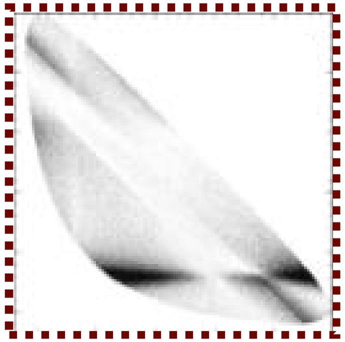
Decay amplitudes

(no D-mix nor CPV)

$$A(B^- \to [K_S\pi^+\pi^-]K^-) \propto \left(\right.$$

$D^0 \to K_S\pi^+\pi^-$

S_

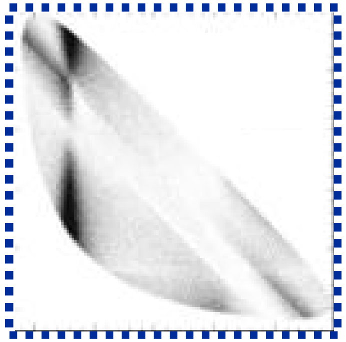


b→c S+

$$+ r_B e^{-i\gamma + i\delta_B}$$

$\overline{D}^0 \to K_S\pi^+\pi^-$

S_



b→u S+ $\left. \right)$

$$S_{\mp} \equiv m^2(K_S\pi^{\mp})$$

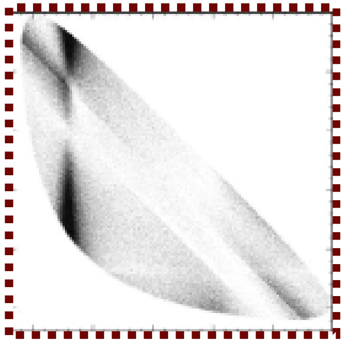
r_B=|A(b→u)|/|A(b →c)|

δ_B –strong phase difference between A(b→u) and A(b→c)

$$A(B^+ \to [K_S\pi^+\pi^-]K^+) \propto \left(\right.$$

$\overline{D}^0 \to K_S\pi^+\pi^-$

S_

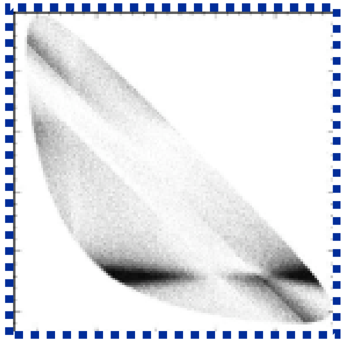


$\overline{\text{b}}$→$\overline{\text{c}}$ S+

$$+ r_B e^{+i\gamma + i\delta_B}$$

$D^0 \to K_S\pi^+\pi^-$

S_



$\overline{\text{b}}$→$\overline{\text{u}}$ S+ $\left. \right)$

Interference terms in decay rates are proportional to

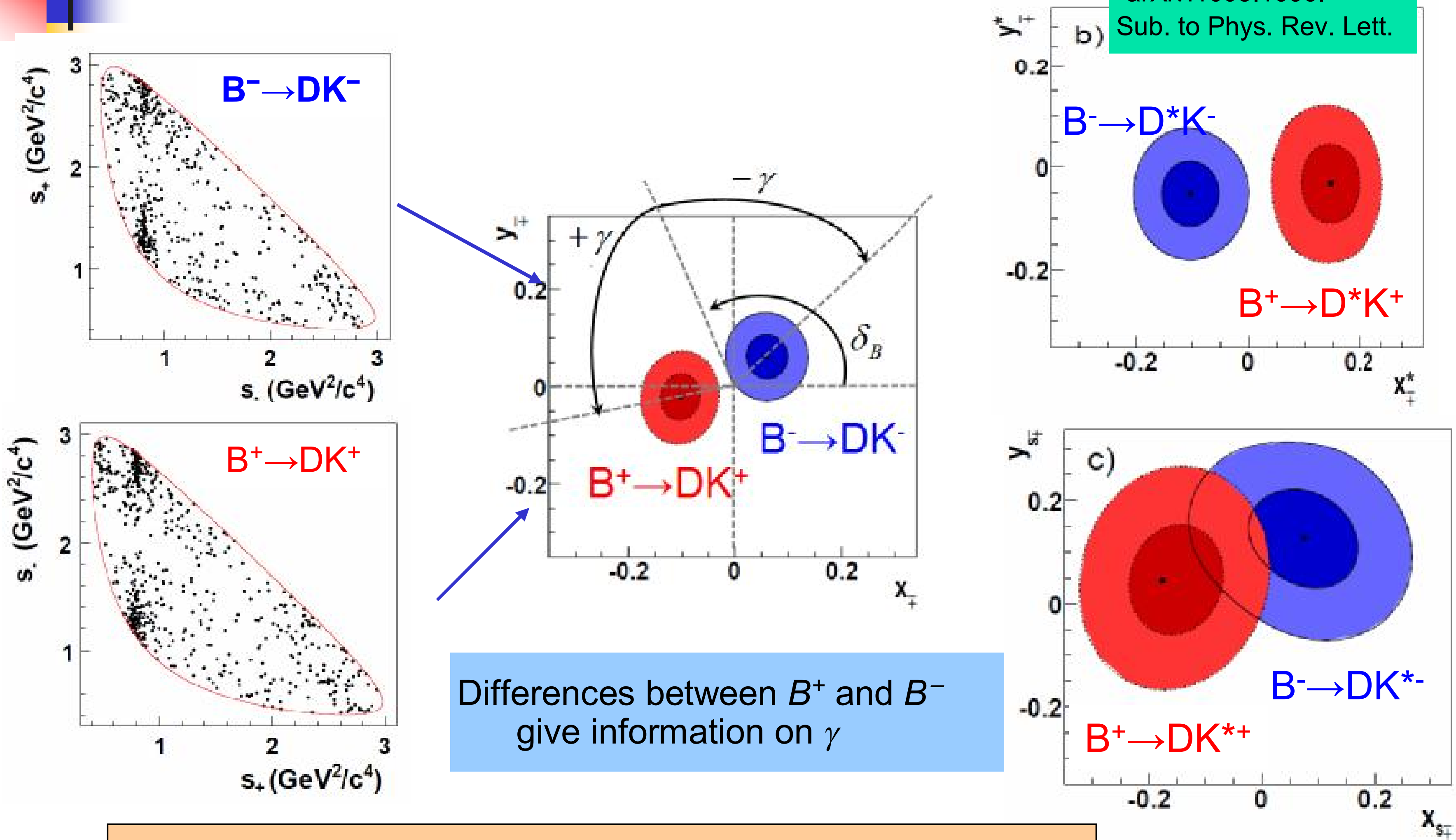
$$x_{\mp} = r_B \cos(\delta_B \mp \gamma)$$

$$y_{\mp} = r_B \sin(\delta_B \mp \gamma)$$

Fit for $x_{\mp}$ and $y_{\mp}$ is done for each decay mode

Evidence for direct CP violation in the measurement of the CKM angle γ with $B^{\mp} \to D^{(*)}K^{(*)\mp}$ decays: D Dalitz-plot method

arXiv:1005.1096.
Sub. to Phys. Rev. Lett.



Differences between B^+ and B^- give information on γ

$$\gamma\ (\mathrm{mod}\ 180^\circ) = (\ 68 \pm 14(\mathrm{stat}) \pm 4(\mathrm{syst}) \pm 3(\mathrm{mod})\ )^\circ$$

3.5 significance of CPV

Evidence for direct CP violation in the measurement of the CKM angle γ with $B^{\mp} \to D^{(*)} K^{(*)\mp}$ decays: GLW method

arXiv:1007.0504.
Sub. to Phys. Rev. D

- Reconstruct $B^{\pm} \to DK^{\pm}$ final states with $D \to K^+K^-, \pi^+\pi^-$ (CP even) and $D \to K_S\pi^0, K_S\omega, K_S\phi$ (CP odd) (five different final states for each B charge)
- Extract signal yields fitting directly to observables $R^{\pm}_{K/\pi}$, $R_{K/\pi}$, and $A_{CP\pm}$

$$R^{\pm}_{K/\pi} = \frac{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}\pi^-) + \Gamma(B^+ \to D_{CP\pm}\pi^+)};$$

$$R_{K/\pi} = \frac{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \overline{D}^0K^+)}{\Gamma(B^- \to D^0\pi^-) + \Gamma(B^+ \to \overline{D}^0\pi^+)}$$

$$A_{CP\pm} = \frac{\Gamma(B^- \to D_{CP\pm}K^-) - \Gamma(B^+ \to D_{CP\pm}K^+)}{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to D_{CP\pm}K^+)};$$

$$R_{CP\pm} = 2\frac{\Gamma(B^- \to D_{CP\pm}K^-) + \Gamma(B^+ \to \overline{D}_{CP\pm}K^+)}{\Gamma(B^- \to D^0K^-) + \Gamma(B^+ \to \overline{D}^0K^+)}$$

$$R_{CP\pm} \approx \frac{R^{\pm}_{K/\pi}}{R_{K/\pi}}$$

Results:

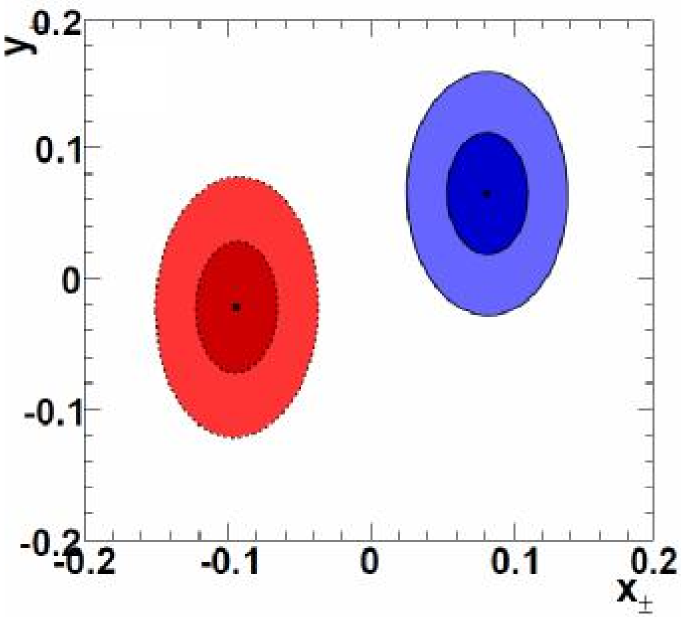
$A_{CP+} = 0.25 \pm 0.06(\text{stat}) \pm 0.02(\text{syst})$
$A_{CP-} = -0.09 \pm 0.07(\text{stat}) \pm 0.02(\text{syst})$
$R_{CP+} = 1.18 \pm 0.09(\text{stat}) \pm 0.05(\text{syst})$
$R_{CP-} = 1.07 \pm 0.08(\text{stat}) \pm 0.04(\text{syst})$

Significance of CPV in $B^{\pm} \to DK^{\pm}$ from $A_{CP}+$ is 3.6 σ, which constitutes first evidence for direct CP violation in $B \to DK$ decays

$$x_{\pm} = \frac{1}{4}\left[R_{CP+}(1 \mp A_{CP+}) - R_{CP-}(1 \mp A_{CP-})\right] \longrightarrow$$

$$x_- - x_+(\text{Dalitz}) = 0.163 \pm 0.055 \qquad (3.0\sigma)$$
$$x_- - x_+(\text{GLW}) = 0.189 \pm 0.062 \qquad (3.1\sigma)$$

Evidence for direct CP violation in the measurement of the CKM angle γ combined Dalitz-plot and GLW method results



$$\gamma\,(\mathrm{mod}180^\circ) = (68 \pm 14(\mathrm{stat}) \pm 4(\mathrm{syst}) \pm 3(\mathrm{model}))^\circ$$

$$r_B(DK) = 0.096 \pm 0.029$$

$$r_B^*(D^*K) = 0.133^{+0.042}_{-0.039}$$

$$\chi r_S(DK^*) = 0.149^{+0.066}_{-0.062}$$

$$\gamma\,(\mathrm{mod}\ 180^\circ) = (78.4\,^{+10.8}_{-11.6} \pm 3.6 \pm 8.9)^\circ$$

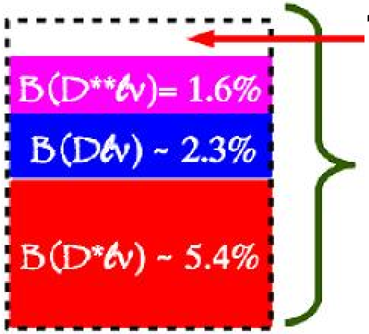
$$r_B(DK) = 0.160^{+0.040}_{-0.038}$$

$$x_- - x_+(\mathrm{Dalitz} + \mathrm{GLW}) = 0.175 \pm 0.040$$

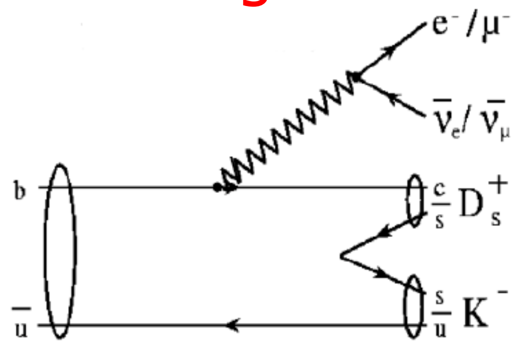
4.4σ significance of CPV in $B^\pm \to DK^\pm$ only, Dalitz+GLW combined

Semileptonic B-meson decays $b \to c l \nu$

Measurement of $B \to D_S^{(*)} K l \nu$ branching fraction

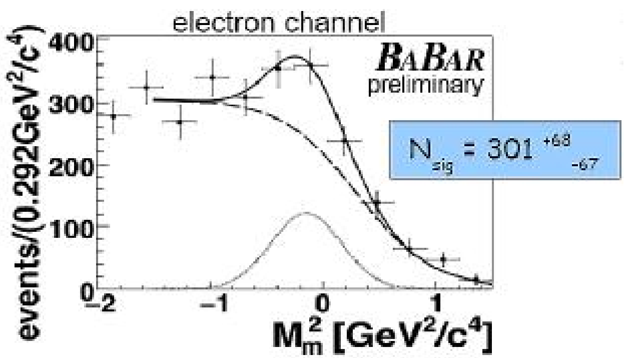


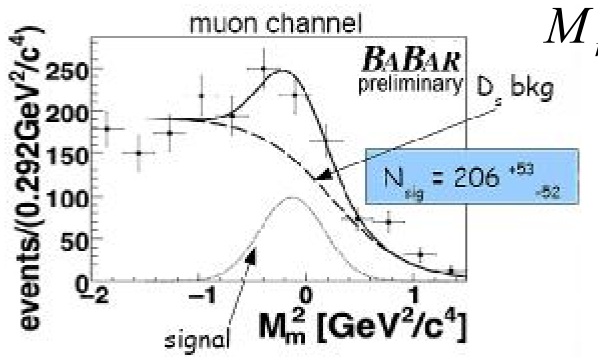
$B(B \to X_c \ell \nu) = (10.99 \pm 0.28)\%$



Reconstructed D_S decay modes: $\phi(K^+K^-)\pi$; $K^{*0}(K^{\pm}\pi^{\mp})$; $K_S(\pi^+\pi^-)K$

Signal yields are extracted via extended maximum likelihood fit to missing mass distributions





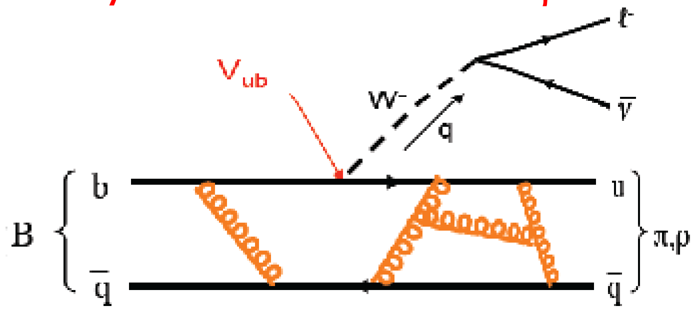
$$M_m^2 = (E_{beam} - E_Y)^2 - |\vec{p}_Y|^2$$

Y = $D_S K$ *l* candidate

$$\mathcal{B}(B \to D_s^+ K^- \ell^- \bar{\nu}_\ell) = (6.13^{+1.04}_{-1.03} stat. \pm 0.43_{syst.} \pm 0.51(\mathcal{B}(D_s))) \times 10^{-4}$$

Semileptonic B-meson decays $b \to u \ell \nu$

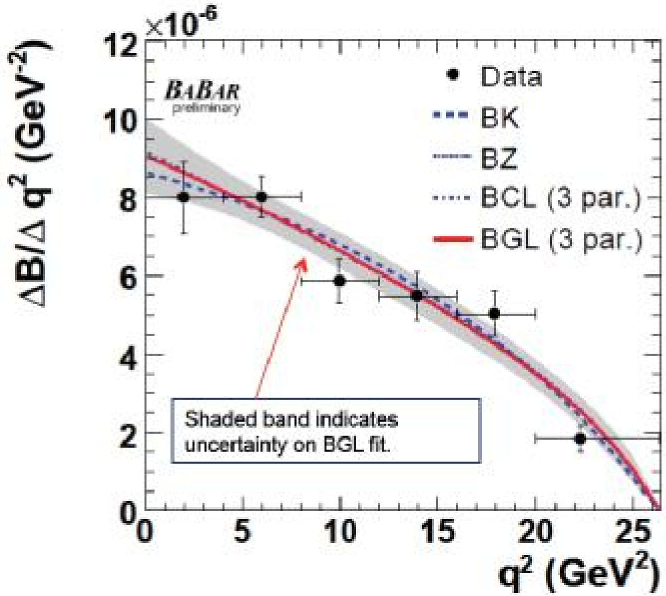
Study of $B \to \pi \ell \nu$ and $B \to \rho \ell \nu$ decays and determination of $|V_{ub}|$



$$B \to \pi \ell \nu : \frac{d\Gamma}{dq^2} = |V_{ub}|^2 \frac{G_F^2 |\vec{p}_\pi|^3}{24\pi^3} |f_+(q^2)|^2$$

$$B \to \rho \ell \nu : \frac{d\Gamma}{dq^2} = |V_{ub}|^2 \frac{G_F^2 |\vec{p}_\rho| q^2}{96\pi^3} |F_\rho(q^2)|^2$$

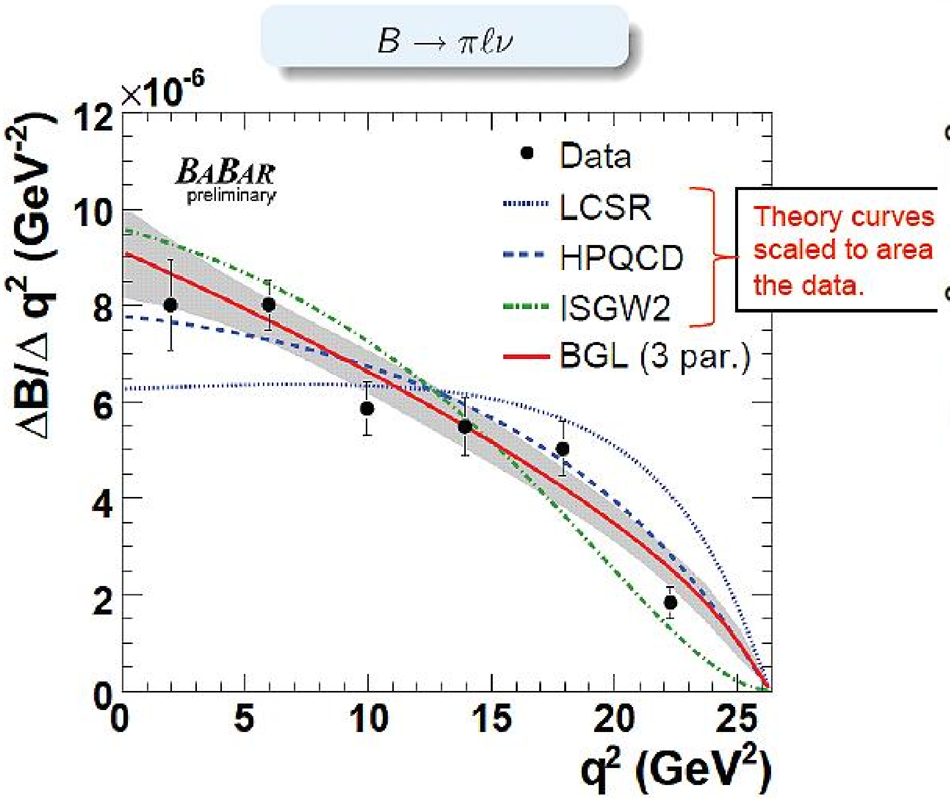
Physics goals: measure |Vub| and test QCD calculations of form factors
Form factor parameterization:

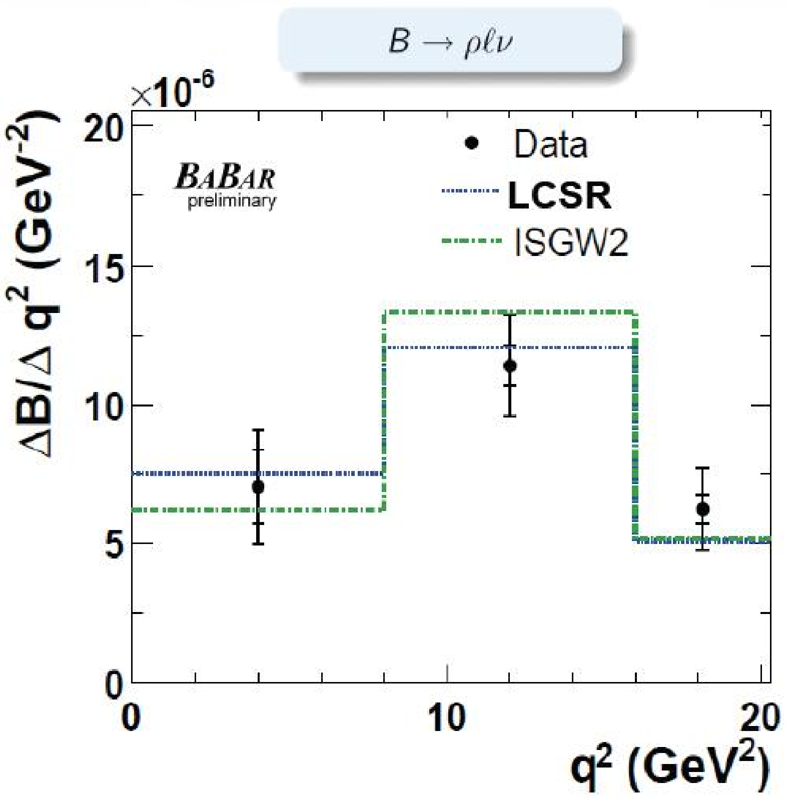


$f_+(q^2)$ parameterizations	
1 param.	Becirevic, Kaidalov (BK) Phys Lett B 478, 417 (2000)
2 param.	Ball, Zwicky (BZ) PLB 644, 38 (2007)
n param.	Bourrely, Caprini, Lellouch (BCL) PRD 79, 013008 (2009)
n param.	Boyd, Grinstein, Lebed (BGL) PRL 56, 303 (1997)

Study of B→$\pi\ell\nu$ and B→ $\rho\ell\nu$ decays

Study of B→$\pi\ell\nu$ and B→ $\rho\ell\nu$ decays: comparison with theory



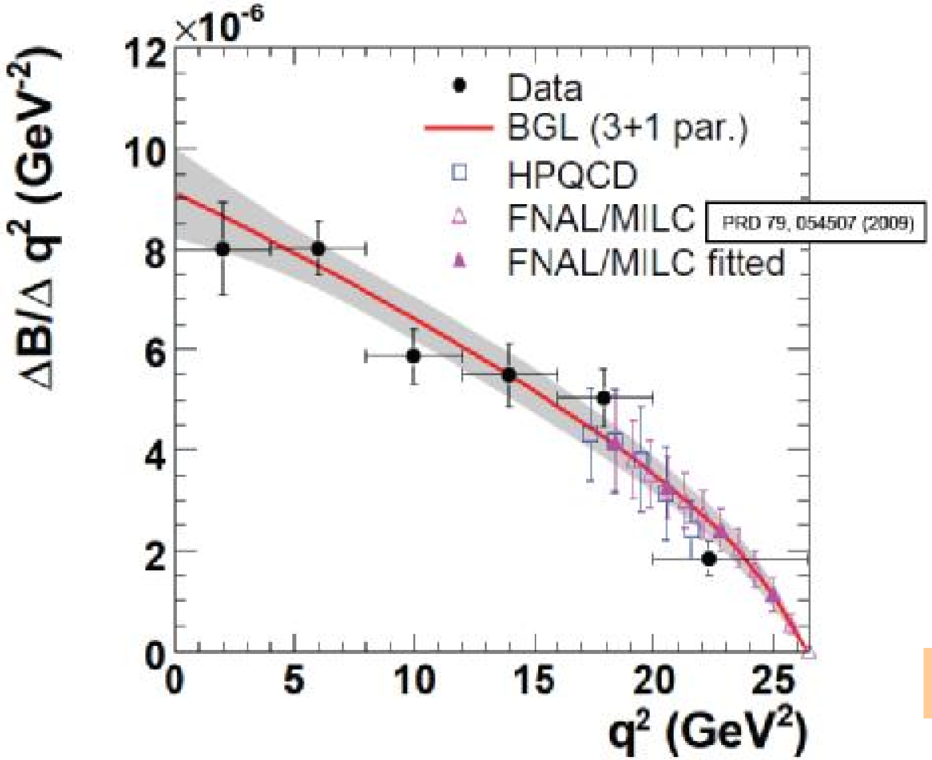


Theory model	$P(\chi^2)$
HPQCD (PRD 73, 074502 (2006))	13%
ISGW2 (PRD 52, 2783 (1995))	0.2%
LCSR (PRD 71, 014015, (2005))	$<10^{-5}$

Errors are too large to distinguish between B→ $\rho\ell\nu$ predictions

Study of $B\to\pi\ell\nu$ and $B\to\rho\ell\nu$ decays

Study of $B\to\pi\ell\nu$ and $B\to\rho\ell\nu$ decays: determination of $|V_{ub}|$ from full q^2 range



Simultaneous fit to data and theory

- 3 parameters: BGL quadratic polynomial
- 4th parameter: relative normalization between theory and data, $\alpha\ |V_{ub}|^2$
- Theory points are correlated, so not all are used in fit.

$|V_{ub}|=(2.99\pm0.35)\times10^{-3}$ HPQCD (1 point)

$|V_{ub}|=(2.92\pm0.37)\times10^{-3}$ FNAL/MILC (1 point)

$|V_{ub}|=(2.95\pm0.31)\times10^{-3}$ FNAL/MILC (4 points)

$BF(B^0\to\pi^-\ell^+\nu)=(1.41\pm0.05\pm0.07)\times10^{-4}$

$BF(B^0\to\rho^-\ell^+\nu)=(1.75\pm0.15\pm0.27)\times10^{-4}$

Most precise branching fraction measurements

σ(data BF)=3%

σ(data q^2 shape)=5%

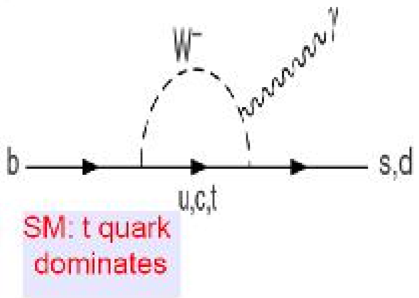
σ(data FF norm.)=8.5%

σ_{total}=10.5%

Measurement of b→dγ, b→sγ, and $|V_{td}/V_{ts}|$

arXiv: 1005.4087

Radiative penguin transitions are flavor changing neutral currents, forbidden at tree level at Standard Model

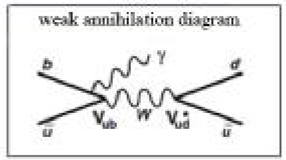


b→dγ transition is CKM suppressed with respect to b→sγ by a factor ~20 in the SM

Motivation

Analysis of equivalent b→dγ and b→sγ decays can be used to measure the |Vtd/Vts| ratio of CKM matrix elements:

$$\frac{BF(B\to\rho\gamma)}{BF(B\to K^*\gamma)} = S_p\left|\frac{V_{td}}{V_{ts}}\right|^2\left(\frac{1-m_\rho^2/M_B^2}{1-m_{K^*}^2/M_B^2}\right)^3\zeta^2[1+\Delta R]$$



Form factor ratio

Well measured

Isospin factor: 1 for $\rho^\pm$; 0.5 for ρ^0

Weak annihilation amplitude corrections

Constraint on $|V_{td}/V_{ts}|$ is independent of measured from B_s/B_d mixing frequencies: discrepancies between two could indicate new physics
Theoretical uncertainty for the $|V_{td}/V_{ts}|$ ratio is ~8% for exclusive b→s,d γ decay modes and ~1%(?) for inclusive decays ratio.

Measurement of $b \to d\gamma$, $b \to s\gamma$, and $|V_{td}/V_{ts}|$

Analysis Overview

Measure partial branching fractions of sum of seven decay modes in four regions:

- $B \to X_d \gamma$ and $B \to X_s \gamma$
- Low hadronic mass ($0.5 < m_{had} < 1.0$ GeV/c^2), dominated by $B \to (\rho,\omega)\gamma$ and $B \to K^*\gamma$ resonances
- High hadronic mass ($1.0 < m_{had} < 2.0$ GeV/c^2), containing non-resonant decays

Extrapolate from partial to inclusive BFs within each mass bin

- Need to include unreconstructed decay modes – requires knowledge of fragmentation of hadronic systems X_d and X_s

Used full BABAR dataset of 471×10^6 $B\bar{B}$ pairs

$B \to X_d \gamma$	**$B \to X_s \gamma$**
$B^0 \to \pi^+ \pi^- \gamma$	$B^0 \to K^+ \pi^- \gamma$
$B^+ \to \pi^+ \pi^0 \gamma$	$B^+ \to K^+ \pi^0 \gamma$
$B^+ \to \pi^+ \pi^- \pi^+ \gamma$	$B^+ \to K^+ \pi^- \pi^+ \gamma$
$B^0 \to \pi^+ \pi^- \pi^0 \gamma$	$B^0 \to K^+ \pi^- \pi^0 \gamma$
$B^0 \to \pi^+ \pi^- \pi^+ \pi^- \gamma$	$B^0 \to K^+ \pi^- \pi^+ \pi^- \gamma$
$B^+ \to \pi^+ \pi^- \pi^+ \pi^0 \gamma$	$B^+ \to K^+ \pi^- \pi^+ \pi^0 \gamma$
$B^+ \to \pi^+ \eta \gamma$	$B^+ \to K^+ \eta \gamma$

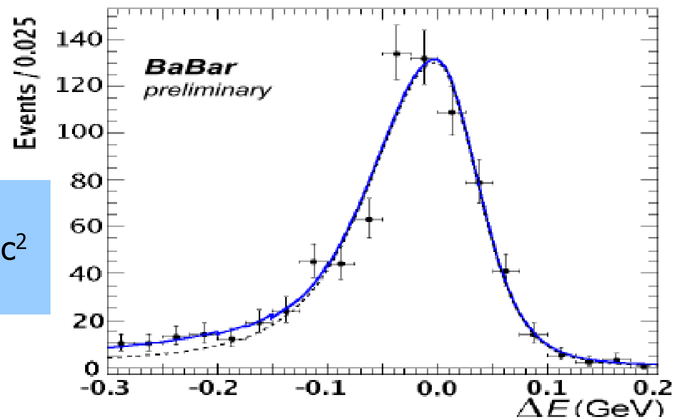
Combine mass ranges for inclusive BFs in $m_{had} < 2.0$ GeV/c^2 and calculate $|V_{td}/V_{ts}|$

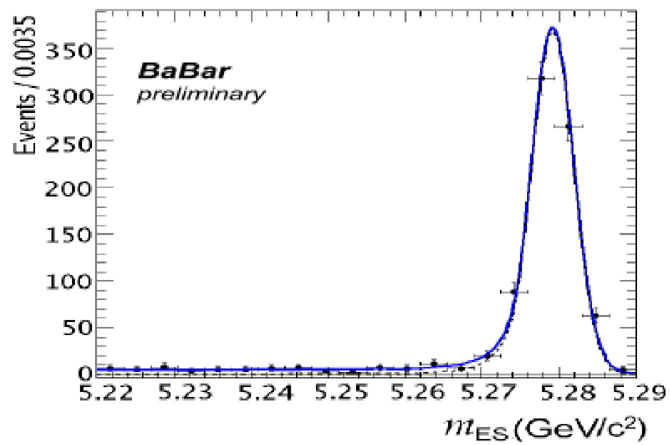
- For $|V_{td}/V_{ts}|$ – need to extrapolate to all masses. This extrapolation is based on theoretical model of photon spectrum, not on experimental data

Measurement of b→dγ, b→sγ, and $|V_{td}/V_{ts}|$

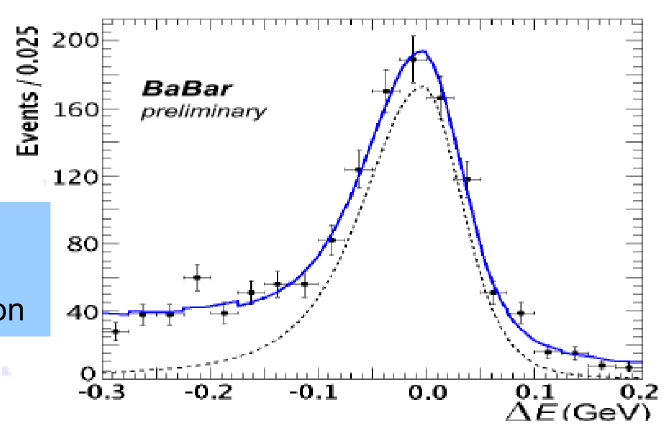
Maximum likelihood fit results for $B \to X_S \gamma$ (M_{ES} and ΔE projections)

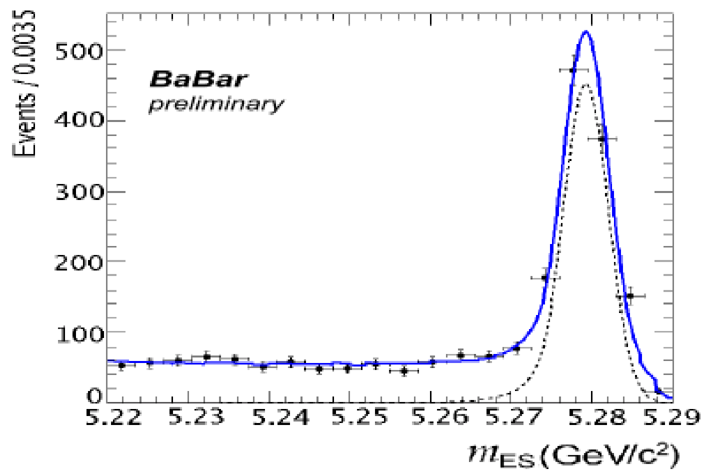
Low mass
(0.5 – 1.0) GeV/c^2
$B \to K^* \gamma$ region





High mass
(1.0 – 2.0) GeV/c^2
non-resonant region





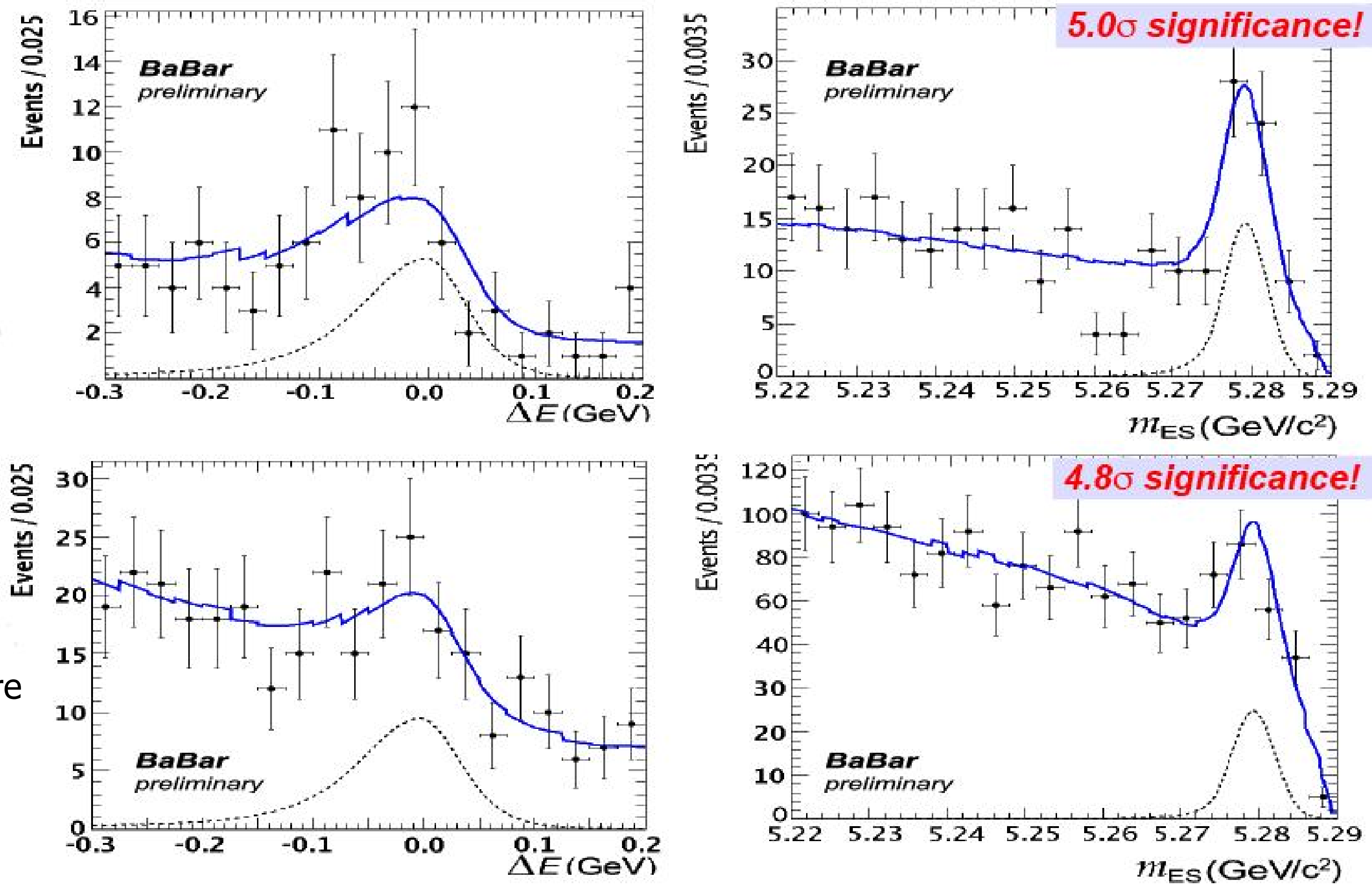
Measurement of b→dγ, b→sγ, and $|V_{td}/V_{ts}|$

Maximum likelihood fit results for $B \to X_d \gamma$ (M_{ES} and ΔE projections)

Low mass
(0.5 – 1.0) GeV/c^2
$B \to (\rho,\omega)\gamma$ region

High mass
(1.0 – 2.0) GeV/c^2
non-resonant region

Jagged line artefacts are due to several binned histogram PDFs



First significant observation of b → dγ nonresonant decay modes

Measurement of $b \to d\gamma$, $b \to s\gamma$, and $|V_{td}/V_{ts}|$

Results:

		Partial BF	Inclusive BF
$B \to X_s\gamma$	low mass	$(1.89 \pm 0.08 \pm 0.08) \times 10^{-5}$	$(3.83 \pm 0.16 \pm 0.15) \times 10^{-5}$
$B \to X_s\gamma$	high mass	$(6.57 \pm 0.28 \pm 0.59) \times 10^{-5}$	$(19.2 \pm 0.8 \pm 1.7 \pm 2.3) \times 10^{-5}$
$B \to X_d\gamma$	low mass	$(1.20 \pm 0.31 \pm 0.11) \times 10^{-6}$	$(1.25 \pm 0.32 \pm 0.12) \times 10^{-6}$
$B \to X_d\gamma$	high mass	$(3.21 \pm 0.81 \pm 0.46) \times 10^{-6}$	$(7.90 \pm 1.98 \pm 1.12 \pm 1.88) \times 10^{-6}$

Inclusive branching fractions for $m_{had} < 2.0$ GeV/c^2:

$$BF(B \to X_s\gamma) = (23.0 \pm 0.8 \pm 1.9 \pm 2.3) \times 10^{-5}$$
$$BF(B \to X_d\gamma) = (9.15 \pm 2.01 \pm 1.24 \pm 1.88) \times 10^{-6}$$

Theoretical formula for |Vtd/Vts| is based on total inclusive BF, so extrapolation of measured inclusive branching fraction to full hadronic mass range is needed. Extrapolation is done according to Kagan-Neubert photon spectrum model [PRD **58**, 094012 (1998)]. Additional error (model) – from b-quark mass uncertainty

$$BF(B \to X_s\gamma) = (38.2 \pm 1.3(\text{stat.}) \pm 3.2(\text{syst.}) \pm 3.8(\text{extrap.}) \pm 1.6(\text{model})) \times 10^{-5}$$
$$BF(B \to X_d\gamma) = (15.3 \pm 3.4(\text{stat.}) \pm 2.1(\text{syst.}) \pm 3.2(\text{extrap.}) \pm 0.3(\text{model})) \times 10^{-6}$$

$$BF(B \to X_d\gamma)/ BF(B \to X_s\gamma) = 0.040 \pm 0.009(\text{stat.}) \pm 0.005(\text{syst.}) \pm 0.010(\text{extrap.})$$

(model error cancels in BF ratio)

Measurement of $b \to d\gamma$, $b \to s\gamma$, and $|V_{td}/V_{ts}|$

$|V_{td}/V_{ts}|$ Extraction:

$$\frac{\Gamma(b \to d\gamma)}{\Gamma(b \to s\gamma)} = \zeta^2 \left|\frac{V_{td}}{V_{ts}}\right|^2 (1 + \Delta R)$$

The values of ζ and ΔR are calculated using the Wolfenstein ρ and η parameters as input. Since the world average of these parameters is based on previous |Vtd/Vts| measurements the ρ and η parameters were re-expressed using world average of CKM angle β [HFAG, E. Barberio *et al*. arXiv:0704.3575(hep-ex)]

Full mass region:
$|V_{td}/V_{ts}|$=0.199±0.022(stat.)±0.012(syst.)±0.027(extrap.) ±0.002(th.)

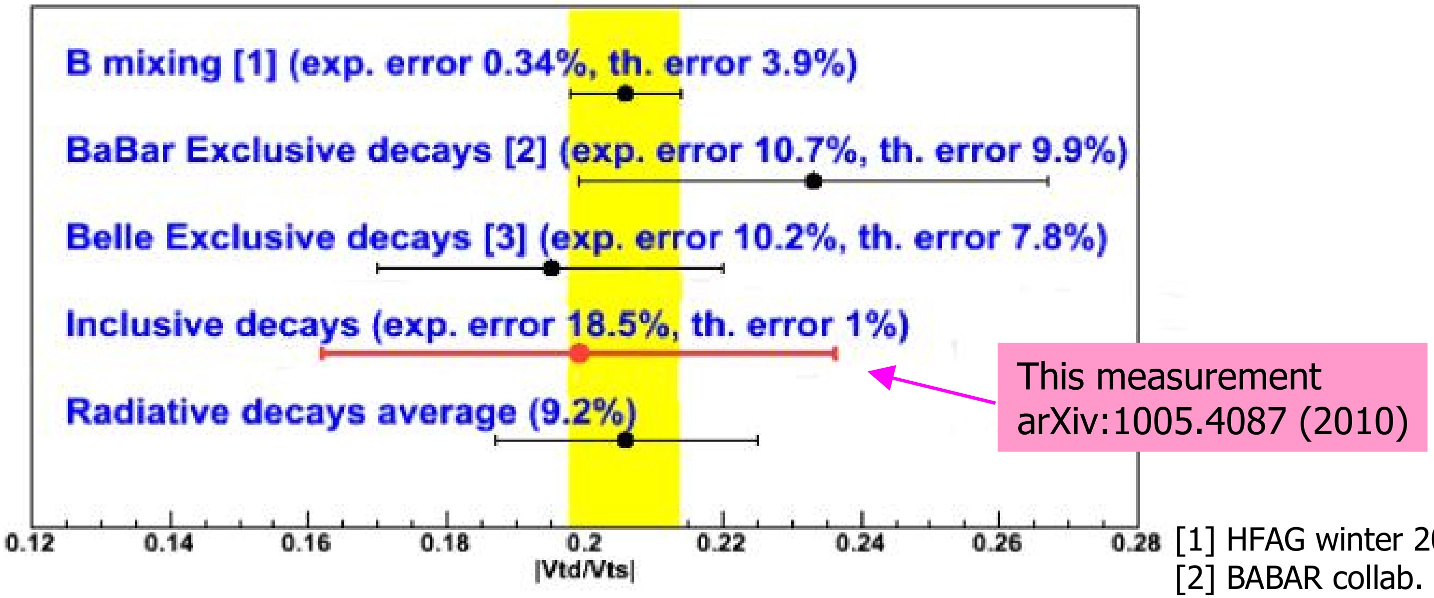
Cross-check: low mass region only:
$|V_{td}/V_{ts}|$=0.197±0.026(stat.)±0.009(syst.)±0.010(th.)

agreement with previous measurements:
BABAR $|V_{td}/V_{ts}|$=0.233±0.025(exp.)±0.023(th.) [BaBar collab. PRL 98, 151802 (2007)]
Belle $|V_{td}/V_{ts}|$=0.195±0.020(exp.)±0.015(th.) [Belle collab. PRL 101, 111801 (2008)]

Measurement of $b \to d\gamma$, $b \to s\gamma$, and $|V_{td}/V_{ts}|$

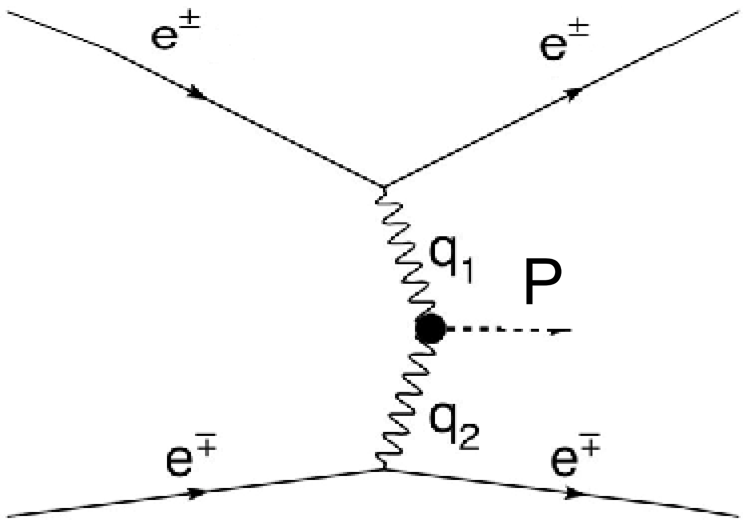
Conclusions

- First significant measurement of non-resonant $b \to d\gamma$ decays
- Measurements of $B \to K^*\gamma$, $b \to s\gamma$, and $B \to (\rho,\omega)\gamma$ are compatible with previous results
- Measurement of $|V_{td}/V_{ts}|$ is compatible and competitive with previous results with significantly smaller theoretical uncertainty.



[1] HFAG winter 2006 results
[2] BABAR collab. PRL 98 151802 (2007)
[3] Belle collab. PRL 101, 111801 (2008)

Study of two-photon processes $e^+e^- \to e^+e^-P$



- Electrons are scattered predominantly at small angles.
- For pseudo scalar meson production the cross section depends on only one form factor $F(q_1^2, q_2^2)$, which describes the $\gamma^*\gamma^* \to P$ transition.

No-tag mode:

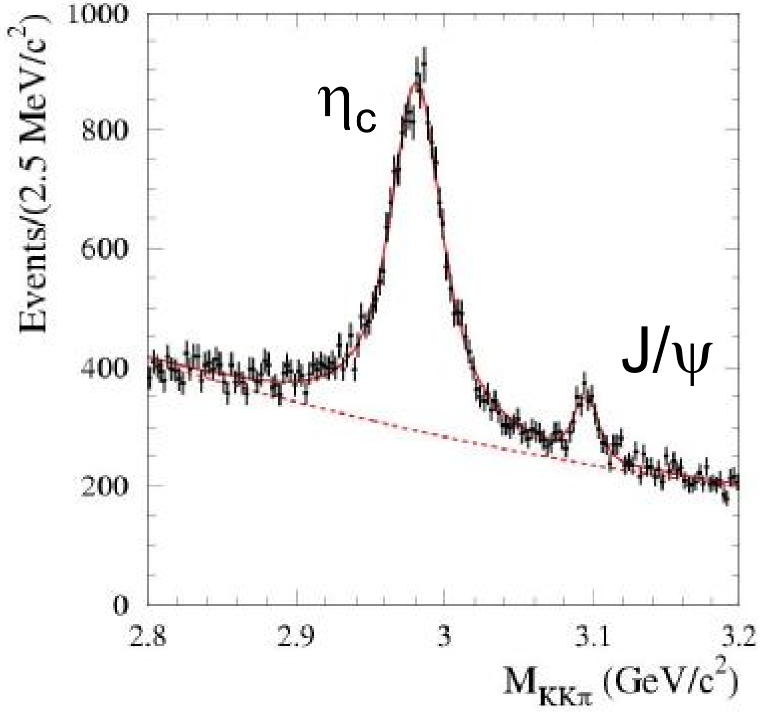
✓both electrons are undetected
✓q_1^2, $q_2^2 \approx 0$
✓$\Gamma_{\gamma\gamma}$ or F(0,0)
✓Study of resonance parameters

Single-tag mode:

✓one of electrons is detected
✓$Q^2=-q_1^2$
✓ $d\sigma/dQ^2 \sim 1/Q^6$ for light mesons
✓$F(Q^2,0)$

$e^+e^- \to e^+e^-\eta_c$, $\eta_c \to K_S K^+\pi^-$, no-tag mode

J.P.Lees et al., PRD **81**, 052010 (2010)



$N(\eta_c)$=13890±320±670

η_c resonance parameters:

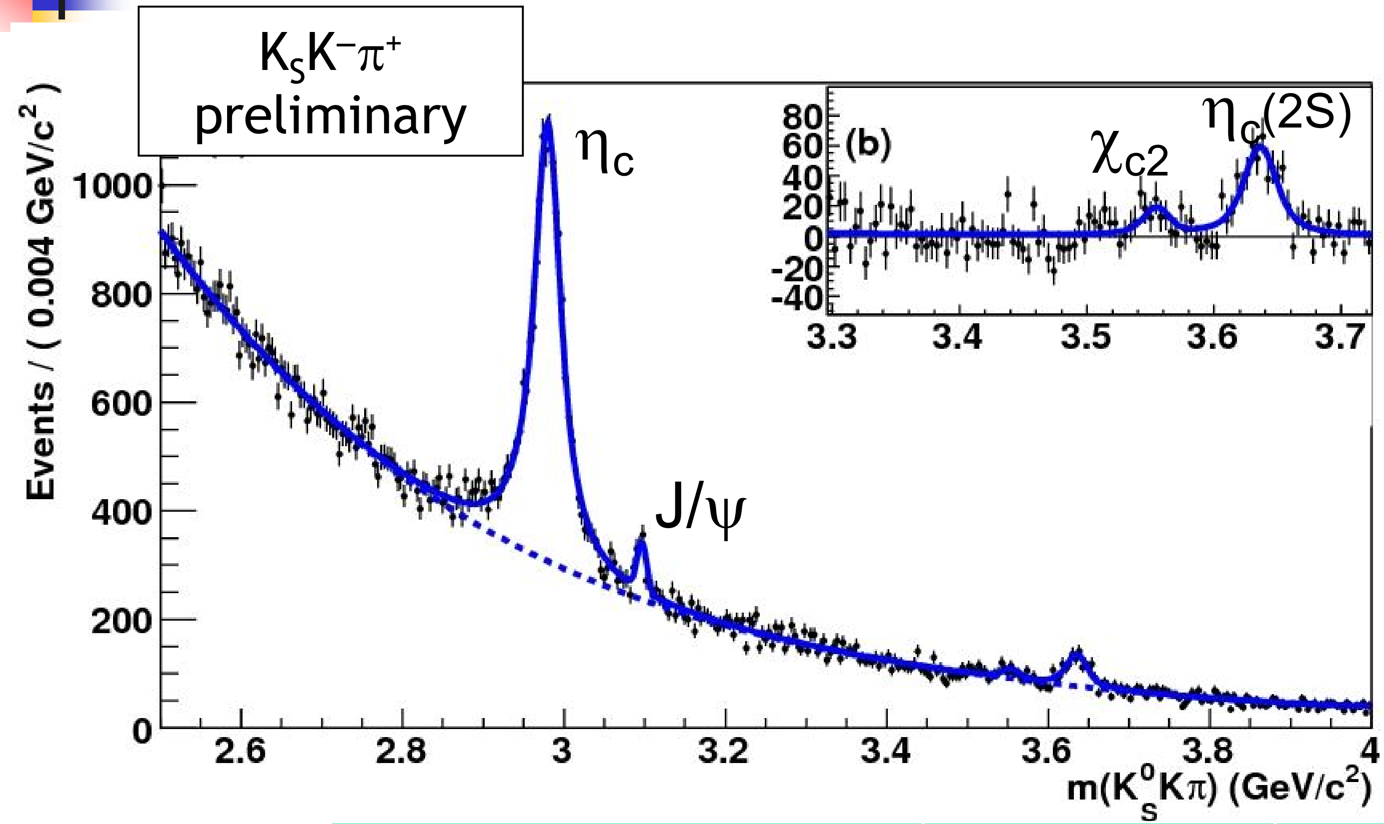
	Mass, MeV	Width, MeV
PDG	2980.5±1.2	27.4±2.9
BABAR(88 fb^{-1})	2982.5±1.1±0.9	34.3±2.3±0.9
BABAR(470 fb^{-1}),	2982.2±0.4±1.5	31.7±1.2±0.8

Main sources of systematic uncertainties are unknown background shape and possible interference between the η_c and non-resonant two-photon amplitudes.

BABAR: $\Gamma(\eta_c\to\gamma\gamma)\mathbf{B}(\eta_c\to KK\pi)$ = 0.379±0.009±0.031 keV

PDG: 0.44±0.04 keV, CLEO: 0.407±0.022±0.028 keV

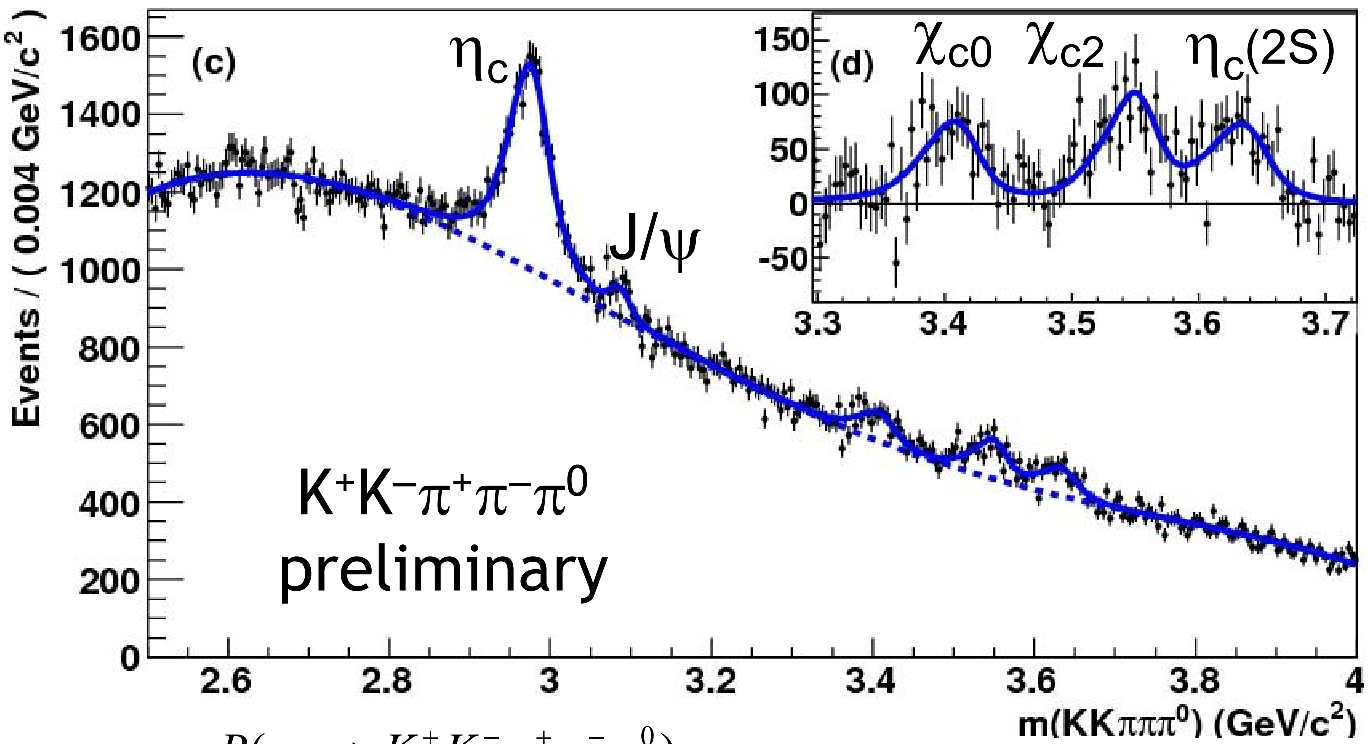
$e^+e^- \to e^+e^-\eta_c(2S)$, no-tag mode



620±70±30 $\eta_c(2S)$ events are observed.

	Mass, MeV	Width, MeV
PDG	3637±4	14±7
BABAR(88 fb^{-1})	3630.8±3.4±1.0	17.0±8.3±2.5
BABAR(521 fb^{-1}), preliminary	3638.3±1.5±0.5	14.2±4.4±2.5

$e^+e^- \to e^+e^-\eta_c(2S)$, no-tag mode



1190±130±180
$\eta_c(2S)$ events are observed.

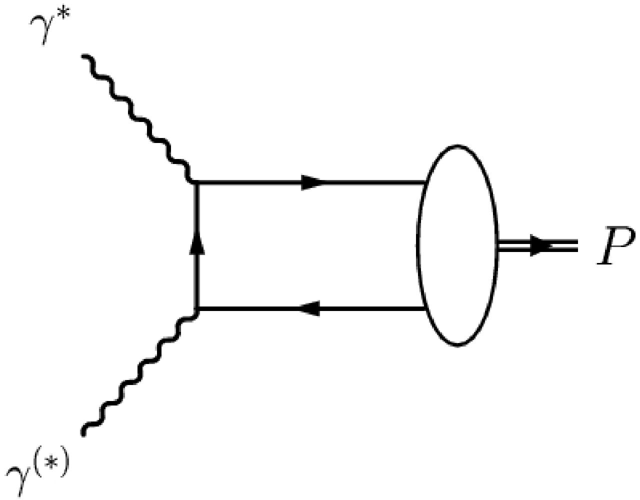
$$\frac{B(\eta_c \to K^+K^-\pi^+\pi^-\pi^0)}{B(\eta_c \to K_S K^\pm \pi^\mp)} = 1.44 \pm 0.06 \pm 0.26,$$

$$\frac{B(\eta_c(2S) \to K^+K^-\pi^+\pi^-\pi^0)}{B(\eta_c(2S) \to K_S K^\pm \pi^\mp)} = 2.2 \pm 0.4 \pm 0.5$$

$e^+e^- \to e^+e^- P$, single tag

$$F(Q^2) = \int_0^1 T(x,Q^2)\,\varphi(x,Q^2)\,dx$$

x is the fraction of the meson momentum carried by one of the quarks

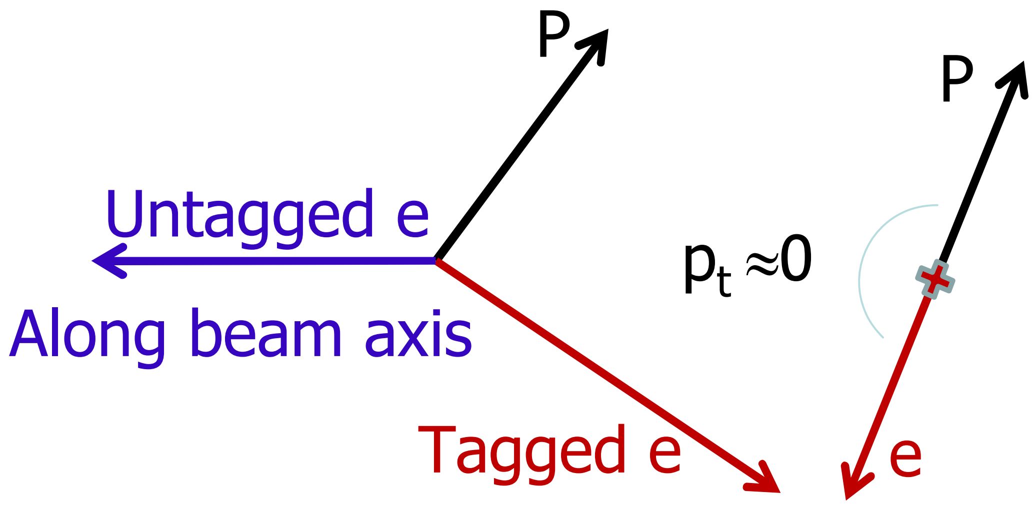


Hard scattering amplitude for $\gamma^*\gamma \to q\bar{q}$ transition which is calculable in pQCD

Nonperturbative pion distribution amplitude (DA) describing transition $P \to q\bar{q}$

Data on the form factor are used to test phenomenological models for the meson distribution amplitude.

$e^+e^- \to e^+e^- P$, single tag event selection



- ✓electron is detected and identified
- ✓meson decay products are detected and reconstructed
- ✓electron + meson system has low p_t
- ✓missing mass in an event is close to zero

$$dN/dQ^2 \Rightarrow d\sigma/dQ^2 \Rightarrow |F(Q^2)|$$

$e^+e^- \to e^+e^- \eta_c$ form factor

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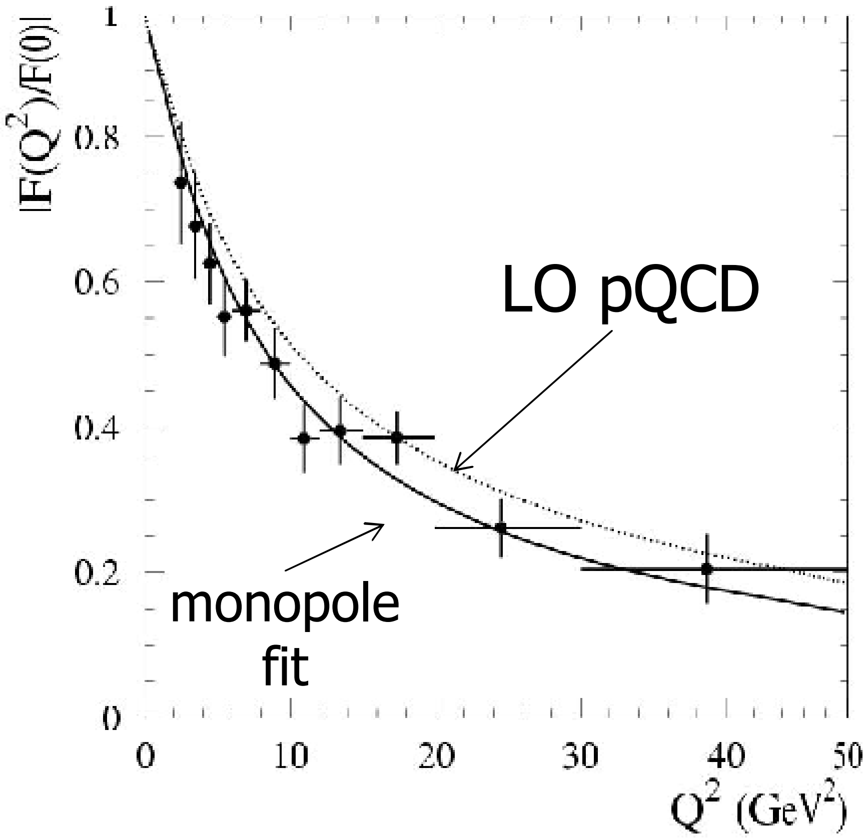
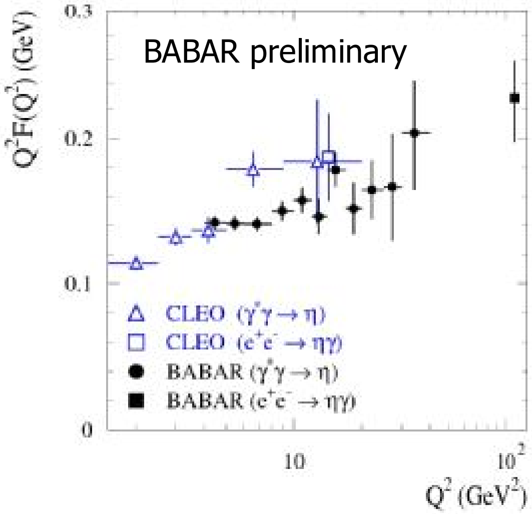


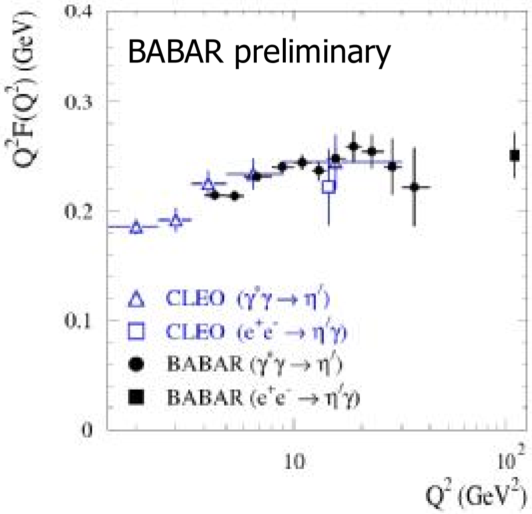
- The form factor is normalized to *F*(0) obtained from no-tag data
- The form factor data are fit with the monopole function

$$F(Q^2) = F(0) \big/ (1 + Q^2 / \Lambda)$$

- The result Λ=8.5±0.6±0.7 GeV² does not contradict to the vector dominance model with $\Lambda = m^2_{J/\psi}$=9.6 GeV².
- pQCD: Due to relatively large c-quark mass, the η_c form factor is rather insensitive to the shape of the η_c distribution amplitude. Λ is expected to be about 10 GeV² (T. Feldmann, P.Kroll, Phys. Lett. B 413, 410 (1997)).
- Lattice QCD: Λ=8.4±0.4 GeV² (J.J.Dudek, R.G.Edwards, Phys. Rev. Lett. 97, 172001 (2006)).

η and η′ form factors





Systematic uncertainties independent of Q^2 are 2.9% and 3.5% for η and η' form factors, respectively

CLEO and BABAR data on time-like form factor extracted from $e^+e^- \to \eta^{(\prime)}\gamma$ cross section measurements at Q^2=14.2 GeV^2 (CLEO) and 112 GeV^2 (BABAR) are added

η-η′ mixing in the quark-flavor basis:

$$|\eta\rangle = \cos\phi|n\rangle - \sin\phi|s\rangle; \quad |\eta'\rangle = \sin\phi|n\rangle + \cos\phi|s\rangle; \text{ where } |n\rangle = \frac{1}{\sqrt{2}}\left(|\bar{u}u\rangle + |\bar{d}d\rangle\right); \ |s\rangle = |\bar{s}s\rangle$$

The form factors for $|n\rangle$ and $|s\rangle$ states are introduced:

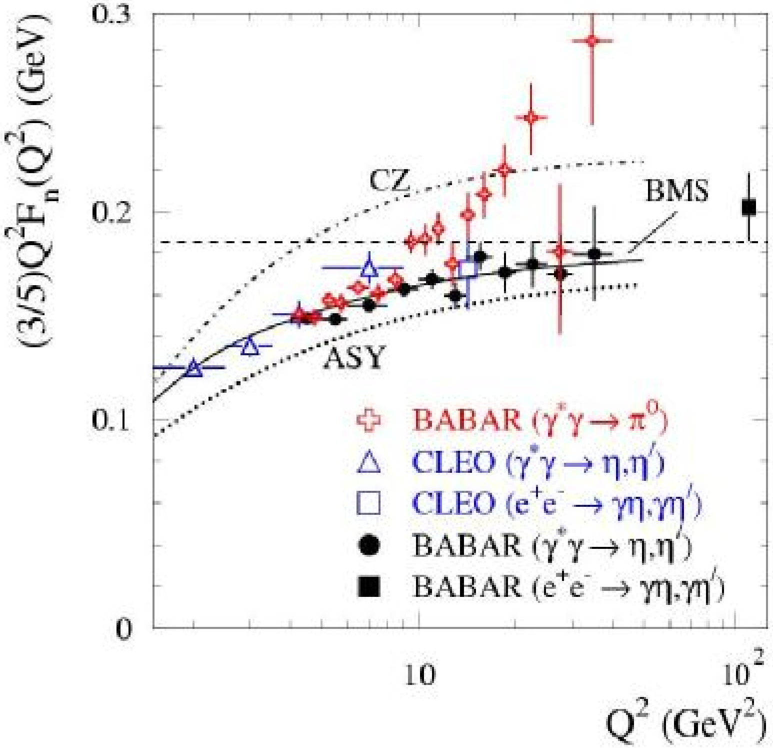
$$F_\eta = \cos\phi F_n - \sin\phi F_s, \quad F_{\eta'} = \sin\phi F_n + \cos\phi F_s$$

$\phi \approx 41°$

with asymptotic limits $Q^2F_s(Q^2) = \frac{2}{3}f_s, \ Q^2F_n(Q^2) = \frac{5\sqrt{2}}{3}f_n$

where decay constants are expected to be $f_n=f_\pi$, fs=1.34f_π , and DA for the $|n\rangle$ state is close to the π^0 DA with the only difference: a factor of 3/5 coming from quark charges

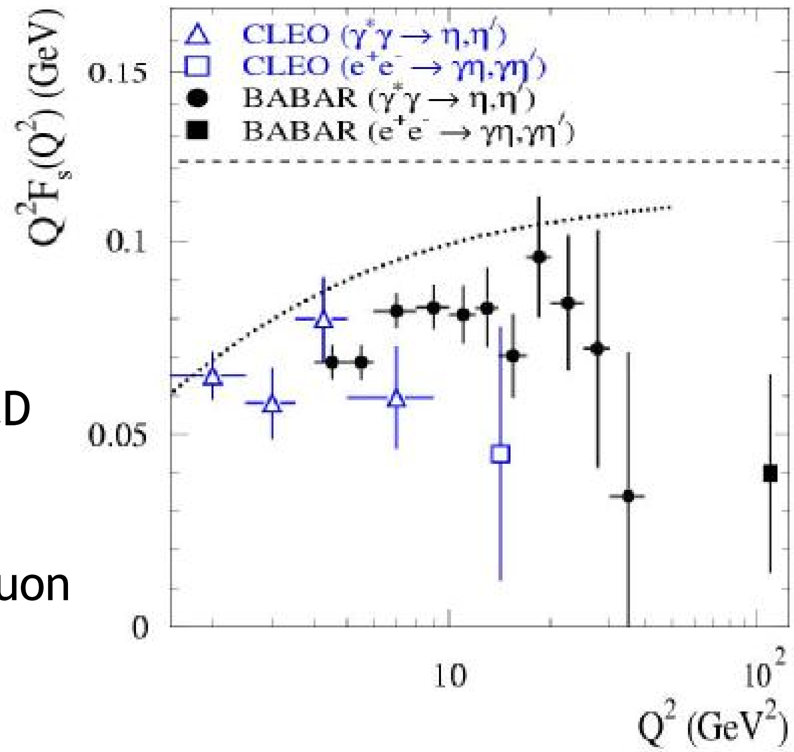
Form factors for |n⟩ and |s⟩ states



- The Q^2 dependencies of the measured |n⟩ and π^0 form factors are strongly different.
- The data on the |n⟩ form factor are described well by the model with BMS DA.

A.P.Bakulev, S.V.Mikhailov, N.G.Stefanis, Phys. Rev. D 67, 074012
light-cone sum rule method at NLO pQCD+twist-4 power corrections.

- For |s⟩ all data points lie well below the pQCD prediction for the asymptotic DA.
- The result for |s⟩ strongly depends on mixing parameters, for example, on a possible two-gluon contents in η' .



Summary

- High accuracy measurement of CKM angle γ by Dalitz-plot analysis with low model uncertainty. Compelling evidence of direct CP violation in $B^{\pm} \rightarrow D^{(*)}K^{(*)\pm}$ decays
- Most presize measurements of the $B^0 \rightarrow \pi^- l^+ \nu$ and $B^0 \rightarrow \rho^- l^+ \nu$ branching fractions, tests of q^2 spectrum agreement with theoretical predictions, and new determination of $|V_{ub}|$
- Study of $B \rightarrow X_d \gamma$ and $B \rightarrow X_s \gamma$ decays, new measurement of $|V_{td}/V_{ts}|$, first significant measurement of $B \rightarrow X_d \gamma$ nonresonant decays
- New precise measurements of the η_c and $\eta_c(2S)$ masses and widths, first observation of the decay modes $\eta_c \rightarrow K^+K^-\pi^+\pi^-\pi^0$ and $\eta_c(2S) \rightarrow K^+K^-\pi^+\pi^-\pi^0$.
- $\gamma\gamma^* \rightarrow \eta_c, \eta, \eta'$ transition form factors are measured in the range from 2 to 50 GeV^2 (η_c) and from 4 to 40 GeV^2 (η, η'). The η_c form factor data are in good agreement with QCD and VDM predicitions. The Q^2 dependencies of η and η' transition form factors strongly differ from that of $\gamma\gamma^* \rightarrow \pi^0$ transition form factor.