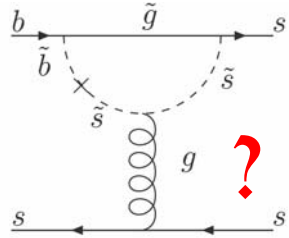
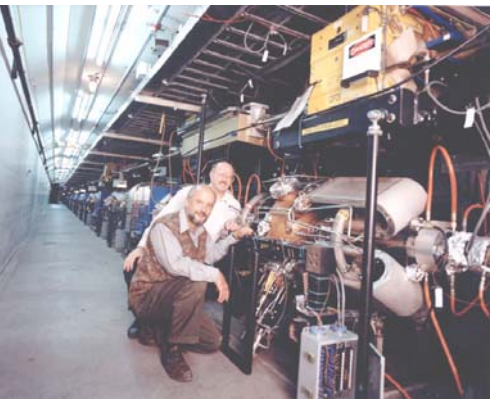
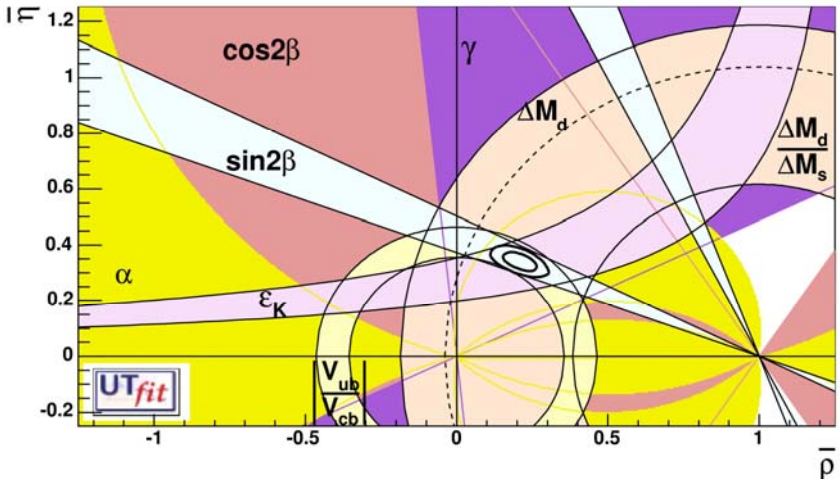
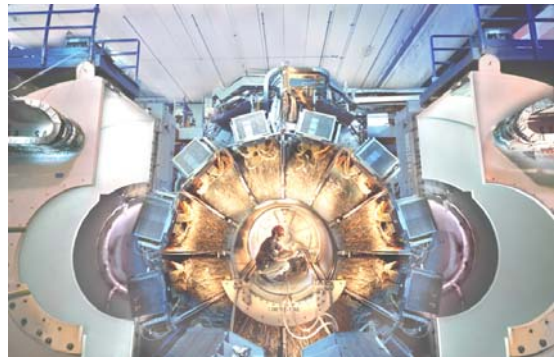
B and Super-B Factories

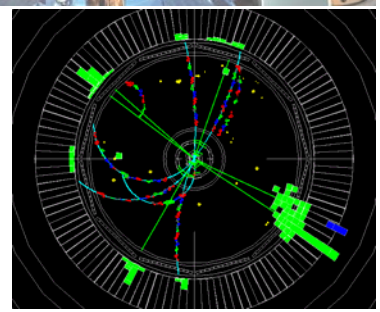
Science, Achievements, Outlook

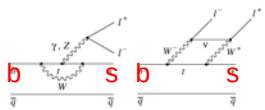


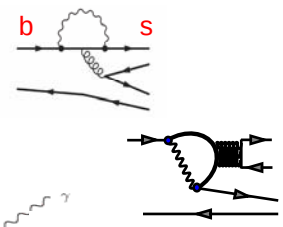


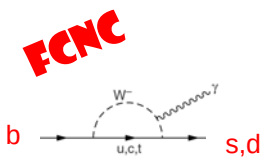


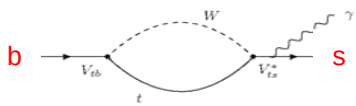


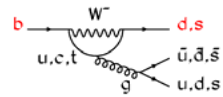












Christos Touramanis

PPAP Report, 9 March 2005

BABAR™

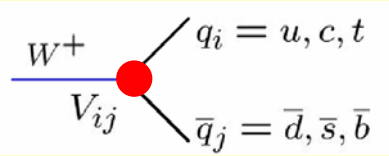
THE UNIVERSITY of LIVERPOOL

Flavor physics in B-Factories

- Science Case
- Delivery (data, results, publications)
- Outlook
- Super-B Factory
- Conclusions

Our primary physics objective

Flavor Physics is concerned with:

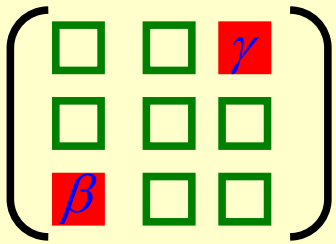


Charged Current Weak Interaction

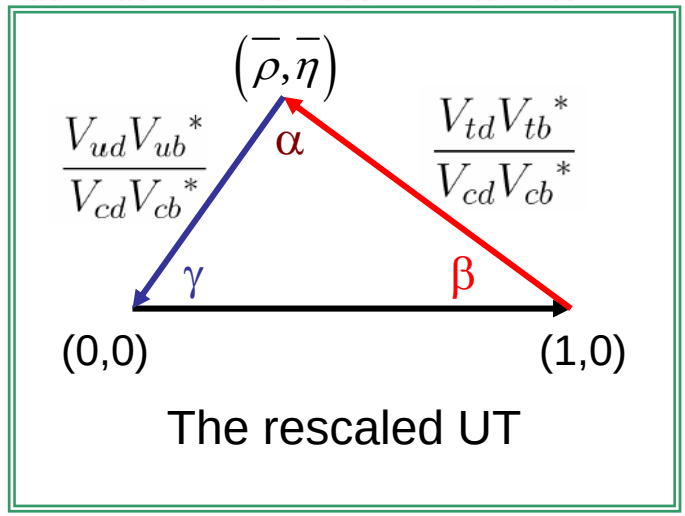
CKM mechanism ≡ FP in the SM

$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

- 3x3 unitary matrix
  - 3 angles, 1 phase
- phase → CP Violation
- usual convention: phase in smallest elements



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



α,β,γ: CP Violation in B system
sides: B decays, mixing

measuring (α,β,γ) is equivalent to measuring (ρ,η)

Motivation

- Baryon asymmetry in the Universe – Sakharov conditions

$$\eta_B \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma}$$

SM and Standard Cosmology:

e.g. A. Riotto, M. Trodden, Annu. Rev. Nucl. Part. Sci. 1999, 49:35-75

$$\frac{n_B}{n_\gamma} \simeq \frac{n_{\bar{B}}}{n_\gamma} \simeq 10^{-18}$$

WMAP

$$\eta_B^{\,CMB} = (6.5 \pm 0.4) \times 10^{-10}$$

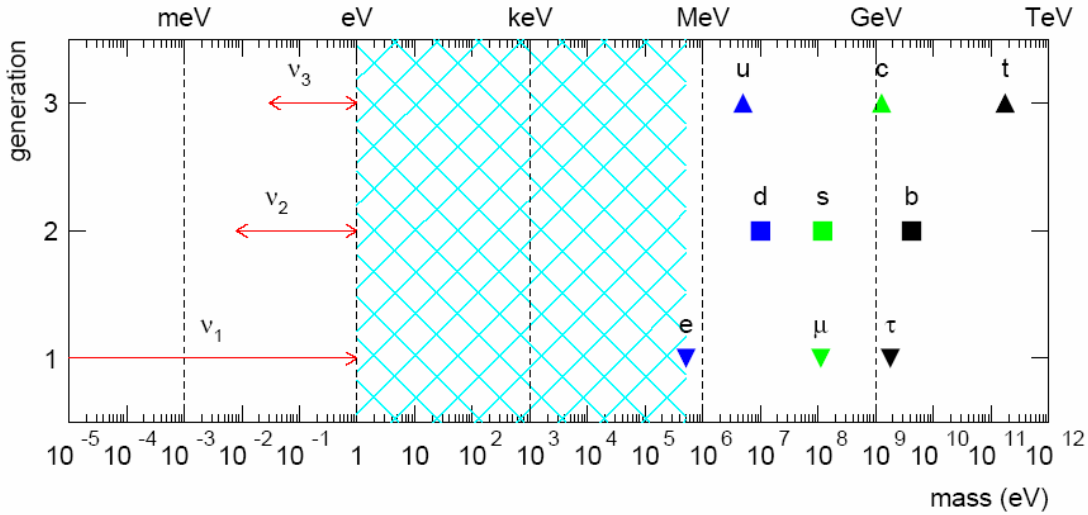
D.N. Spergel et al., astro-ph/0302209

Deuterium

$$\eta_B^{\,BBN} = (6.1 \pm 0.6) \times 10^{-10}$$

V. Barger et al., Phys. Lett. B 566 (2003)

- Mass and Mixing Hierarchies – GUTs?



Neutrinos

$$U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

Quarks

$$V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.005 \\ 0.2 & 1 & 0.04 \\ 0.005 & 0.04 & 1 \end{pmatrix}$$

The long road to unification

We like the KM model because it introduces *CP* violation in a natural way, as a result of weak mixing between the quarks analogous to the Cabibbo angle in the GIM model. Thus two puzzles are reduced to one. Looked at another way, it gives a *raison d'être* to the fifth and sixth quarks, needed in the simplest Weinberg-Salam theory to cancel anomalies and restore renormalizability if there is a heavy lepton.

John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
Nuclear Physics B109 (1976) 213–243

Unification and simplification hopes 30 years ago

Still pushing the envelope (*example, one of many*)

One major goal of this paper has been to understand the masses and mixings of the neutrinos, suggested by the atmospheric and the solar neutrino anomalies, *in conjunction with* those of the quarks and charged leptons. Adopting familiar ideas of generating eigenvalues through off-diagonal mixings, we find that the bizarre pattern of masses and mixings observed in the charged fermion sector can be adequately described (with ~ 10% accuracy) within an economical $SO(10)$ framework. A concrete proposal was

K.S. Babu [a], Jogesh C. Pati [b], Frank Wilczek
Nuclear Physics B 566 (2000) 33–91

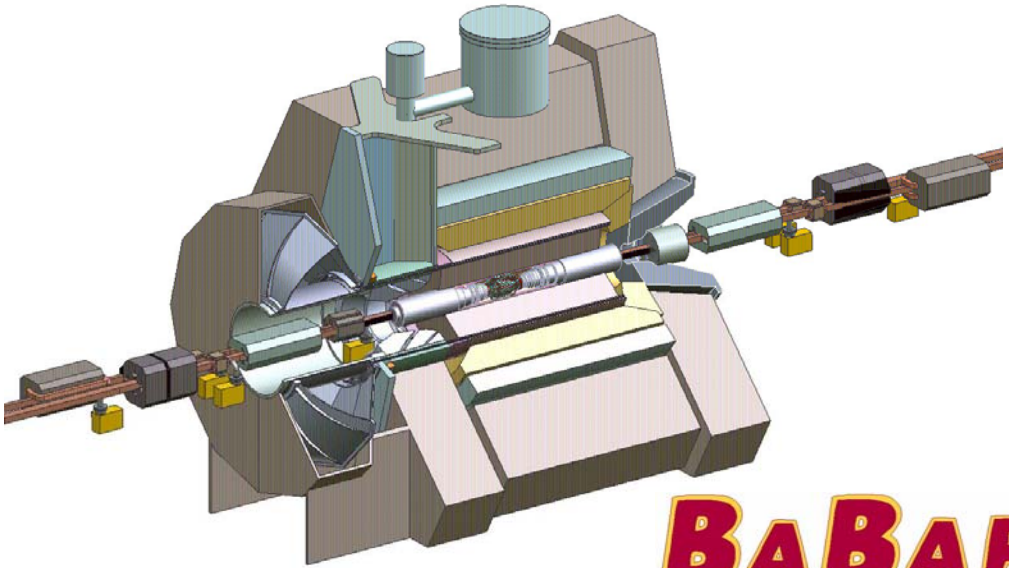
SM "metrology" and windows to NP

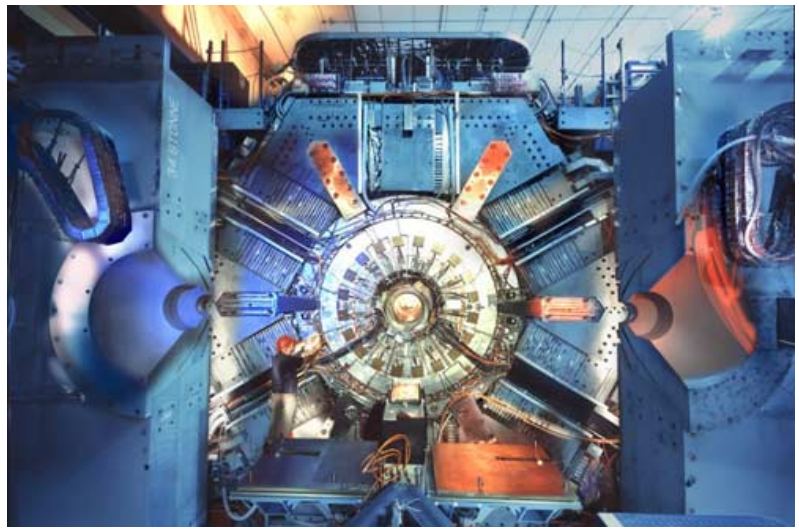
- A, λ, ρ, η: Fundamental Constants of Nature
  - SM: the majority of fundamental parameters are Flavor ones (masses and mixings)

- CPV and Flavor: Window to New Physics (NP)
  - Quantum interference: sensitivity to higher energy scales
  - Historical role in development of SM (GIM, CKM)
  - Most NP scenarios introduce deviations in rare processes

- Strategy:
  - High precision reference measurements
  - Multiple searches for deviations in rare processes

Booming demographics in 2004





- New country: Spain
- New UK group: Warwick
- New US, German groups
- UK: 11 groups, ~10% of collaboration

11 countries, 80 Institutes, 617 authors (latest paper)

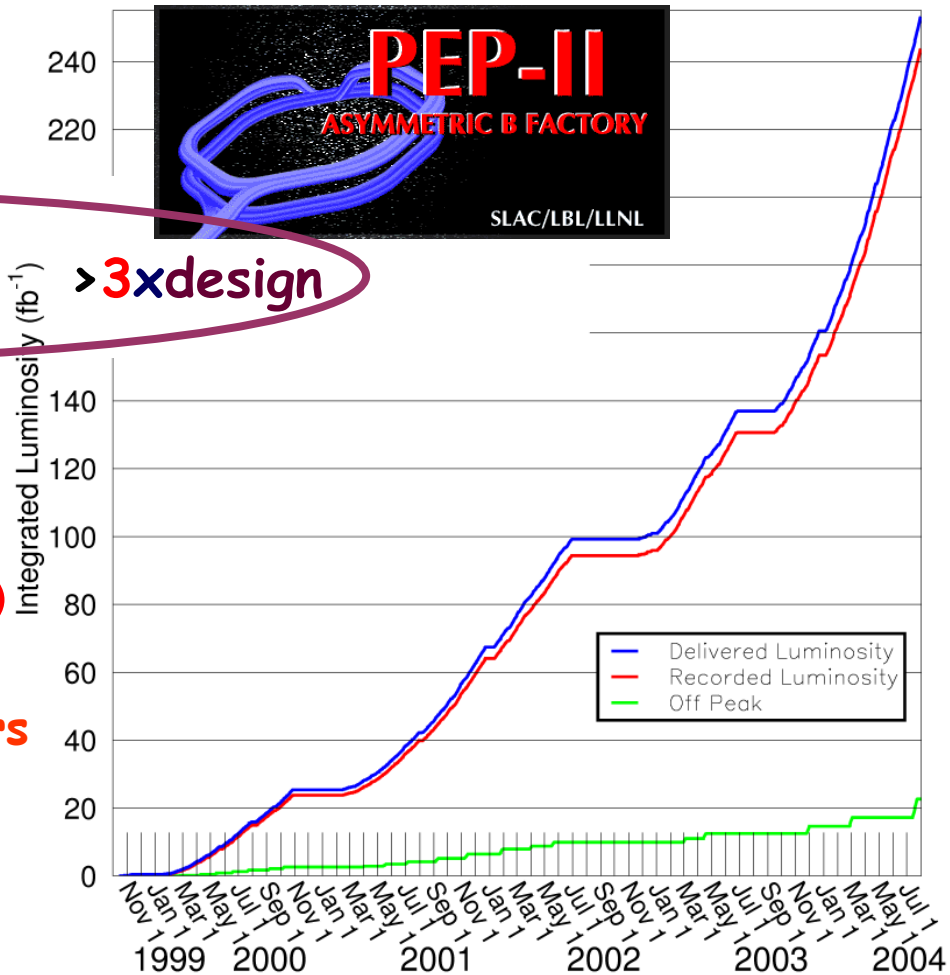
Unprecedented data delivery performance

PEP-II Records	
Peak luminosity	0.923×10^{34} $cm^{-2}\ s^{-1}$
Best day	710.5 pb^{-1}
Best 30 days	17.04 fb^{-1}
BABAR logged	246.4 fb^{-1}

>3xdesign

~245 million $B\bar{B}$ pairs

(Summer 2004)



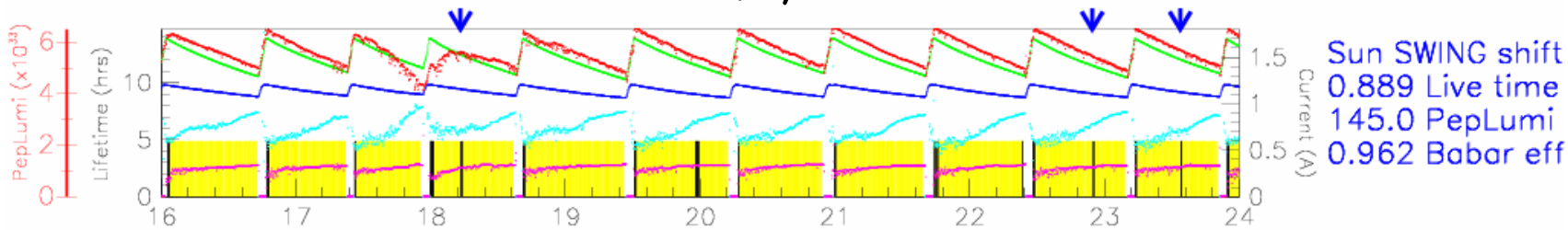
Regular data doubling cycle: 10-18 months

Long Run starting: March 05 – summer 06: Double the data sample

Double data sample again by 2008 (reach $1ab^{-1}$, *i.e.* 10^9 B pairs)

PEP-II highlight: Trickle Injection

Best shift, no trickle

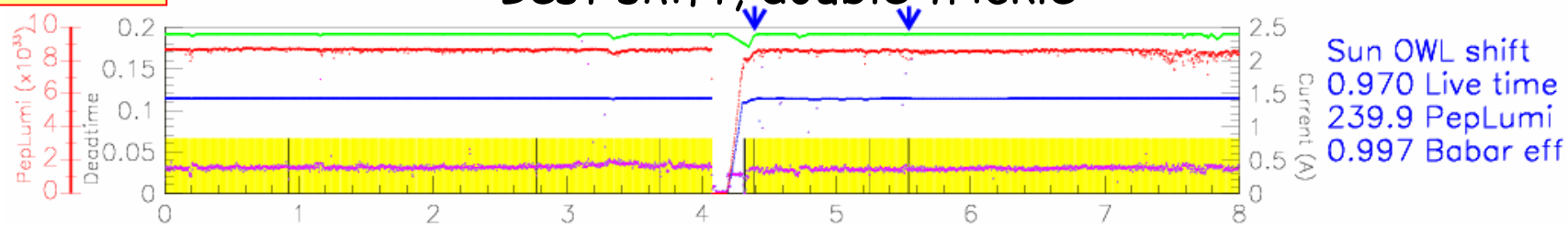


Nov 2003

Best shift, LER only trickle

Mar 2004

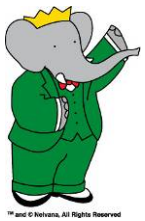
Best shift, double trickle



PEP-II: ~5 Hz continuous
KEKB: at ~5-10 min intervals

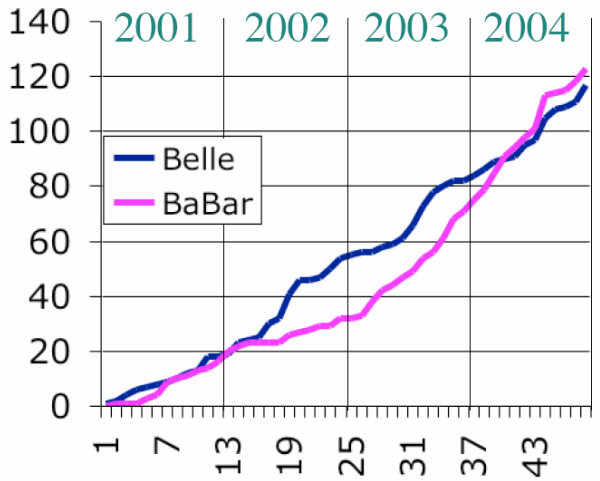
PEP-II Lumi
HER current
LER current

Exemplary Physics Productivity



56 PRL/PRD papers published in 2004
>1 paper/week!

	BABAR	Belle
Publications	123	117
Papers submitted to ICHEP04	72	70
Parallel session talks at ICHEP04	22	21



Journal submissions since 01/01/01

Other major BABAR activities

- Muon system (IFR) upgrade:
  - New forward RPCs
  - LSTs installed in two barrel sextants
  - All LSTs now delivered
- Drift Chamber R/O upgrade
- L3 trigger upgrade (z)
- Computing:
  - CM2 (new computing model)
  - Now Root-based data store
  - Regional computing (RAL Tier-A)
  - "DAQ to conf." in < 1 month
- Physics Productivity Optimization
- "Machine-Detector" interface (backgrounds)
- Super-B workshops; Roadmap committee

physics: β

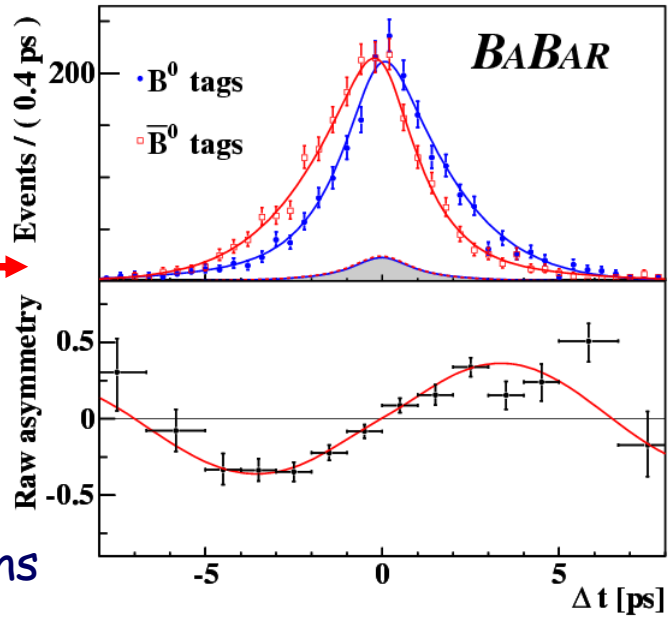
Precision measurement

$\sin 2\beta = 0.725 \pm 0.043$ Indirect

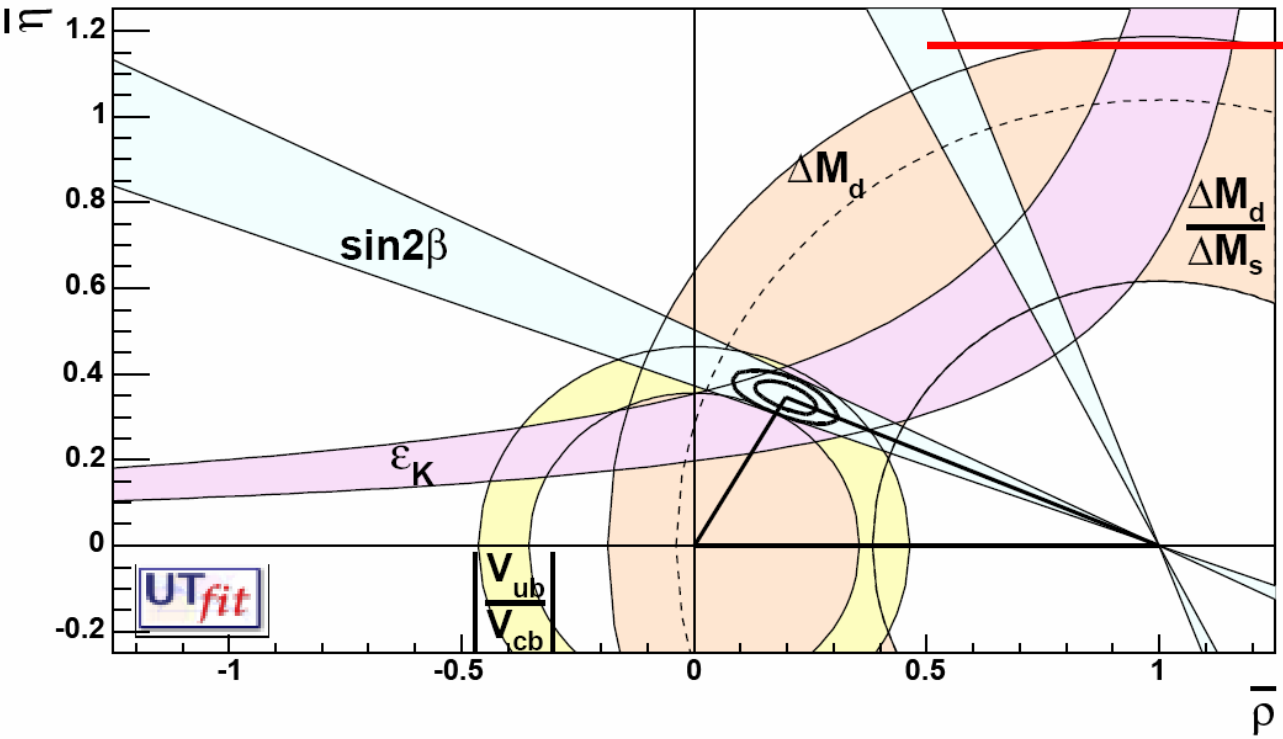
$\sin 2\beta = 0.722 \pm 0.046$ BABAR

$\sin 2\beta = 0.728 \pm 0.061$ Belle

$\beta = 23.4° \pm 1.5°$ Global



Impressive agreement with SM (CKM) expectations



cos2β < 0
*Ruled out at 87% C.L. by TD-angular analysis of J/ψK**

UTfit: hep-ph/0501199

physics : α

Unique from BABAR:

- TD $\rho^+\rho^-$

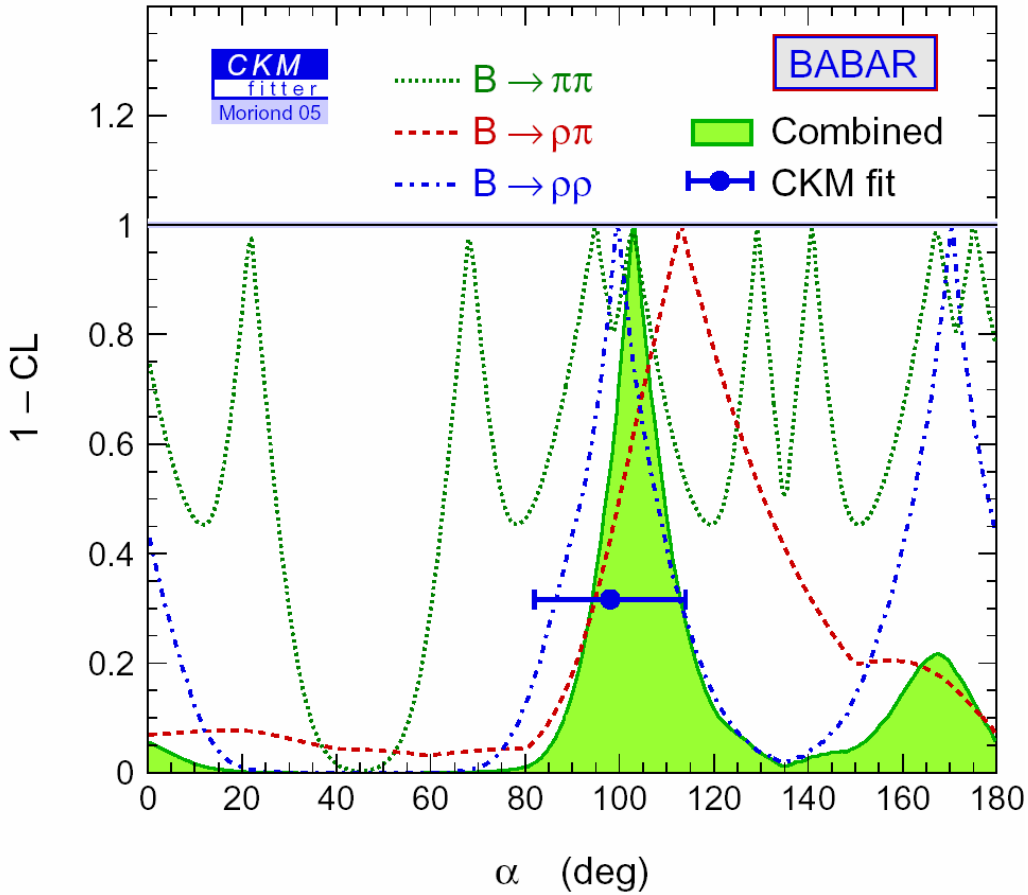
$$\alpha = 100^\circ \pm 13^\circ_{TOTAL}$$

- TD Dalitz plot analysis ($\rho\pi$)

$$\alpha = 96^{\circ\,+27^\circ}_{-17^\circ\,stat} \pm 6^\circ_{syst}$$

Leading to:

$$\alpha = 103^{\circ\,+10^\circ}_{-9^\circ}$$



Huge progress in last two years

$\alpha = 98^\circ \pm 16^\circ$ Indirect

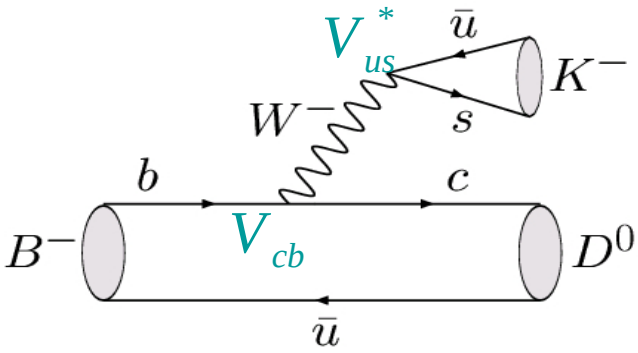
$\alpha = 103^\circ \pm 10^\circ$ Direct

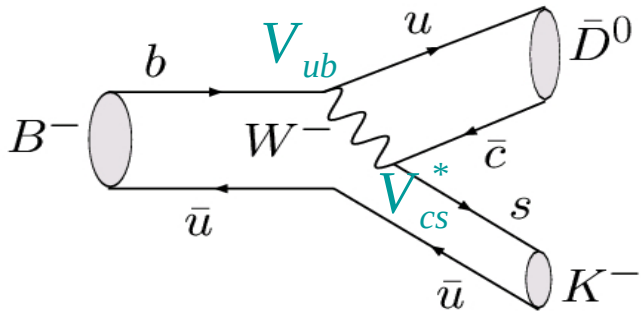
$\alpha = 99^{\circ\,+7^\circ}_{-9^\circ}$ Global

CKMfitter: hep-ph/0406184

BABAR, 2008 (all): $\alpha = x^\circ \pm 3^\circ$

physics : γ





$B^+ \to D_{CP}^{(*)} K^{(*)+}$ Gronau-London-Wyler

$B^+ \to D_{K\pi}^0 h^+$ Atwood-Dunietz-Soni

$B^+ \to D^{(*)0}(D^0 \to K_S \pi\pi) K^+$ Giri-Grossman-Soffer-Zupan

BABAR direct measurement:

$\gamma = [70 \pm 29]^\circ + n\pi$

Methods proven – statistics needed!

$\gamma = 60^\circ \pm 7^\circ$ Indirect

$\gamma = 58.5^\circ \pm 5.8^\circ$ Global

$B^0 \to K^+\pi^-$ First observation of Direct CPV in B decays

BABAR PRL 93 (2004) 131801

$A_{CP} = -0.133 \pm 0.030 \pm 0.009$

Belle

$A_{CP} = -0.101 \pm 0.025 \pm 0.005$

Average $A_{CP} = -0.114 \pm 0.020$

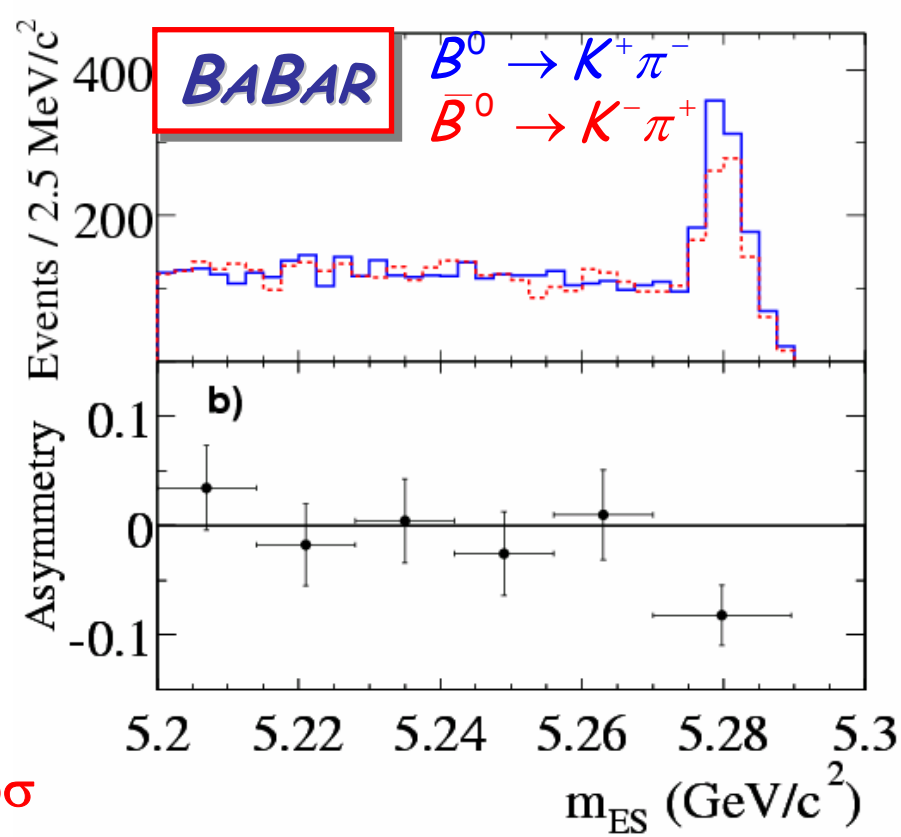
$B^+ \to K^+\pi^0$

$A_{CP} = +0.06 \pm 0.06 \pm 0.01$ *BABAR*

$A_{CP} = +0.04 \pm 0.05 \pm 0.02$ Belle

3.6σ

Average $A_{CP} = +0.049 \pm 0.040$

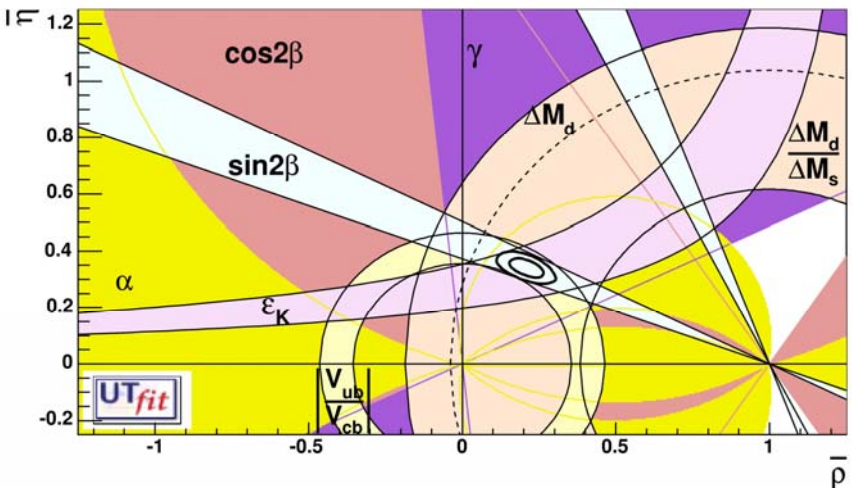


- "B superweak" excluded
- Indication of large strong phases

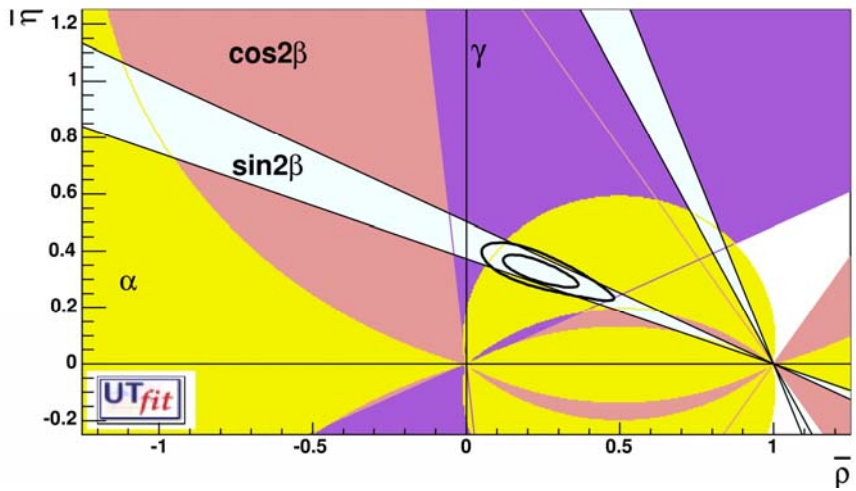
Other physics highlights

- $b \to s\gamma$ inclusive and exclusive BFs and A_{CP} to 5%
- $b \to d\gamma$ limits to 10^{-6}
- First time dependent CP measurement in $b \to s\gamma$ ($K^*\gamma$)
- Semileptonic B decays:
  - Inclusive and exclusive measurements
  - m_{hadron}, E_{lepton} moments fits; HQE (=OPE+HQS) validated
  - $|V_{cb}|$: ±2%
  - $|V_{ub}|$: error <10%, can still improve
- LFV searches
- Pentaquark searches
- New states spectroscopy
- tau physics
- ISR: hadronic vacuum polarization input for g-2 systematics

The CKM mechanism today



$$\bar{\rho} = 0.207 \pm 0.038$$
$$\bar{\eta} = 0.341 \pm 0.023$$

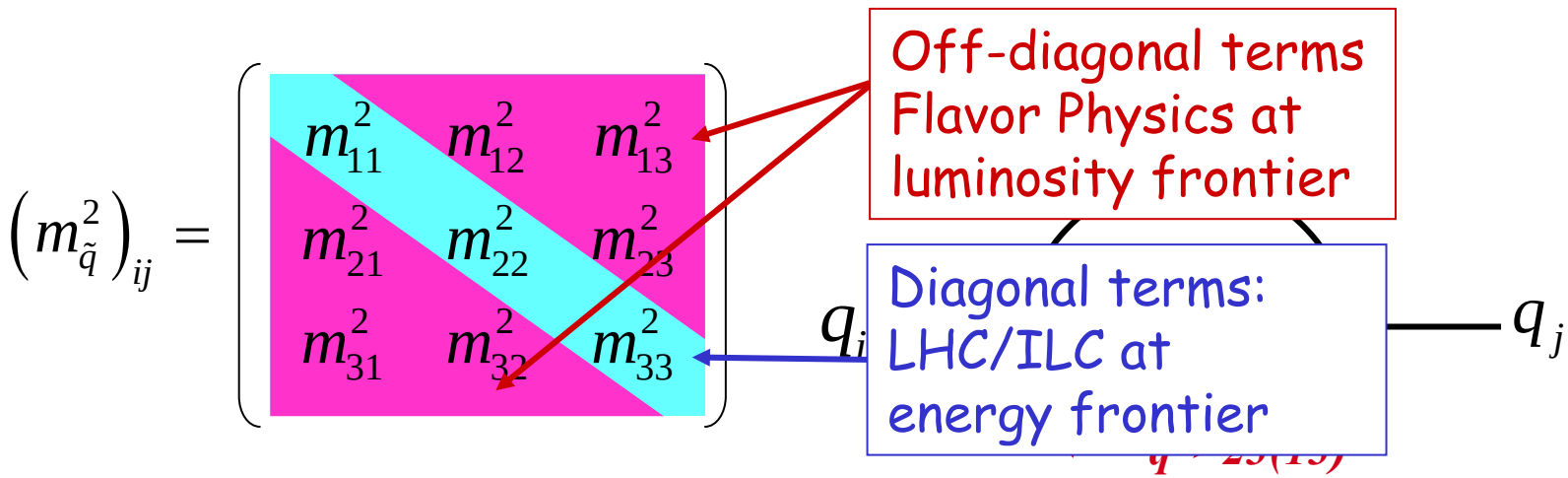


UT angle measurements only
(B Factories; nothing 4 years ago)

- Impressive confirmation of CKM mechanism
- Not looking for alternatives any more
- Looking for New Physics as corrections to CKM

Possible New Physics: SUSY

- ***MSSM parameters > 100!*** [masses + mixing angles + phases]
- ***squark/slepton mass matrix***
  - Sensitive to SUSY breaking mechanism.
  - New sources of flavor mixing

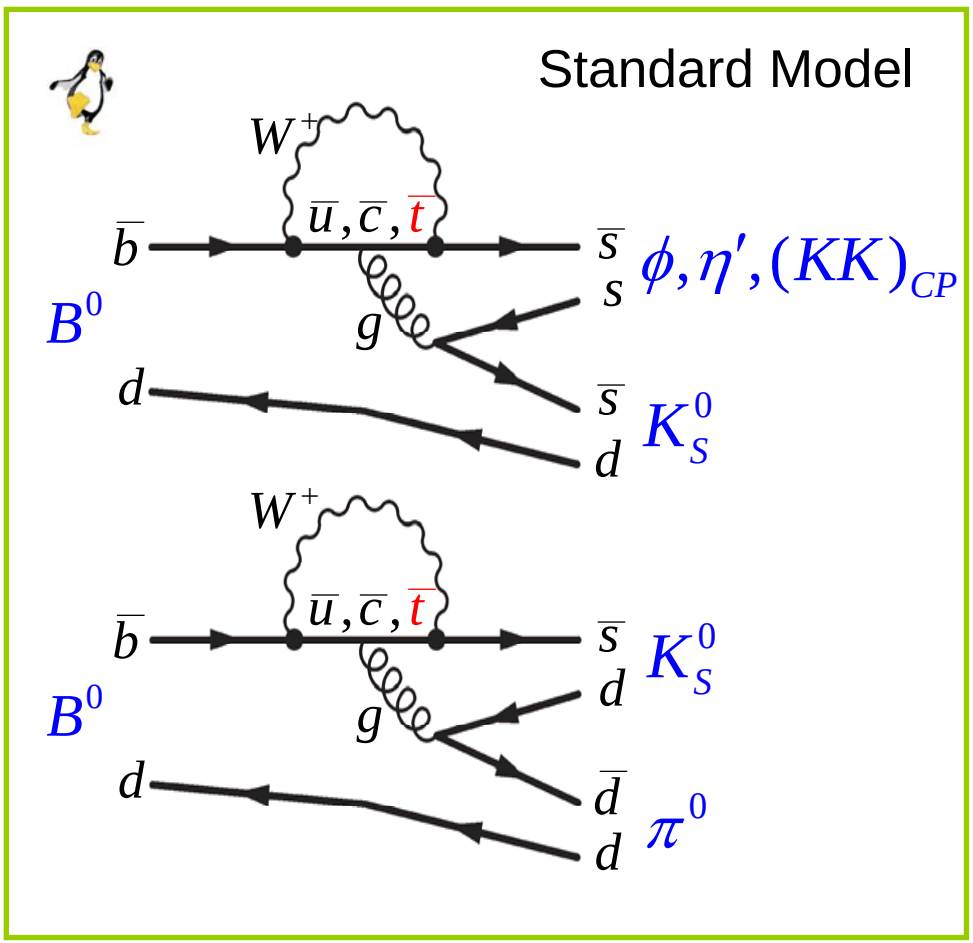


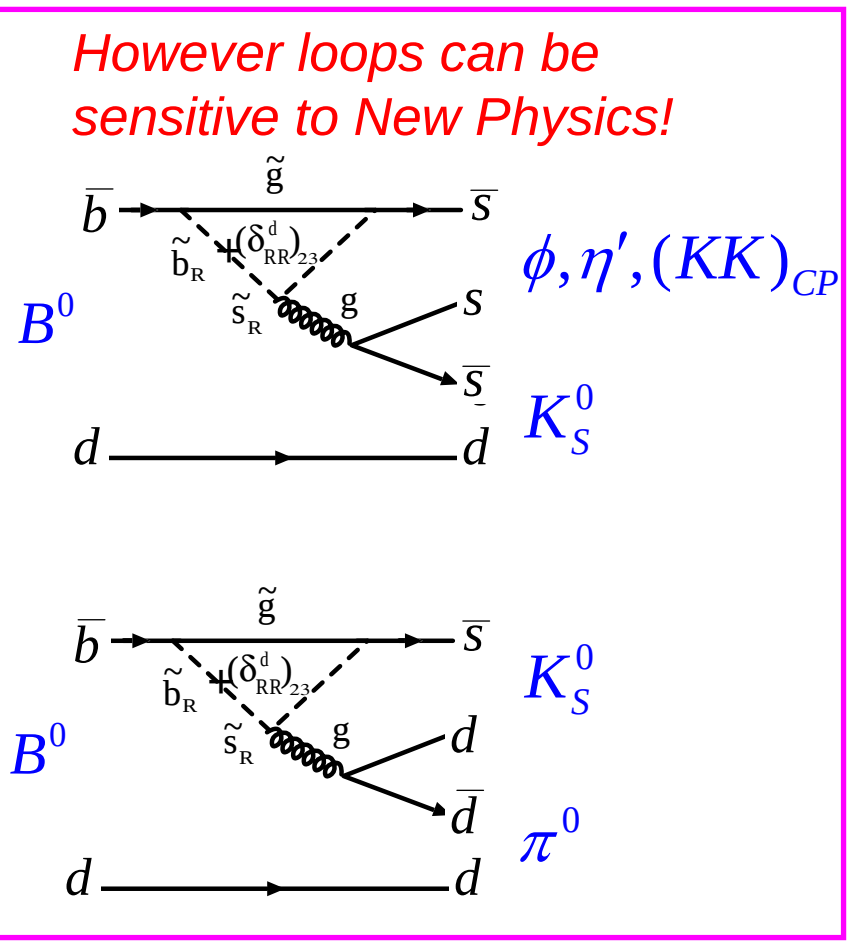
Suppression of FCNC at low energies points to:
- "SUSY GIM" mechanism, or
- LSP >>1TeV

NP signals in FCNC also anticipated in X-dim odels

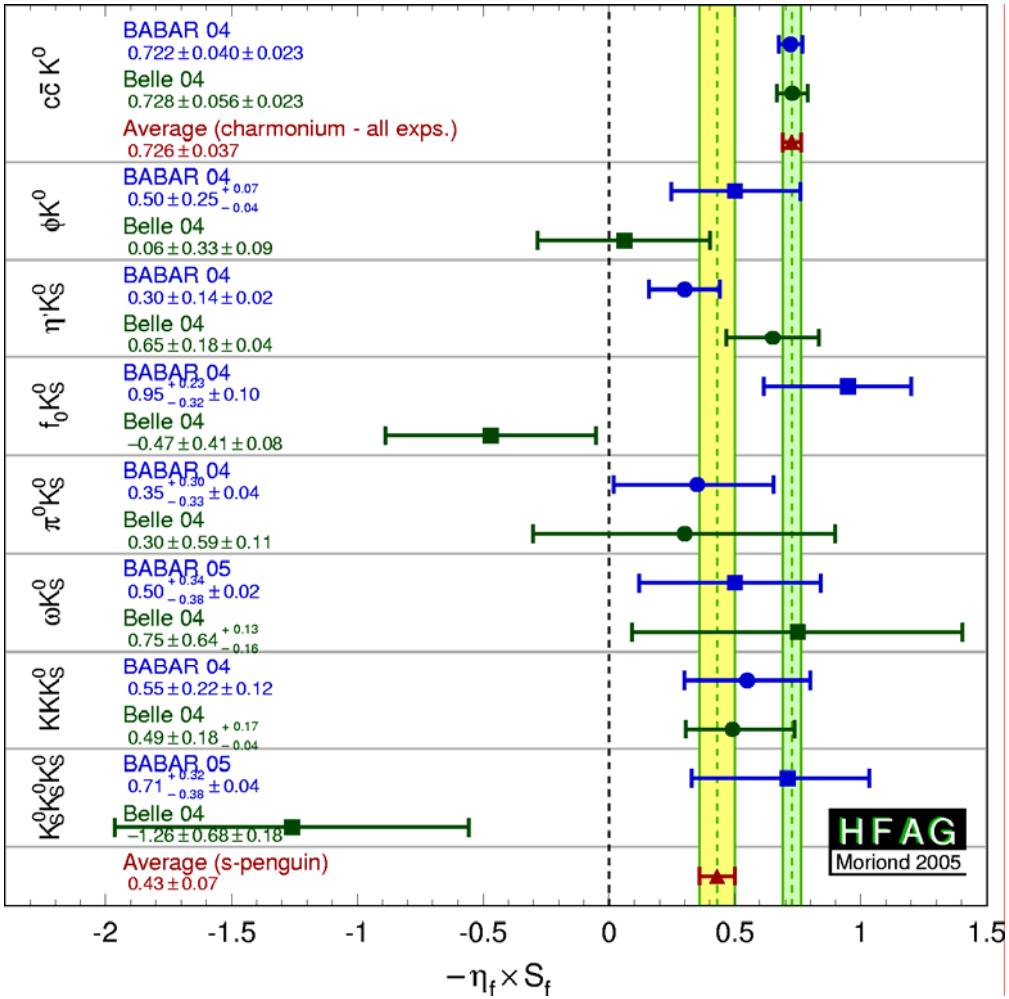
sin2β from Charmless "Penguins"

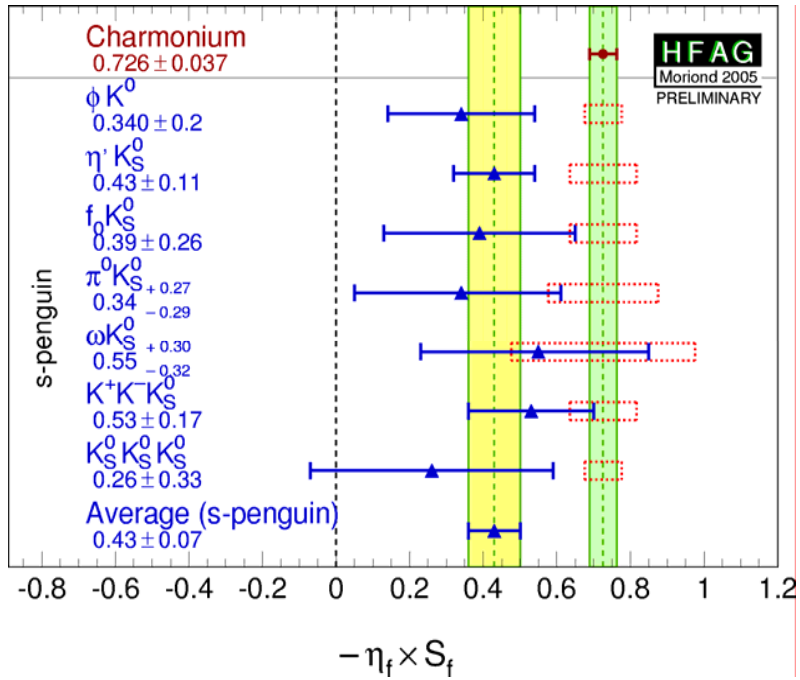
Standard Model: *interference between B mixing and dominant b→sss or b→sdd penguin amplitude gives the same $e^{-i2\beta}$ as in tree process b→ccs.*





Hint of New Physics?





Deviation from SM:

No theory error: **3.7σ**

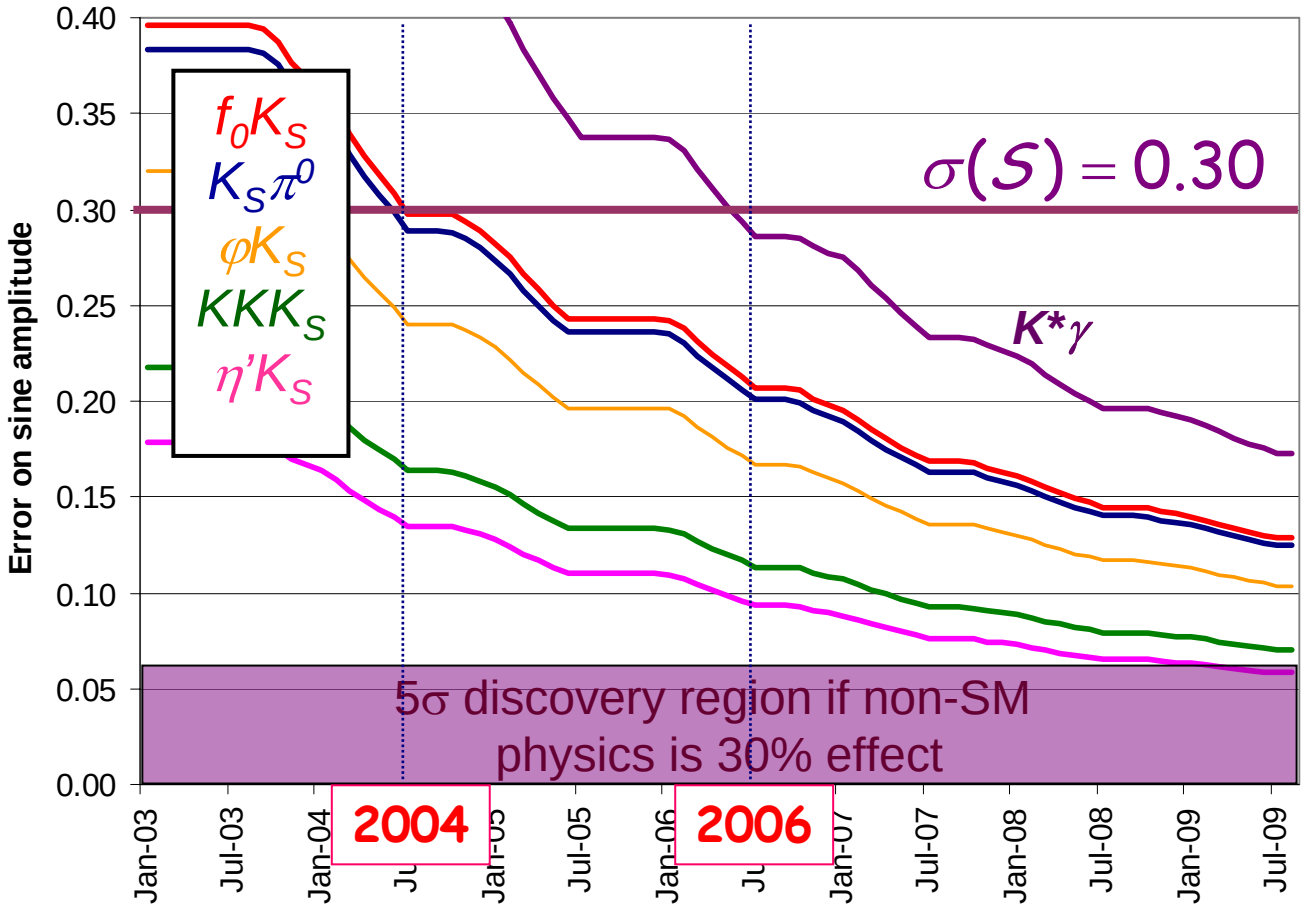
Naïve theory errors: **2.9σ**

Overall good agreement between the two experiments

Systematically lower than Charmonium modes

Outlook

- May have 5σ in average by 2006 if NP effect is 0.3
- Need for better handle on SI effects (theory+exp.)
- May be the deciding factor for 2009-10 operations



Two-year outlook: Run 5

Run 5 delayed by ~5 months following LINAC accident (11 Oct. 2004) and DOE accident investigation

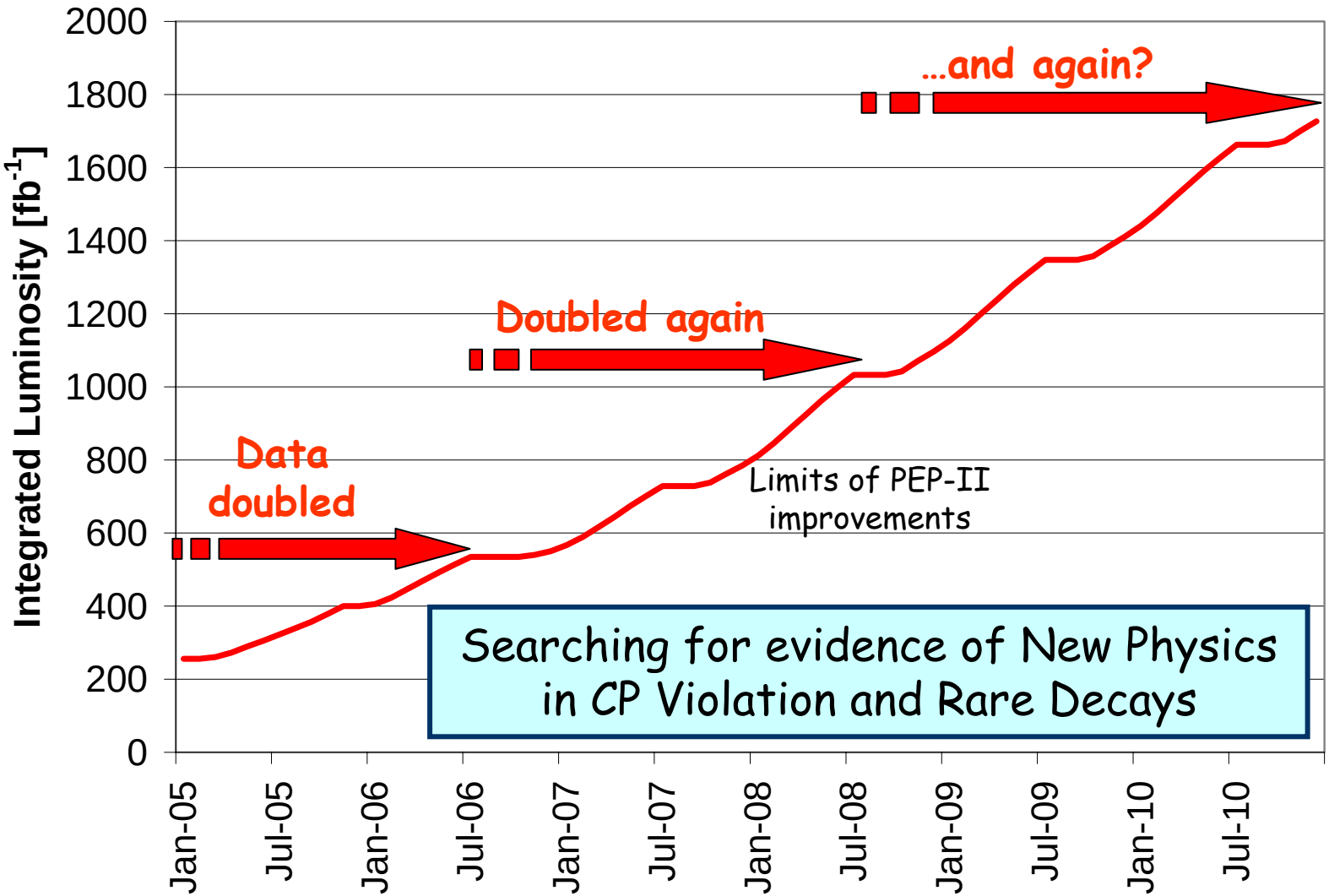
PEP-II and BABAR are in the final stages of preparation for the start of Run 5 that is expected to begin shortly.

The plan is for the run to extend through to July 31, 2006 with one month down this fall.

PEP-II accelerator improvements already in place will allow the peak luminosity to grow to $1.3 \times 10^{34} cm^{-2} s^{-1}$ by the end of the run.

Such an extended running period is projected to allow more than a doubling of the current sample by summer 2006 to a total integrated luminosity of about $530 fb^{-1}$.

Projected PEP-II integrated luminosity



Future luminosity increase factors

Parameter	Present	Future	Luminosity gain ratio	Hardware and work needed
LER current	2450 mA	4500 mA		Two RF stations, new IR vacuum chambers
HER current	1550 mA	2200 mA	1.61	Two RF stations, new IR vacuum chambers
β_y^*	10.5 mm	8.5 mm	1.24	HER higher tunes, RF & power supplies work
ξ_y	0.065 L 0.043 H	0.070 L 0.055 H	1.17	Tune plane, coupling, & IR work
Total			x 2.3	

US funding issues (i)

The SLAC B-Factory is one of the priorities

The FY 2006 budget request also contributes to this program goal by placing high priority on the operations, upgrades and infrastructure for the two major HEP user facilities (Tevatron and Neutrinos at the Main Injector [NuMI]) at the Fermi National Accelerator Laboratory (Fermilab), and the major HEP user facility (the B-Factory) at the Stanford Linear Accelerator Center (SLAC), to produce maximum scientific data to address these fundamental questions.

Operations guaranteed

High Energy Physics (FY 2005 $736.4; FY 2006 $713.9) ..... **-$22.5**

In FY 2006, the focus continues to be on the facilities at **Fermilab** (FY 2005 $303.6; FY 2006 $304.2), and at **SLAC** (FY 2005 $166.2; FY 2006 $144). Fermilab Tevatron will operate 4560 hours in FY 2006, a 6-percent increase over FY 2005. SLAC will operate 5200 hours in FY 2006, a 54-percent increase over FY 2005. SLAC linac funding will also be supported with $30 million in Basic Energy Sciences ..... -$21.6

Some facilities have done much worse:

TJNAF operating hours are reduced by 29 percent;

RHIC operating hours decrease by 61 percent

Extracts from the FY 2006 Congressional Budget, see DOE website

US funding issues (ii)

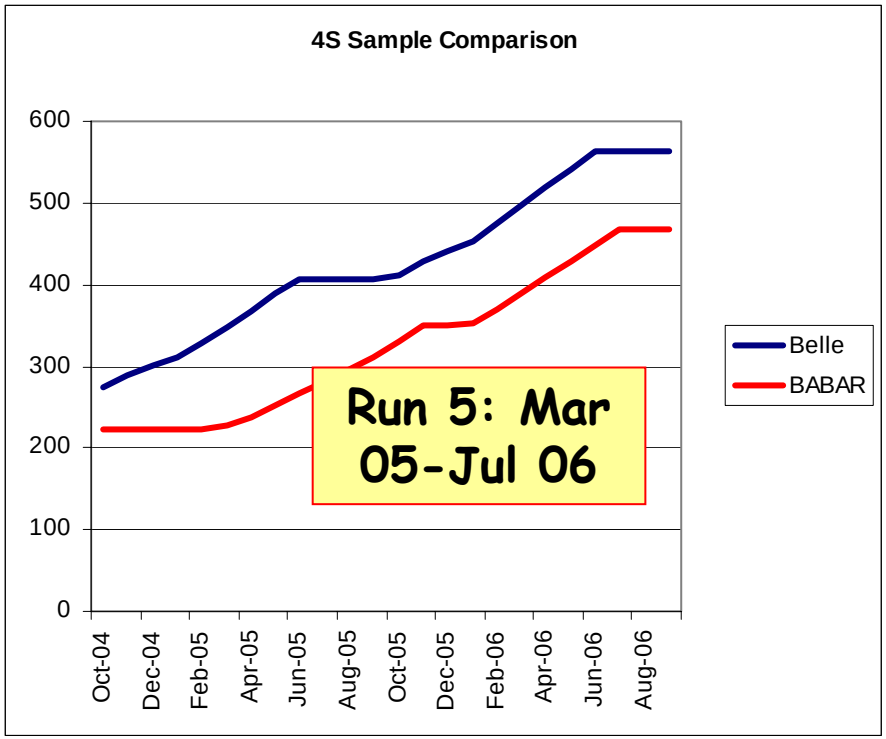
- Funding available for:
  - long run in 2005-06
  - planned PEP-II upgrades to achieve 2.1×10^{34}
  - Operations up to 2008
  - i.e. on track to double data by mid-'06 and again by '08 (~10^9 B pairs)

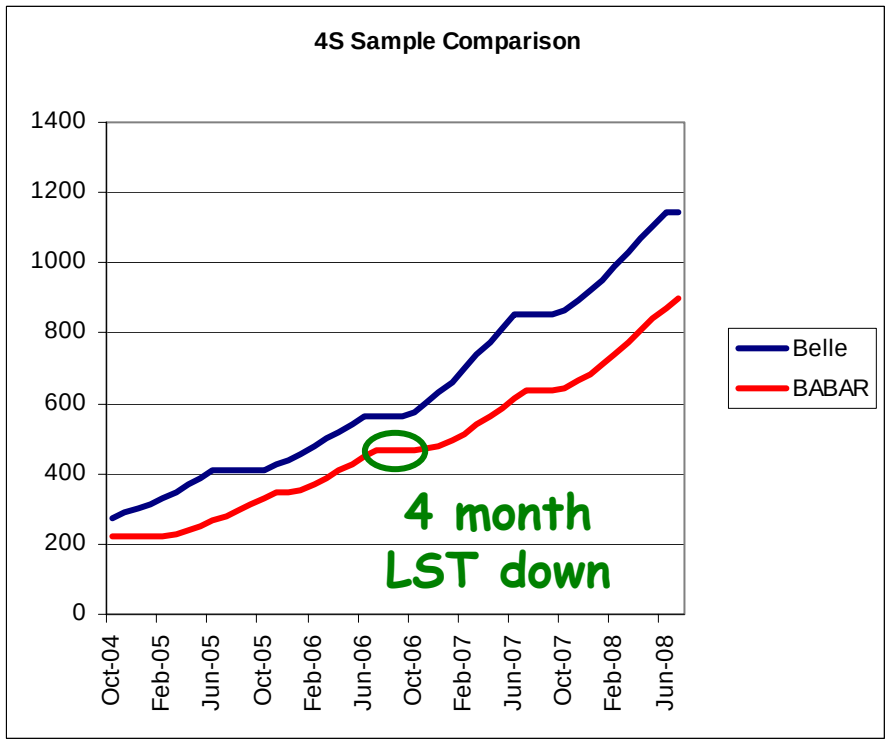
- >2008: LINAC ownership with Basic Energy Sciences
  - End of scheduled B Factory operation
  - LCLS: x-ray FEL, $380M total investment

  - LCLS will use downstream 1/3 of LINAC
  - PEP-II uses upstream 2/3 of LINAC
  - Technically can operate in parallel
  - BES budget already funds SLAC with $30M in 2006

- The case to double the data sample in '09-'10 will have to be based on physics (e.g. potential b to s New Physics signal)

The competition: BABAR vs Belle





Double data by summer 2006

Double again by summer 2008

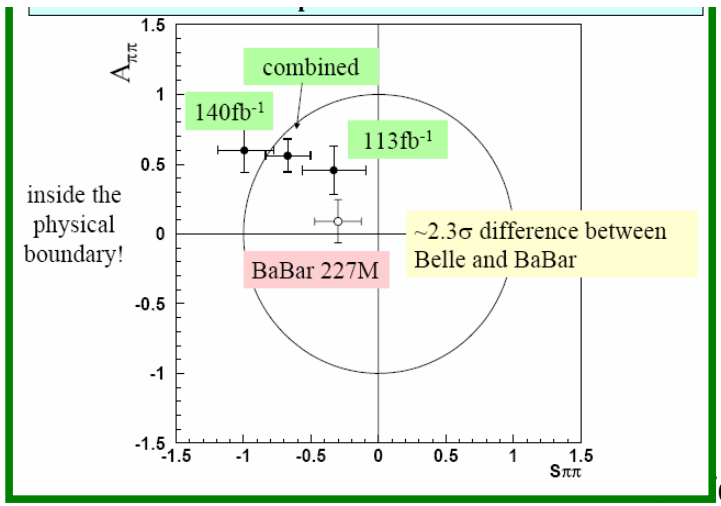
Competition, physics sensitivity

- Belle has been doing well in terms of data volume!
- BABAR has the edge in analysis techniques:
  - precision better by 20%-50% for equal data samples
- Some examples:

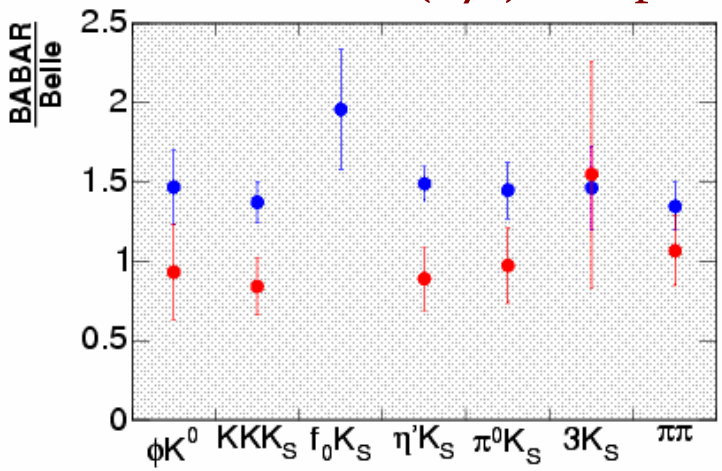
$B \to \pi\pi$

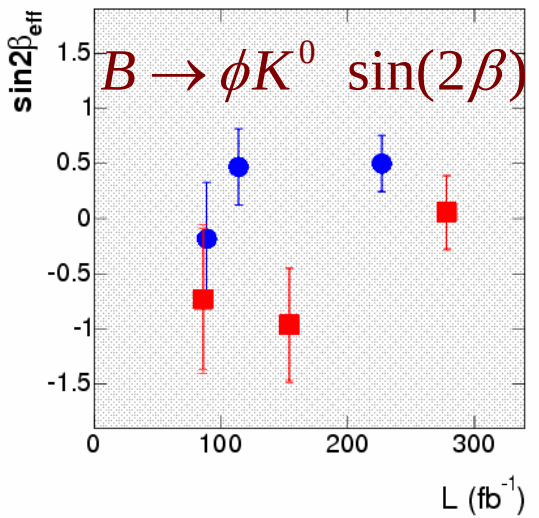
227M $B\bar{B}$	275M $B\bar{B}$
$n_{\pi\pi} = 467 \pm 33$	$n_{\pi\pi} = 666 \pm 43$
$S_{\pi\pi} = -0.30 \pm 0.17 \pm 0.03$	$S_{\pi\pi} = -0.67 \pm 0.16 \pm 0.06$
$C_{\pi\pi} = -0.09 \pm 0.15 \pm 0.04$	$C_{\pi\pi} = +0.56 \pm 0.12 \pm 0.06$
BABAR (ICHEP 04)	BELLE (ASPEN 05)

http://belle.kek.jp/belle/talks/ASPEN05/TCPV-pi+pi-.pdf

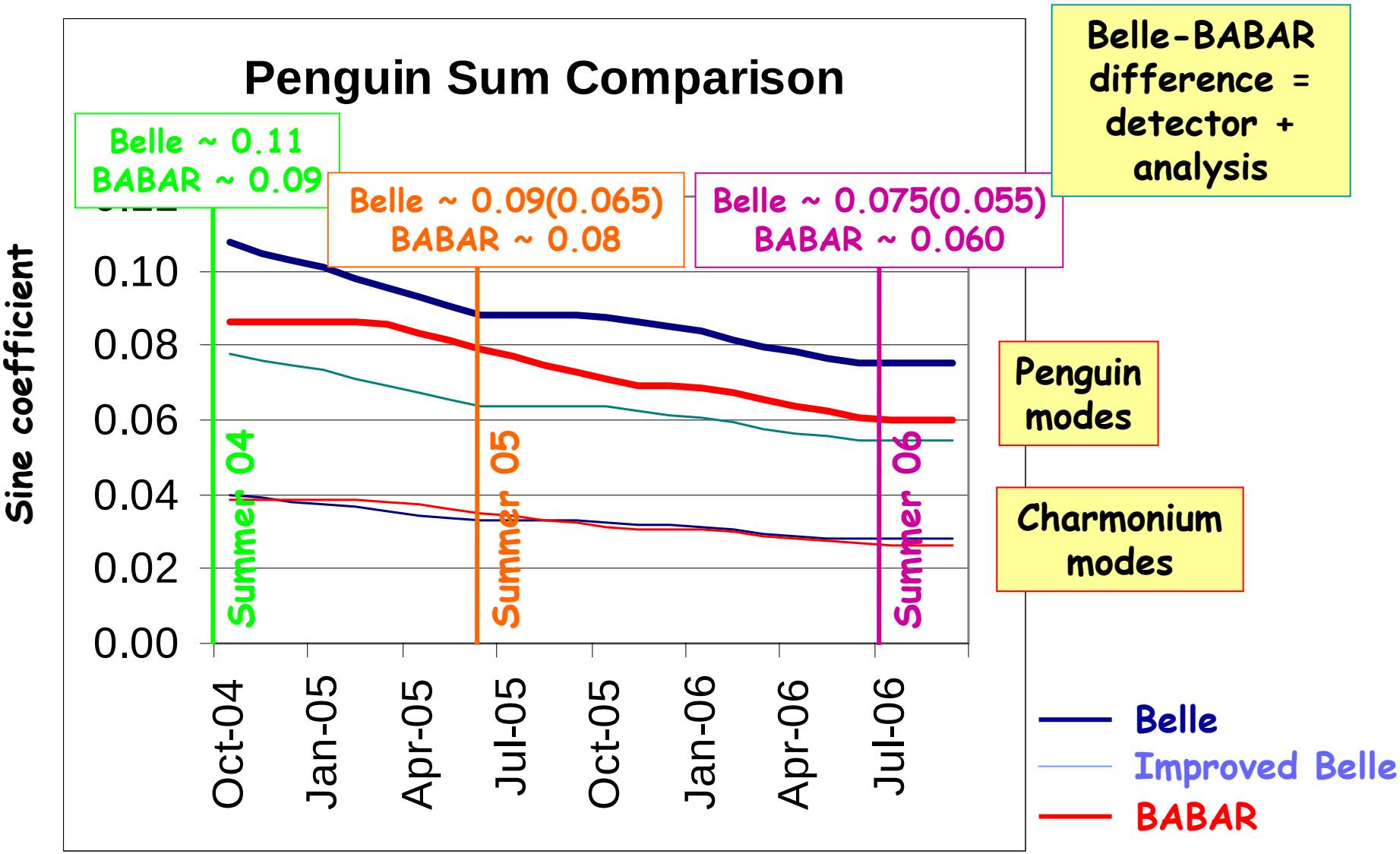


$b \to s$ sin(2β) samples





Penguin performance comparison



Super B Factory: facts

- Super-B option recommended by HEPAP sub-panel (Barish-Bagger report) as priority US project if no ILC in the USA
- P5 recommended BTeV instead – now dead!
- SLAC first accelerator based HEP priority: ILC
- BABAR and Belle in recent years: series of workshops (SLAC-R-709 and KEK Super B LoI, both in 2004)
- BABAR Roadmap Committee, report in October 2004
- Joint BABAR-Belle SuperB workshop series in Hawaii
- Working towards merging Super *B* efforts with Belle and engaging wider community in exploring physics capabilities
- Planned submissions to ongoing US NAS review (EPP2010) and ICFA in 2005
- SuperB-JPARC2-ILCR&D prioritization in Japan in 2005
- Super-B part of global jigsaw (ILC, ITER, NF, Large Underground Lab)
- Cost: ~10% of ILC

Super B Factory: science case

- Impressive volume of work already available
- Super-B can:
  - Discover NP indirectly before the LHC or if NP scale > 1TeV
  - Identify the type of NP in parallel / soon after direct observation of new space-time or quantum degrees of freedom in the LHC
  - Identify the SUSY type and investigate the SUSY breaking mechanism before ILC operations
- Most NP scenarios have implications for Flavor Physics
- We may already have a sign of NP in B Factory data!
- The case will evolve following new results
- Strong case for a Super-B factory is emerging as the theory community realizes the capabilities of such a facility

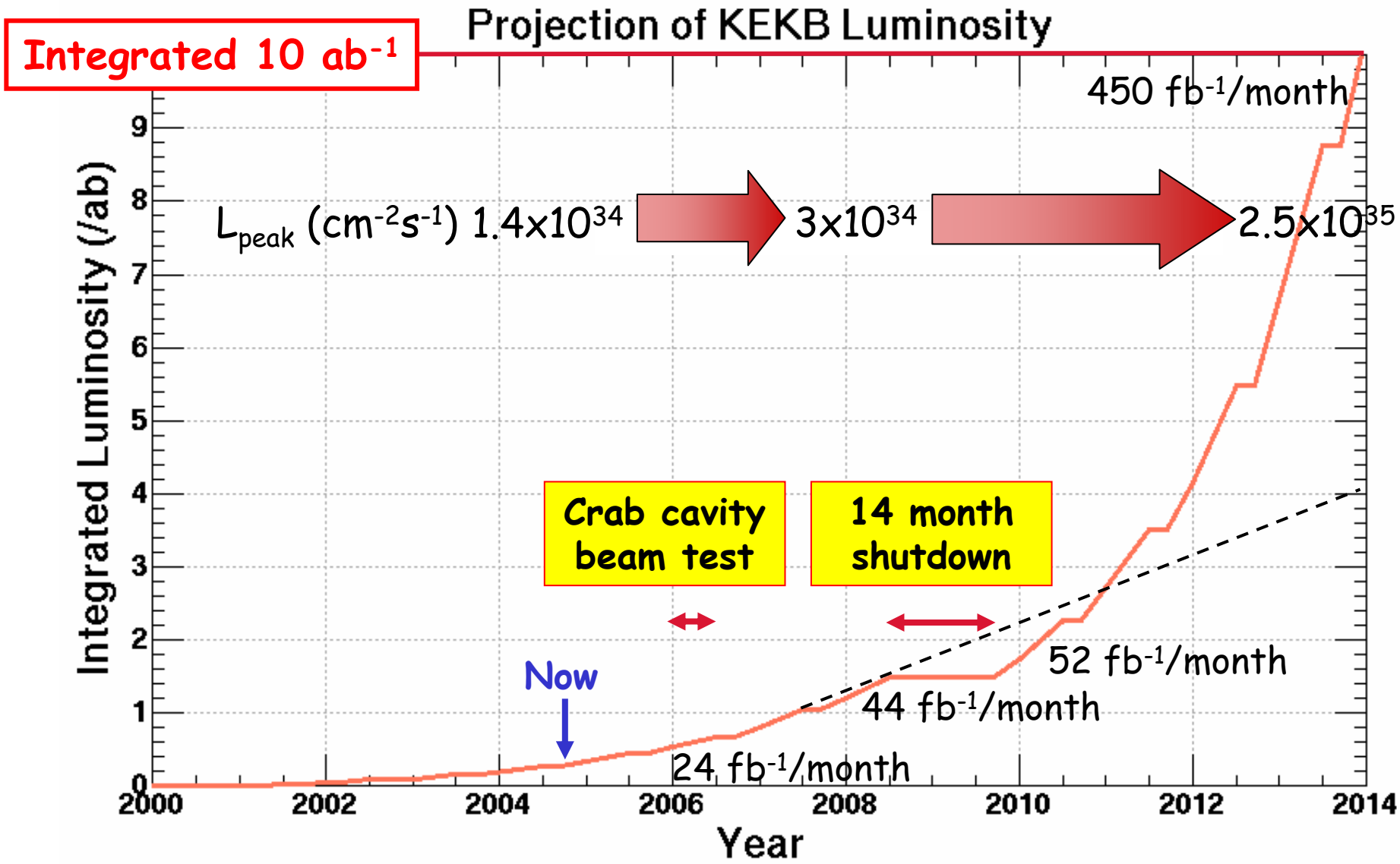
Super B Factory: practical issues

- Aim: start operations early in next decade
- Detector issues:
  - (active?) pixels for vertexing
  - possible full-silicon tracker
  - son-of-DIRC for PID
  - Either crystal (LSO; LYSO; CsI) or Liquid Xenon – main detector cost driver: $(20-90)M
- Detector could be ILC technology demonstrator!
- Good match to UK detector R&D plans
- UK perspective: interest from certain groups; could be the next project of the (currently) strong "flavor" community
- Complementary to LHCb

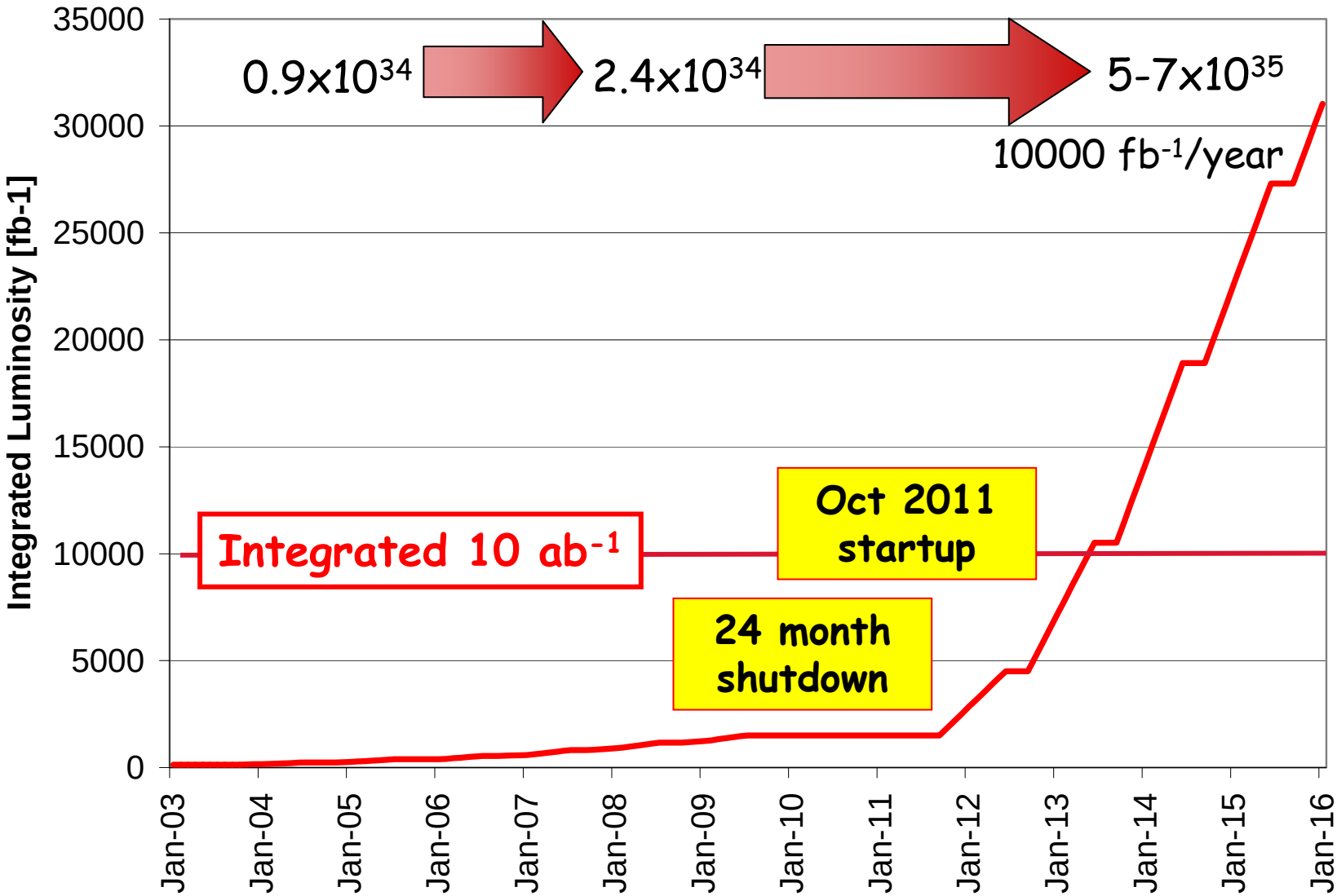
- Does it violate resources unitarity? Determining factors (personal view):
  - Physics output in next few years
  - ILC schedule

- Definitely an option worth considering
- Will have a more solid basis for discussion in a year from now

Super KEKB luminosity projection



Super PEP-II luminosity projection



CONCLUSIONS

- Fundamental, far-reaching physics program
- Impressive delivery and achievement record
- Rich scientific output by any standards or metrics!
- Significant discovery potential in next few years
- Guaranteed data taking for four years
- Strong UK community: most groups in for the long run
- Super-B: watch this space!

The B Factories will continue to dominate the international HEP scene for a few more years, and possibly right to the end of this decade

BABAR-UK has the talent, expertise, recognition, commitment, and determination to continue as a highly active and productive part of our community

I am confident that the PPAP will recommend the continuation of the strong support that PPARC panels and committees at all levels have shown so far, in line with our achievements and potential