Recent results from the Belle and BABAR experiments

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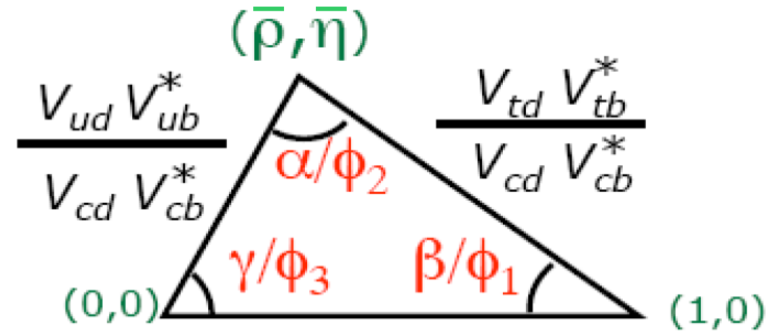
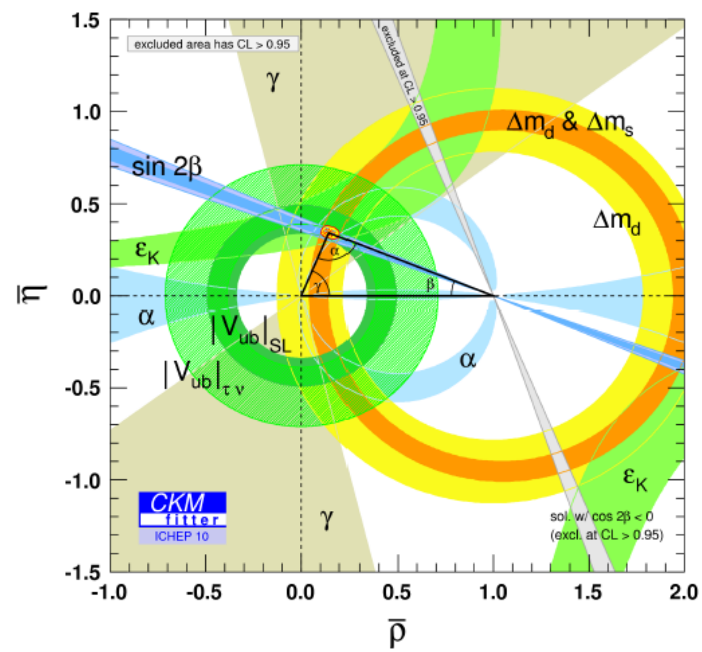
Outline

- γ/ϕ_3 using $B \rightarrow D^{(*)}K^{(*)}$ modes
- $|V_{ub}|$ using inclusive $b \rightarrow u l \nu$ recoil approach and $B \rightarrow \pi l \nu$.

CKM Mechanism confirmed

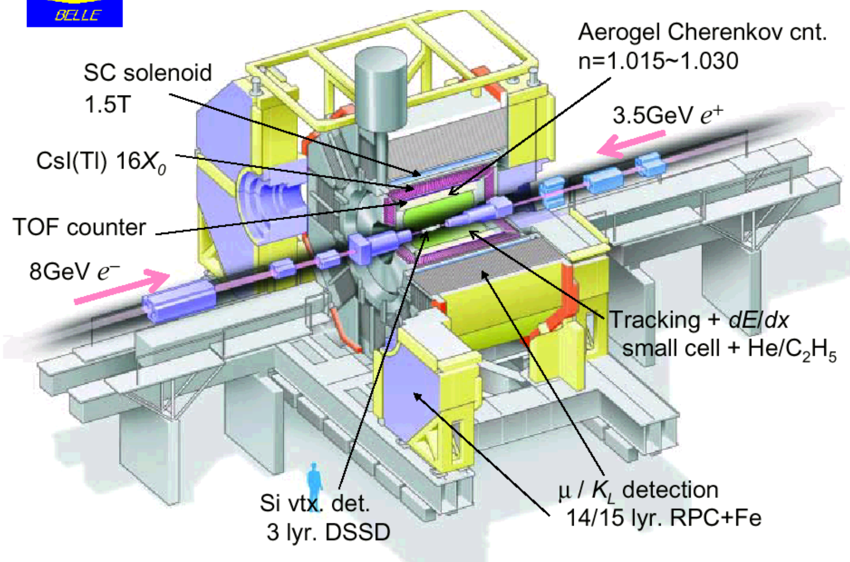
- Current measurements of quark mixing and CP violation are consistent with CKM picture.
- However, our knowledge of b-quark sector of CKM matrix remains limited by experimental uncertainties.
- Improved measurements of least well known components (e.g.,V_{ub} and γ/ϕ_3) will further constrain physics beyond the Standard Model.
- The Belle and BABAR experiments are completing measurements using their final data samples.



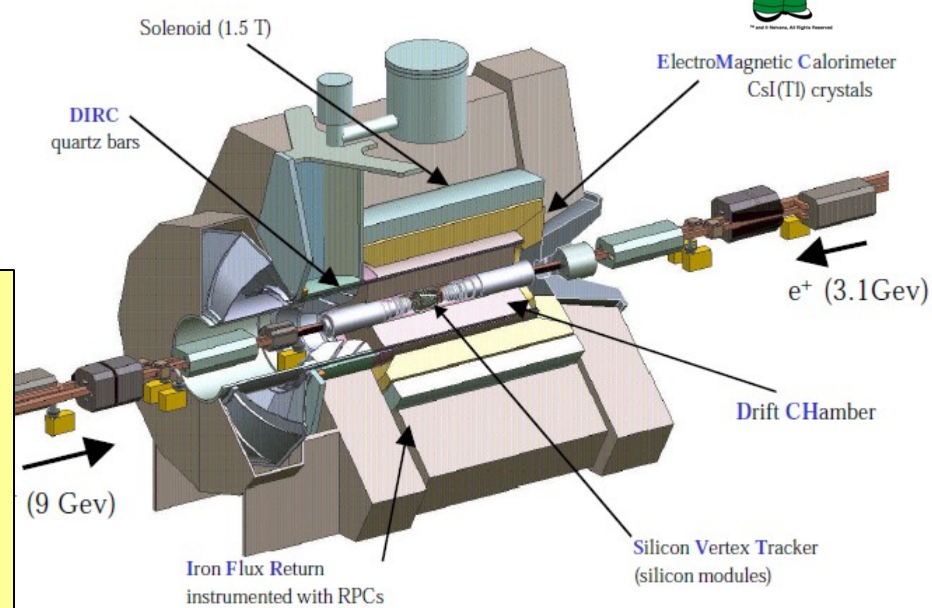


Belle and BABAR experiments:
CKM physics using $e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$ decays

Belle Detector @ KEK

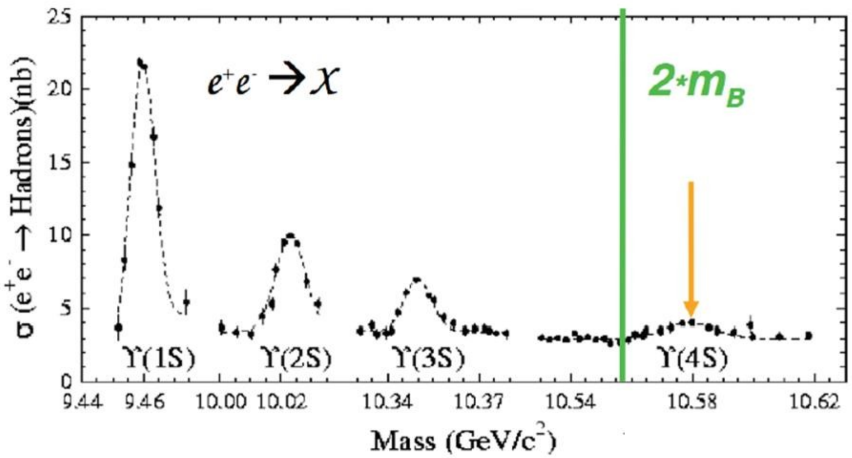


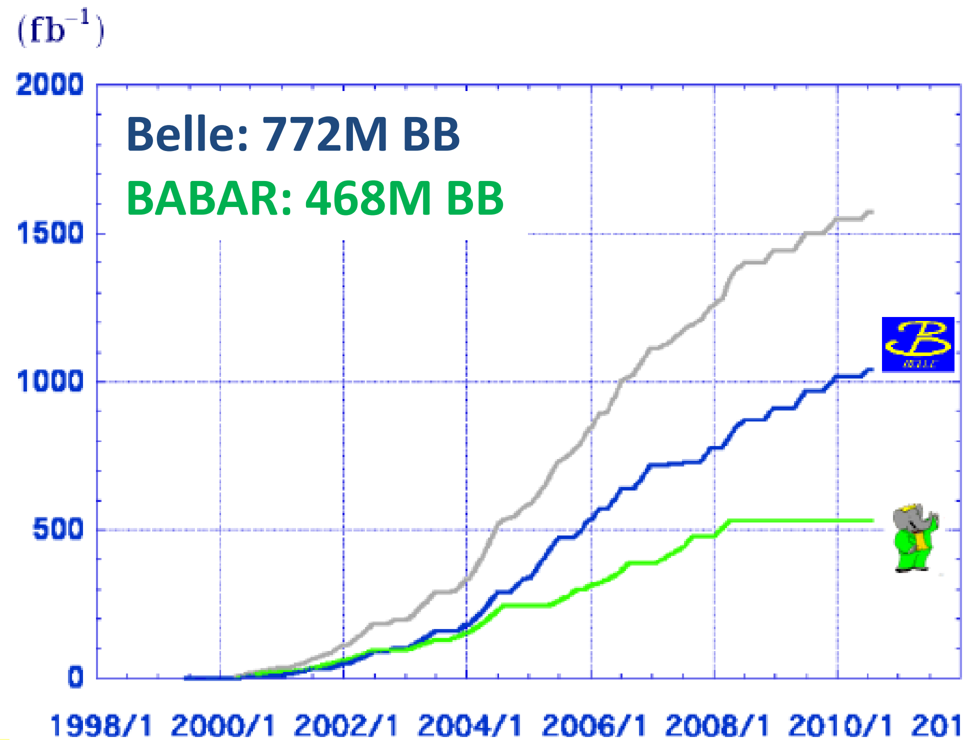
BABAR Detector @ SLAC



- Data collection started 1999
- Both Belle and BABAR are hermetic detectors and have excellent tracking, vertexing and particle ID capabilities
- Boosted center-of-mass enables time-dependent CP-violation analysis

Both experiments are finalizing analysis using their full data sample





Today: New results on:

- γ/ϕ_3 using $B \to D^{(*)}K^{(*)}$ modes
- $|V_{ub}|$ using inclusive $b \to ul\nu$ recoil approach and $B \to \pi l \nu$.

> 1 ab⁻¹

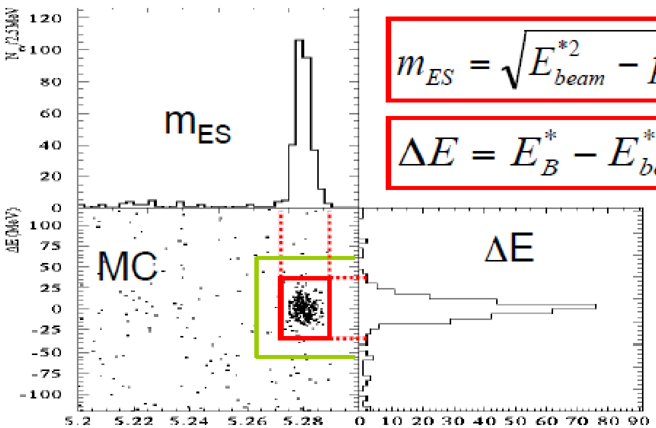
On resonance:
Υ(5S): 121 fb⁻¹
Υ(4S): 711 fb⁻¹
Υ(3S): 3 fb⁻¹
Υ(2S): 24 fb⁻¹
Υ(1S): 6 fb⁻¹
Off reson./scan:
~ 100 fb⁻¹

~ 550 fb⁻¹

On resonance:
Υ(4S): 433 fb⁻¹
Υ(3S): 30 fb⁻¹
Υ(2S): 14 fb⁻¹
Off resonance:
~ 54 fb⁻¹

$B(\Upsilon(4S) \rightarrow BB)$ is ~100%. Achieve clean *B* meson samples by reducing *ee*→*qq* background

Exclusive reconstruction of B decay; kinematic constraint from beam energies

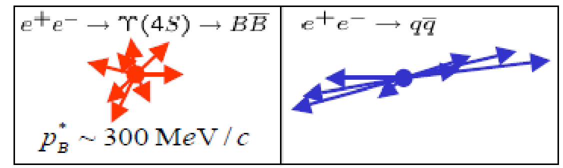


$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

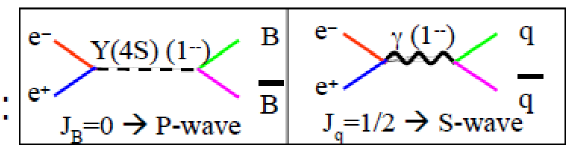
$$\Delta E = E_B^* - E_{beam}^*$$

Continuum ($q\bar{q}$) bkg suppression

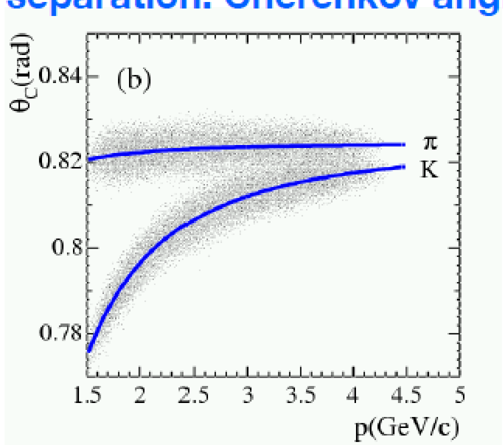
Topology:



Angular distribution:



K/π separation: Cherenkov angle + dE/dx

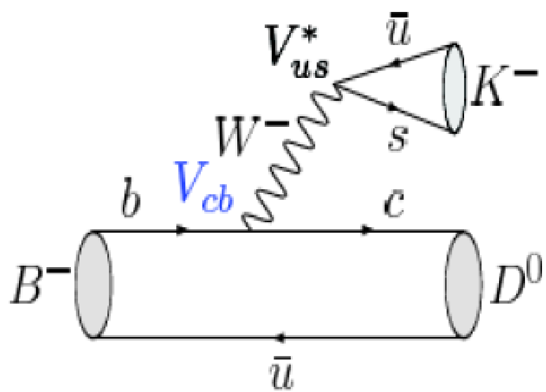


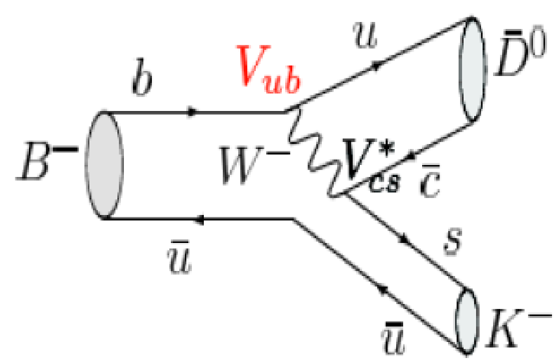
Excellent separation between 1.5 and 4 GeV/c

- Analyses take data driven approach whenever possible.
- Several different multivariate techniques used, particularly for continuum background suppression

$B \rightarrow D^{(*)}K^{(*)}$ decays are a theoretically clean way to measure γ/ϕ_3

Sensitivity to CP violation comes from interference of two tree diagrams ($b \rightarrow c$ and $b \rightarrow u$) in charged or self-tagging neutral $B \rightarrow DK$ decays with final state assessable to both $D^{(*)}$ and $\bar{D}^{(*)}$





Small theoretical uncertainties but experimentally challenging

- Very small branching fractions and generally small interference effects between amplitudes
- Must determine relative amplitude (r_B) and strong phase between $b \rightarrow c$ and $b \rightarrow u$ amplitudes experimentally

Three common approaches using $B \rightarrow D^{(*)}K^{(*)}$ decays

Approach	D decay mechanism	Advantages / Disadvantages
ADS (Atwood, Dunietz, Soni, PRL 78, 3357)	Doubly Cabibbo suppressed $D \rightarrow K\pi$	1. Larger asymmetries (~50%) 2. Smaller rates (BF ~10^{-7}) 3. 4-fold γ ambiguity
GLW (Gronau, London, Wyler, PL B253 483, PL B265 172)	CP eigenstates (Singlely suppressed)	1. Small asymmetries (20-30%) 2. 8-fold γ ambiguity 3. BF ~10^{-6}
GGSZ (Giri,Grossman, Soffer, Zupan, PRD 68, 054018)	Cabibbo favored multibody decays $D \rightarrow K_S\pi^+\pi^-$	1. Larger rates (BF~10^{-5}) 2. Asymmetry varies across D daughter Dalitz plane. Fit to determine γ. 3. 2-fold ambiguity in γ

GGSZ approach: Fit interfering amplitudes in $D \rightarrow K_s\pi^+\pi^-$ and $D \rightarrow K_sK^+K^-$ modes

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

$$A(B^- \rightarrow [K_S\pi^+\pi^-]K^-) \propto$$

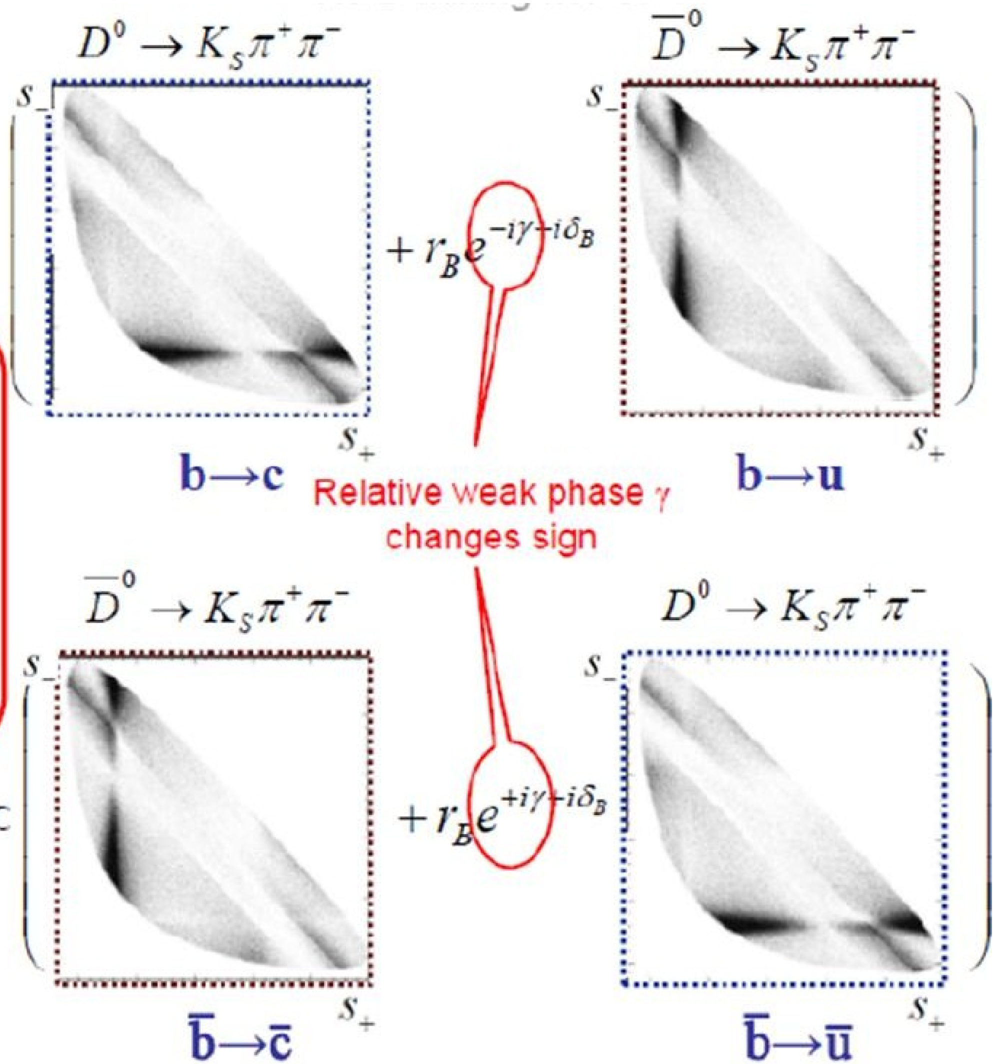
Interference terms in decay rates proportional to

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

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

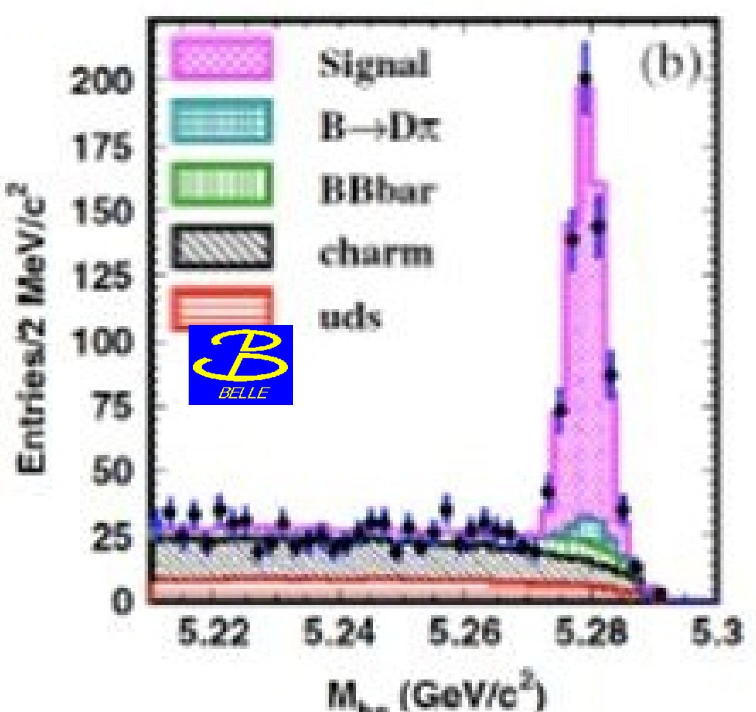
Fit for $x_\pm$ and $y_\pm$ for each B decay mode

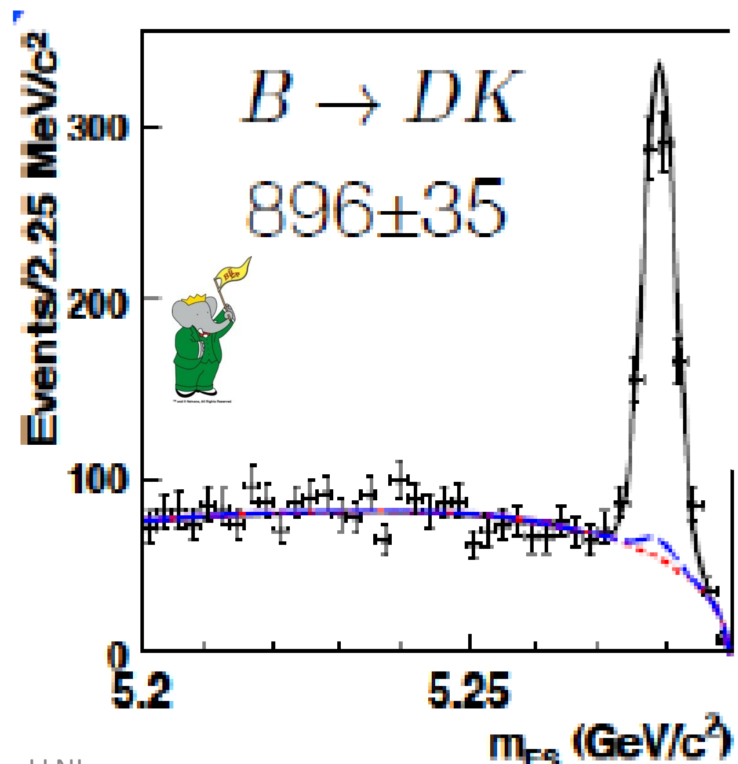
$$A(B^+ \rightarrow [K_S\pi^+\pi^-]K^+) \propto$$



GGSZ event samples: Both experiments still improving analysis method

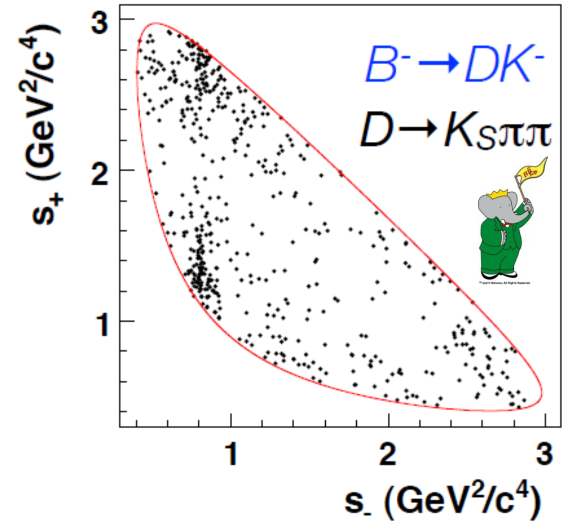
- Belle analysis update adds *D*K* channel with $D^* \rightarrow D\gamma$
- BABAR has improved signal efficiency by ~20% relative to previous result
- The $D \rightarrow K_s\pi\pi$ and $D \rightarrow K_S KK$ Dalitz plot description critical. Both experiments leverage high statistics *D* samples from $e^+e^- \rightarrow q\bar{q}$ events.





GGSZ method results

$$s_{\pm} = m^2(K_S h^{\pm})$$



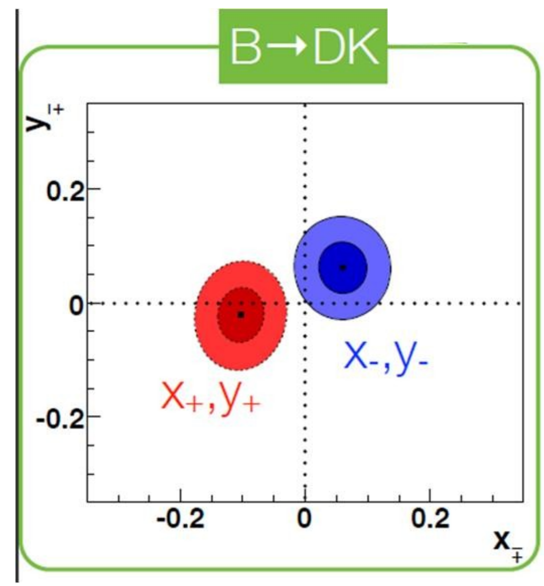
Determine CP parameters for each mode:

$$x_{\pm} = r_{\pm}\cos(\pm\phi_3+\delta)$$
$$y_{\pm} = r_{\pm}\sin(\pm\phi_3+\delta)$$

Both experiments apply a frequentist approach to determine γ from these measurements

$$\gamma(\mathrm{mod}\,180^\circ) = (68 \pm 14 \pm 4 \pm 3)^\circ$$
$$= (78.4^{+10.8}_{-11.6} \pm 3.6 \pm 8.9)^\circ$$

GGSZ is best single approach for measuring γ with current event samples. Final Belle analysis will incorporate model independent approach.



BABAR: PRL 105.121801
Belle: PRD 81.112002

ADS method examines interference of two comparable amplitudes

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

interferes with

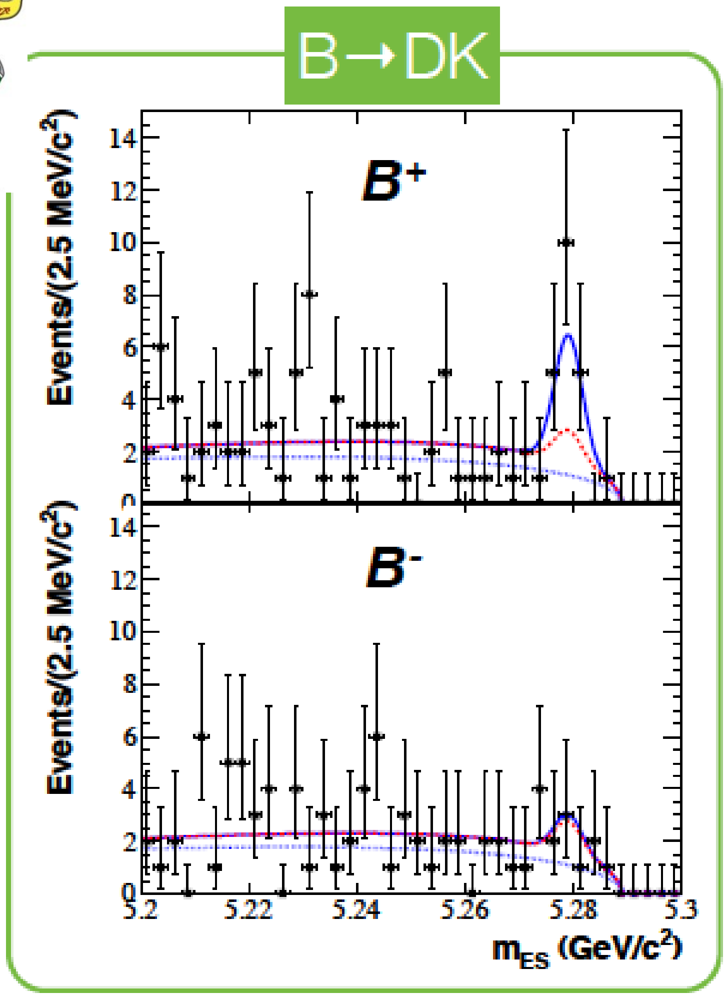
$B^- \to \bar{D}^0 K^-$ *suppressed* $(b \to u)$ *followed by* $\bar{D}^0 \to K^+\pi^-$ *favored* $(\bar{c} \to \bar{s})$

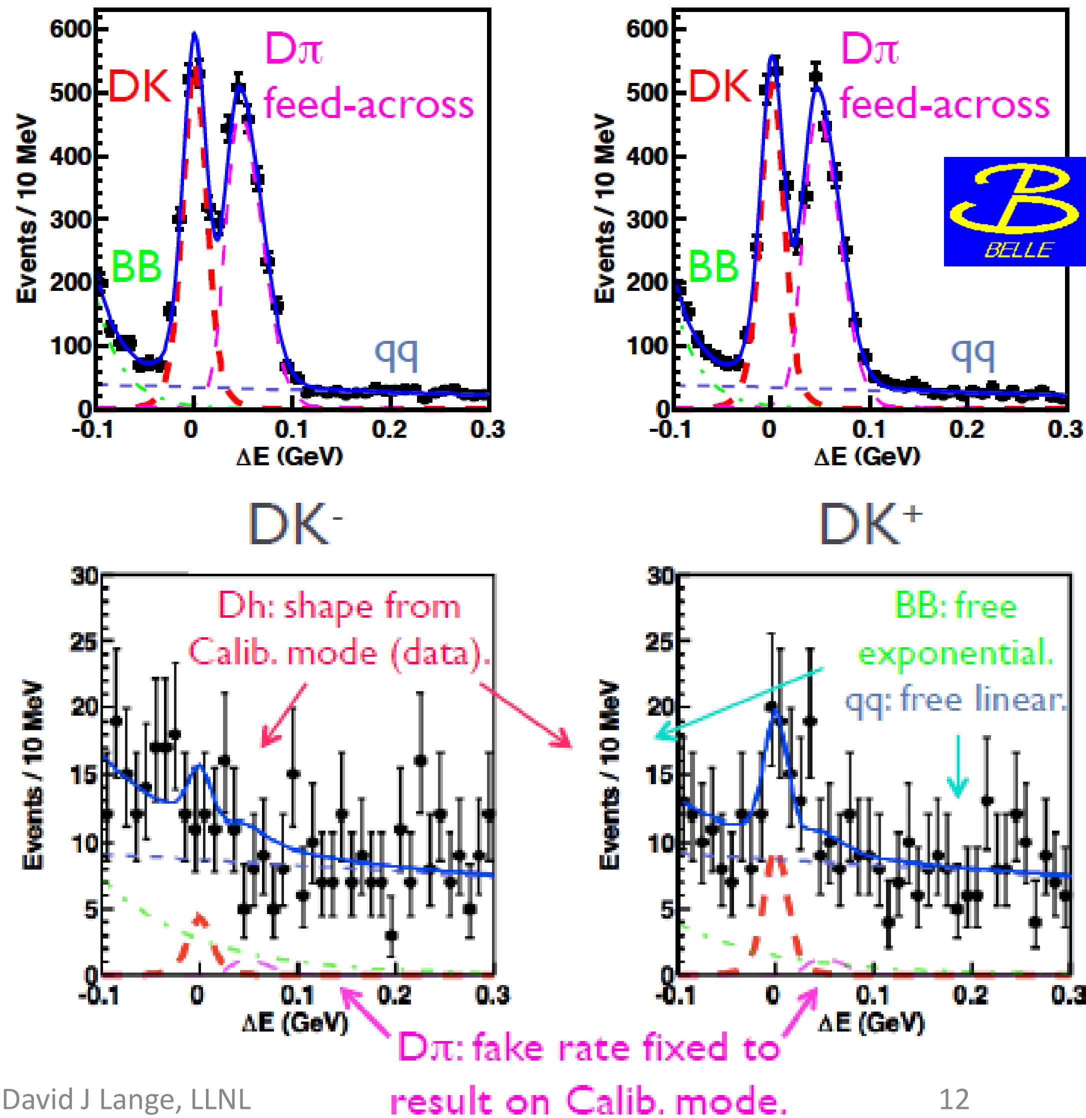
- Use event yields to determine:

$$\mathcal{R}^{(*)\pm} \equiv \frac{\Gamma([K^{\mp}\pi^{\pm}]_D K^{\pm})}{\Gamma([K^{\pm}\pi^{\mp}]_D K^{\pm})} = r_B^{(*)2} + r_D^2 + 2\lambda r_B^{(*)} r_D \cos(\pm\gamma + \delta_D + \delta_B^{(*)})$$

- Primary background is qq continuum. Updated Belle analysis adds NeuroBayes neural network
- Use PID and kinematics to remove potential peaking backgrounds
- CLEO-c measurements determine δ_D and r_D

Belle reports first evidence of ADS signal
BABAR reports 2.1σ signal in *B→DK* and 2.2σ in *B→D*K*

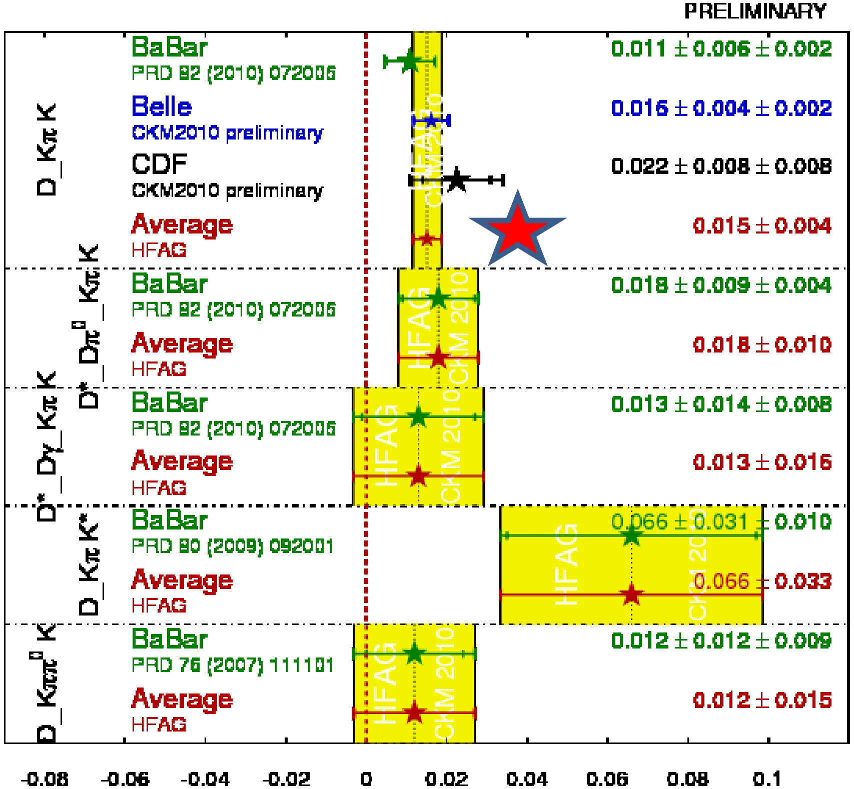




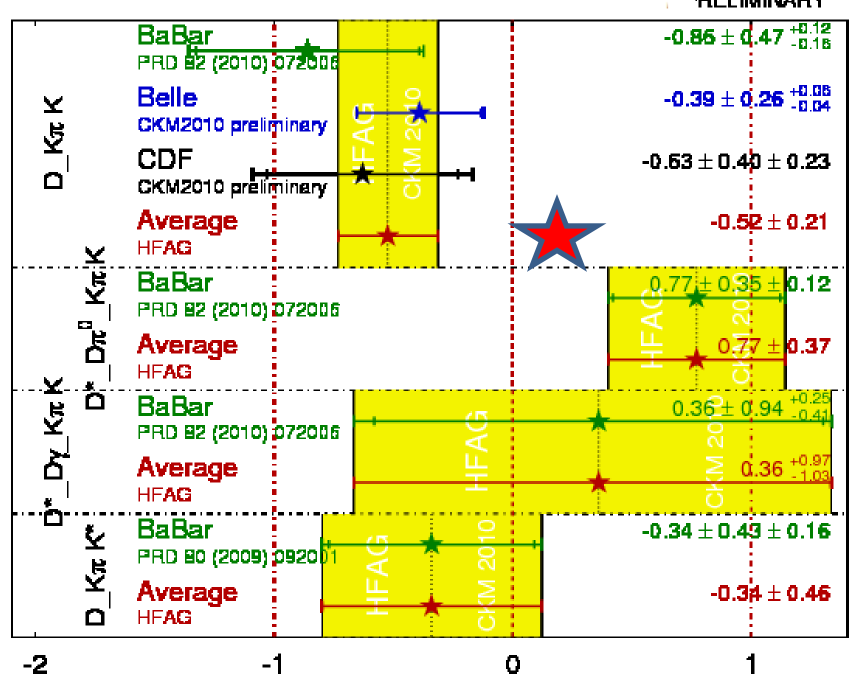
BABAR: PRL 82.072006
Belle: Preliminary

Together the experiments begin to see indication of direct CP violation (A_{ADS})

$$\mathcal{R}_{DK} \equiv \frac{1}{2}(\mathcal{R}^+_{DK} + \mathcal{R}^-_{DK})$$



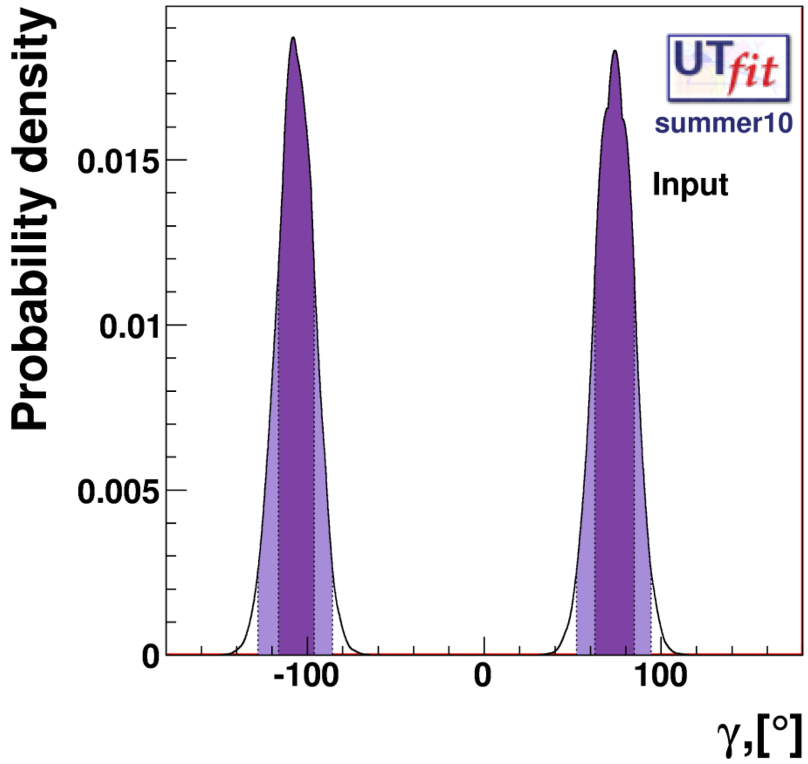
$$\mathcal{A}_{DK} \equiv \frac{\mathcal{R}^-_{DK} - \mathcal{R}^+_{DK}}{\mathcal{R}^-_{DK} + \mathcal{R}^+_{DK}}$$



$$R_{ADS}(DK) = 0.015 \pm 0.004$$

$$A_{ADS}(DK) = -0.52 \pm 0.21$$

γ summary: *B→DK* makes ±11° measurement. Consistent with unitarity constraint on γ

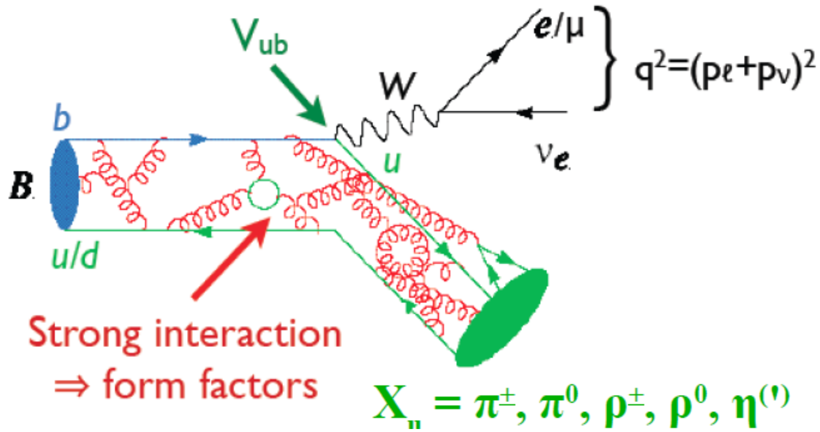


- UT Fit results:

Direct measurement	**(74 ± 11)°**	**Prediction from other parameters**	**(69.6 ± 3.1)°**

Determine $|V_{ub}|$ from measurements of inclusive and exclusive semileptonic decays

Inclusive
$b \to u l \nu$



Exclusive
$B \to \pi l \nu$

$$\Gamma(\bar{B} \to X_u \ell \bar{\nu}) = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3} \left[1 + \mathcal{O}(\alpha_s) + \mathcal{O}(1/m_b^2) + \text{h.c.}\right]$$

Free quark decay — Perturbat. corrections — Non perturb. corrections

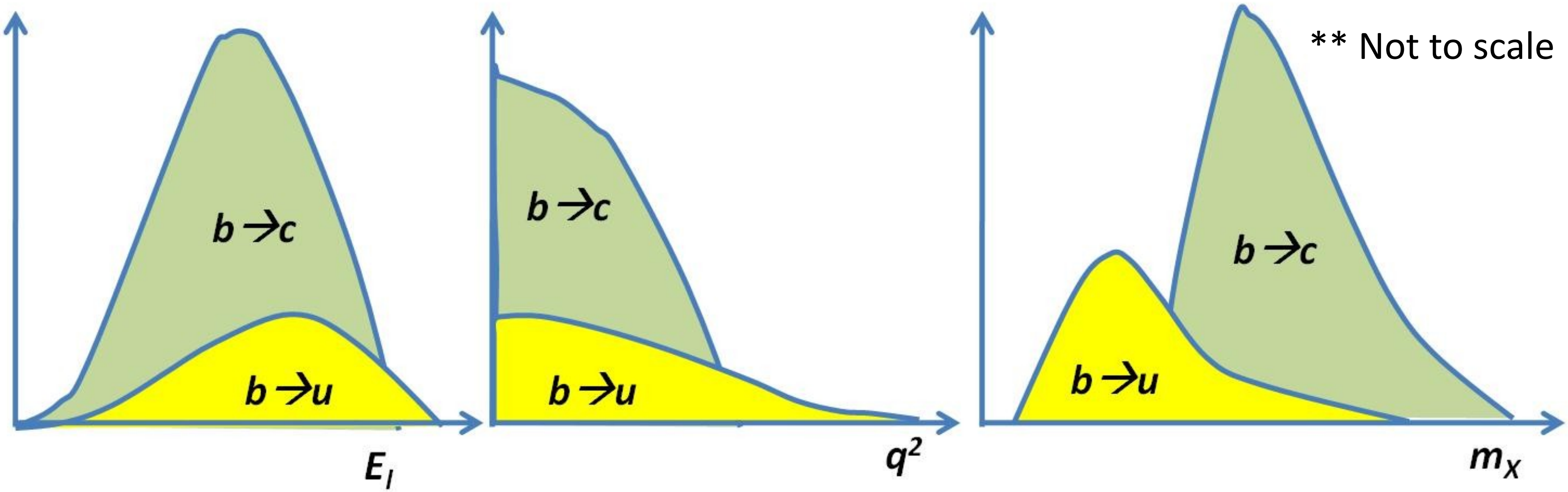
- OPE in α_s and Λ/m_b
- Theory uncertainty on total decay rate is below 5%

$$\frac{d\Gamma}{dq^2}(B \to \pi l \nu) = \frac{G_F^2}{24\pi^3} p_\pi^3 |V_{ub}|^2 |f_+(q^2)|^2$$

- A number of QCD approaches to form factors calculation.
- Smaller exp. event samples

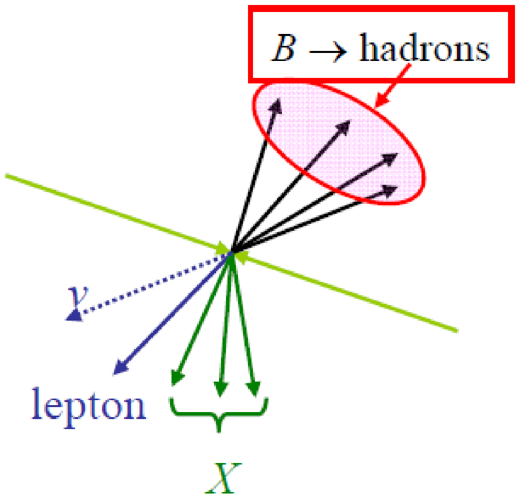
Experimental challenge: Maintain sensitivity to as much of the $b \to u l \nu$ kinematic range as possible

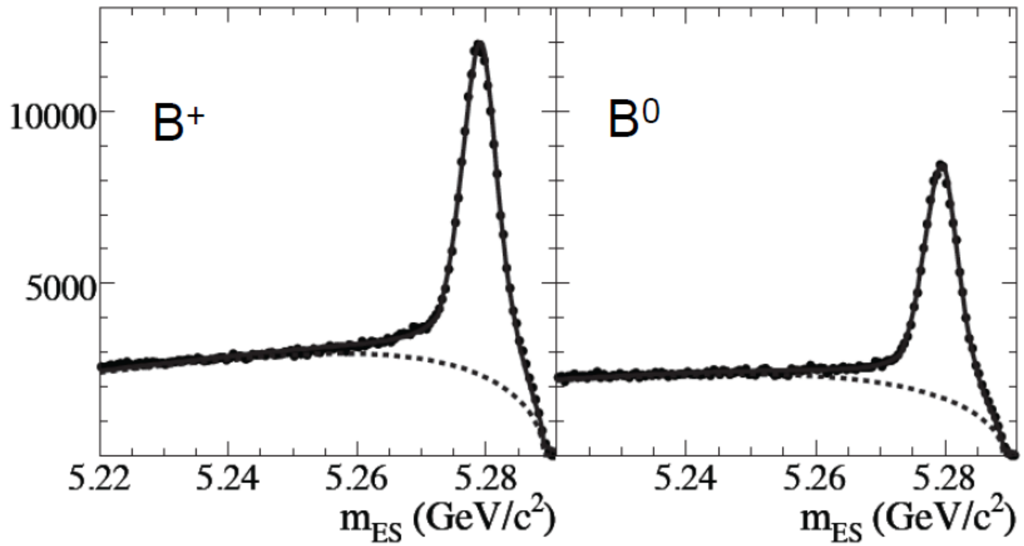
Experimental techniques to reduce $b \rightarrow c l \nu$ have expanded kinematic reach beyond endpoint region



- Use large data samples allow us to trade efficiency to extend sensitivity into a larger portion of kinematic range.
- Both inclusive and exclusive approaches have moved far below traditional $b \rightarrow c$ endpoint analysis.
- Extrapolation of experimental results to full kinematic range is still an important factor in $|V_{ub}|$ determination

Recoil analysis method provides best method to measure inclusive $b \rightarrow u l \nu$ decays

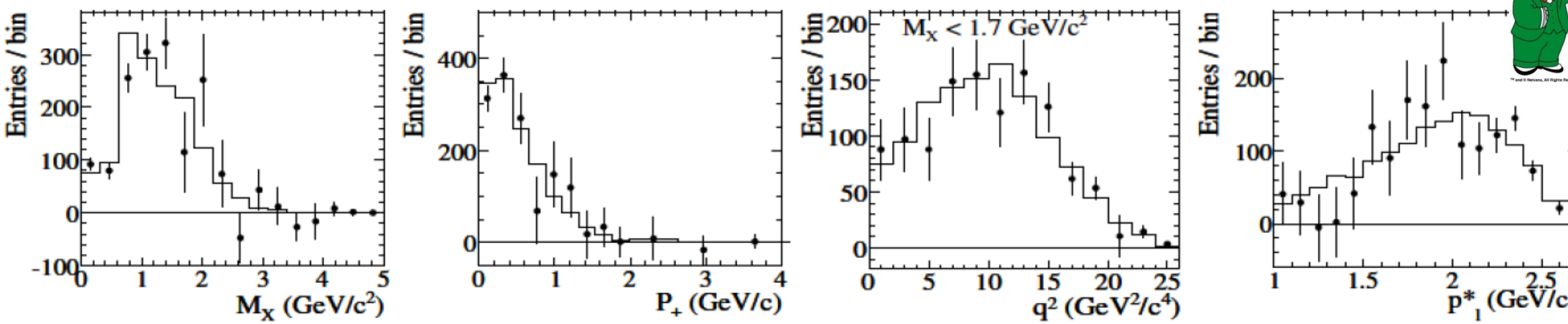




Full reconstruction of B decays using ~1000 of $b \rightarrow c$ hadronic decays

- Low efficiency (~0.04%) but kinematics of signal B decay are completely determined
- Analyze rest of event for $b \rightarrow u l \nu$ signature. Require lepton and use kinematics and particle ID mechanisms to reduce $b \rightarrow c l \nu$ contribution.

BABAR and Belle results on inclusive $b \to ul\nu$ using recoil analysis



Background subtracted distributions

- Joint fit kinematic distributions.
- Sensitivity to $b \to ul\nu$ signal down to lepton p* of 1 GeV.
- Use background sidebands to improve MC modeling of $b \to cl\nu$ contribution.
- Systematic errors primarily from uncertainty in signal kinematic distributions

p*>1 GeV

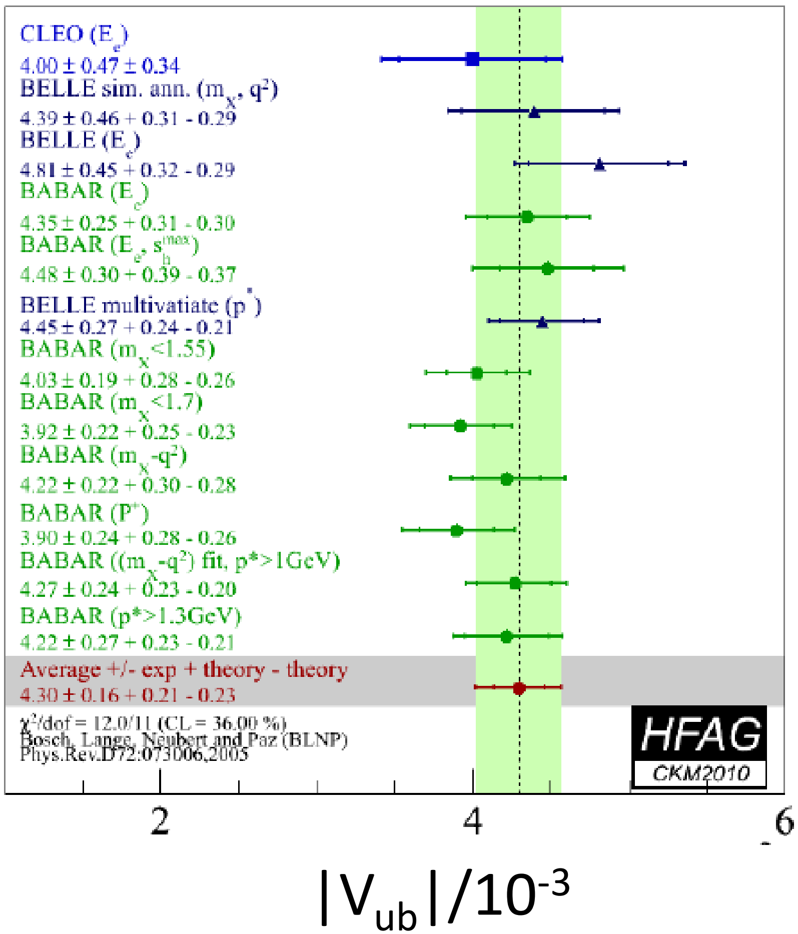
$$\Delta B(X_u l\nu) = (1.80 \pm 0.13 \pm 0.15)x10^{-3}$$

$$= (1.963 \pm 0.17 \pm 0.16)x10^{-3}$$

BABAR: Preliminary
Belle: Preliminary

Summary of |Vub| with inclusive measurements

Inclusive $b \rightarrow ul\nu$ measurements using BLNP model for $\Delta\Gamma$



Theoretical calculation	Experimental average
BLNP (Bosch,Lange, Neubert, Paz, PRD72:073006)	$4.30 \pm 0.16^{+0.21}_{-0.23}$
DGE (Andersen, Gardi, HEP 0601:097)	$4.37 \pm 0.15^{+0.17}_{-0.16}$
GGOU (Gambino, Giordano, Ossola, Uraltsev, JHEP 0710:058)	$4.30 \pm 0.16^{+0.13}_{-0.20}$
ADFR (Aglietti, Di Lodovico, Ferrara, Ricciardi, arXiv:0711.0860)	$4.05 \pm 0.13^{+0.24}_{-0.21}$

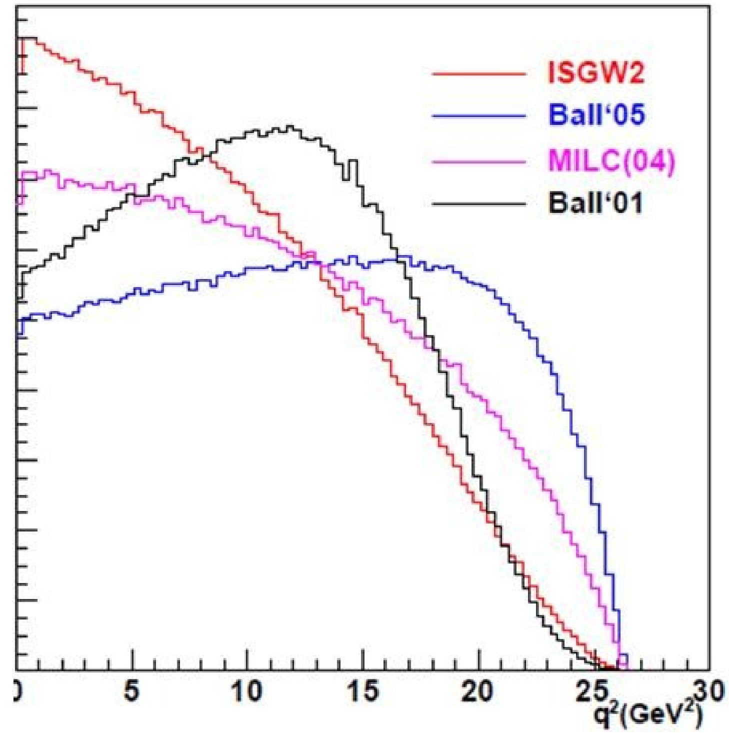
Exclusive $b \to ul\nu$ determinations of $|V_{ub}|$

- $|V_{ub}|$ is related to differential branching fraction for $B \to \pi l \nu$ by q^2 dependent form factor

$$\frac{d\Gamma(B \to \pi l \nu)}{dq^2} = \frac{G_F^2 |V_{ub}|^2}{192\pi^3 m_B^3} \lambda(q^2)^{3/2} |f_+^{\pi}(q^2)|^2$$

- Experimentally measure branching fraction in portion of kinematic range
- Use theory predictions for $|f_+(q^2)|$ to extrapolate to full kinematic range and to $|V_{ub}|$

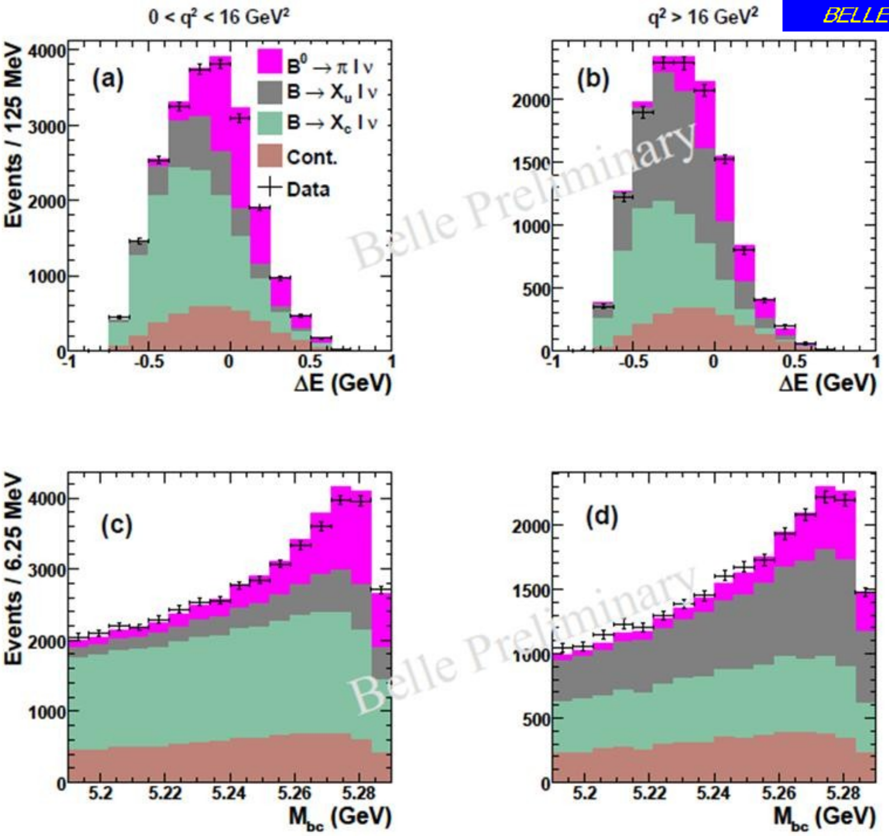
$d\Gamma(\pi l \nu)/dq^2$



Clean e^+e^- environment allows us to inclusively reconstruct neutrino kinematics

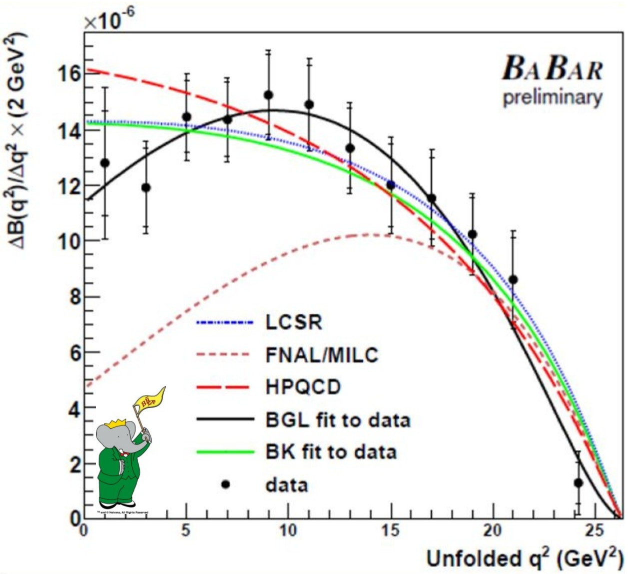
- Exclusively reconstruction π+l, then examine rest of event to make best estimate of missing neutrino momentum.
- Several methods developed that trade off signal efficiency for sample purity.
- Extract partial branching fractions in bins of q^2.
- $B \to \pi l \nu$ is most sensitive mode, however analyses include other channels including $\rho l \nu, \eta l \nu$, and $\eta' l \nu$.

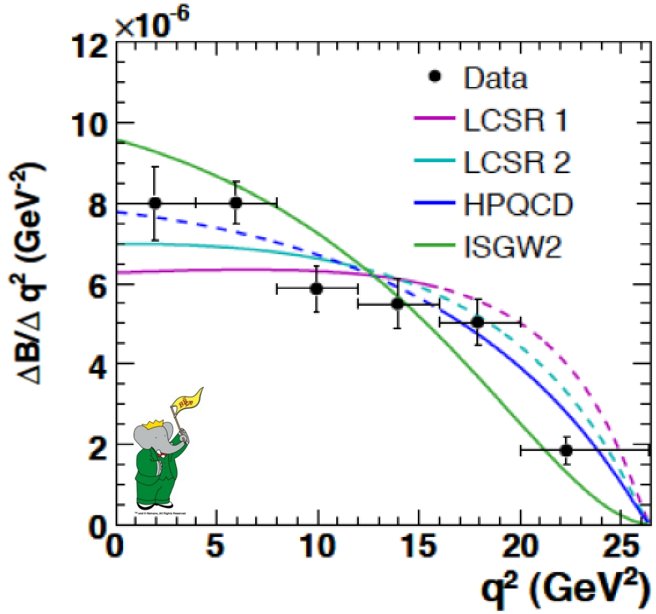
Signal region fit projections

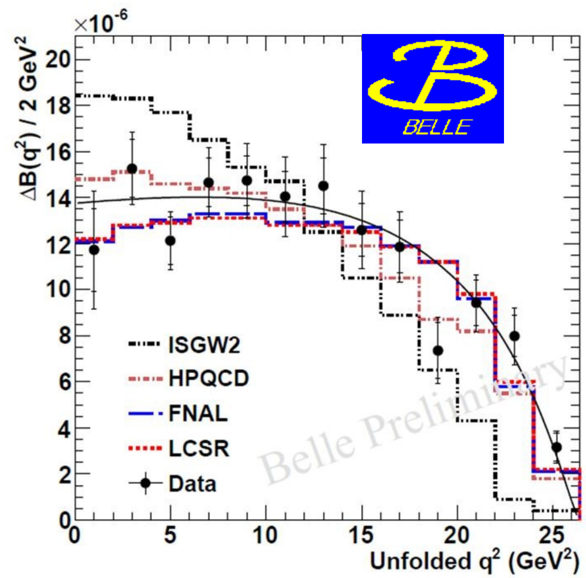


New results from two BABAR analyses and one Belle analysis.

Partial branching fraction as function of q^2 can then be compared to theory







	BABAR hep-ex/1010.0987	BABAR hep-ex/1005.3288	Belle hep-ex/1012.0090
$BF(B\rightarrow\pi l\nu)/10^{-4}$	1.49±0.04±0.07	1.49±0.04±0.07	1.49±0.04±0.07
$BF(B\rightarrow\rho l\nu)/10^{-4}$		1.75±0.15±0.27	
$BF(B\rightarrow\eta l\nu)/10^{-5}$	3.61±0.45±0.44		
$BF(B\rightarrow\eta' l\nu)/10^{-5}$	2.43±0.80±0.34		

$B \rightarrow \pi l \nu$ constraint on $|V_{ub}|$: Reduce total uncertainty from combined experimental and LQCD fit

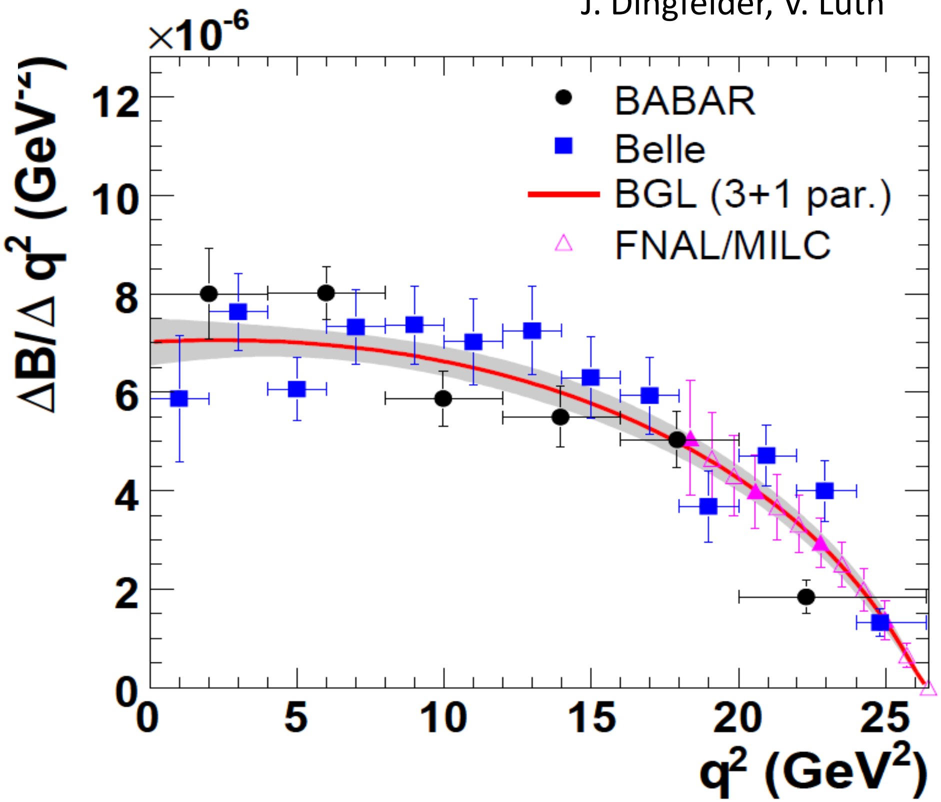
- Perform joint fit using Belle and BABAR data together with LQCD predictions (and uncertainties)
  [approach: FNAL/MILC PRD79:054507]:

$$\chi^2 = \chi^2(\text{data}) + \chi^2(\text{lattice})$$

- This approach reduces the total uncertainty due to the extrapolation to the full kinematic range significantly:

$$|V_{ub}| = (3.26 \pm 0.33)x10^{-3}$$

Average by
J. Dingfelder, V. Lüth



Summary and Outlook

- Measurements of γ with $B \rightarrow DK$:
  - Number of new results from both experiments.
  - GGSZ approach using $D \rightarrow K_s \pi\pi$ Dalitz analysis gives most stringent constraint on γ.
  - First evidence for ADS mode reported by Belle
  - Direct determinations of γ are consistent with indirect CKM constraints on γ.
- Measurements of $|V_{ub}|$:
  - New results using both inclusive and exclusive $b \rightarrow ul\nu$ decays
- Larger data samples needed to test CKM to higher precision and resolve possible tension between $|V_{ub}|$ determined from inclusive $b \rightarrow ul\nu$, exclusive $b \rightarrow ul\nu$ and $B \rightarrow \tau\nu$.