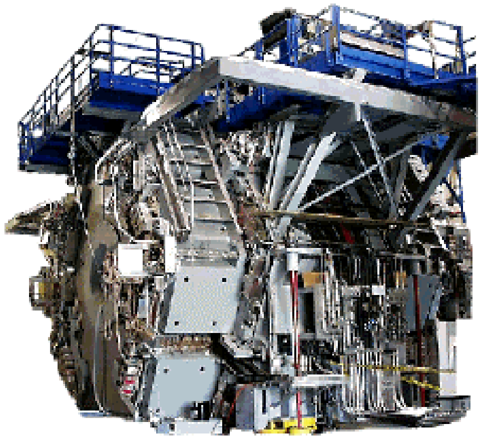
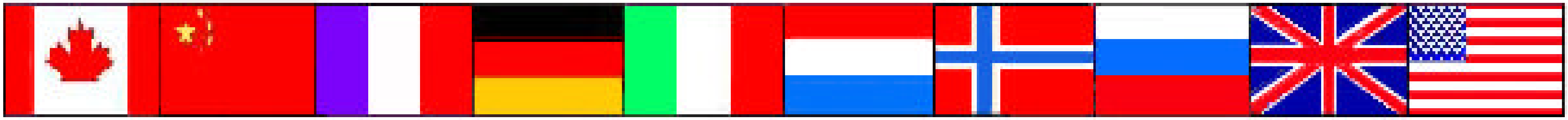


BABAR

Marcello A. Giorgi

at

SLAC Annual Program Review



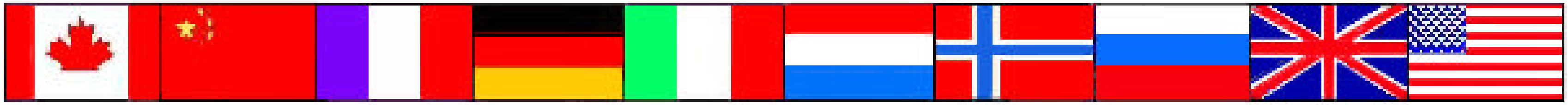
Outline

- BaBar Collaboration
- BaBar Mission
- Past & Present Achievements (FY02&FY03)
- What Next……

BaBar Collaboration Membership -- April 3, 2003

	Faculty	Grad Students	Post-docs	PhD Staff	Non-PhD Staff	Totals
BABAR	177	152	118	127	5	579
US	88	67	75	58	2	290
Non-Us	89	85	43	69	3	289

36 PhD Thesis on BABAR results!!



The *BABAR* Collaboration

10 Countries
75 Institutions
579 Physicists

USA [38/290]
California Institute of Technology
UC, Irvine
UC, Los Angeles
UC, Riverside
UC, San Diego
UC, Santa Barbara
UC, Santa Cruz
U of Cincinnati
U of Colorado
Colorado State
Florida A&M
Harvard
U of Iowa
Iowa State U
LBNL
LLNL
U of Louisville
U of Maryland
U of Massachusetts, Amherst
MIT
U of Mississippi
Mount Holyoke College
SUNY, Albany
U of Notre Dame
Ohio State U
U of Oregon
U of Pennsylvania
Prairie View A&M U
Princeton U
SLAC
U of South Carolina
Stanford U
U of Tennessee
U of Texas at Austin
U of Texas at Dallas
Vanderbilt
U of Wisconsin
Yale

Canada [4/18]
U of British Columbia
McGill U
U de Montréal
U of Victoria

China [1/5]
Inst. of High Energy Physics, Beijing

France [5/55]
LAPP, Annecy
LAL Orsay
LPNHE des Universités Paris VI et VII
Ecole Polytechnique, Laboratoire Leprince-Ringuet
CEA, DAPNIA, CE-Saclay

Germany [3/30]
Ruhr U Bochum
Technische U Dresden
U Rostock

Italy [11/101]
INFN, Bari
INFN, Ferrara
Lab. Nazionali di Frascati dell' INFN
INFN, Genova&U
INFN, Milano&U
INFN, Napoli&U
INFN, Padova&U
INFN, Pisa&U&ScuolaNormaleSuperiore
INFN, Roma &U "La Sapienza"
INFN, Torino&U
INFN, Trieste&U

The Netherlands [1/2]
NIKHEF, Amsterdam

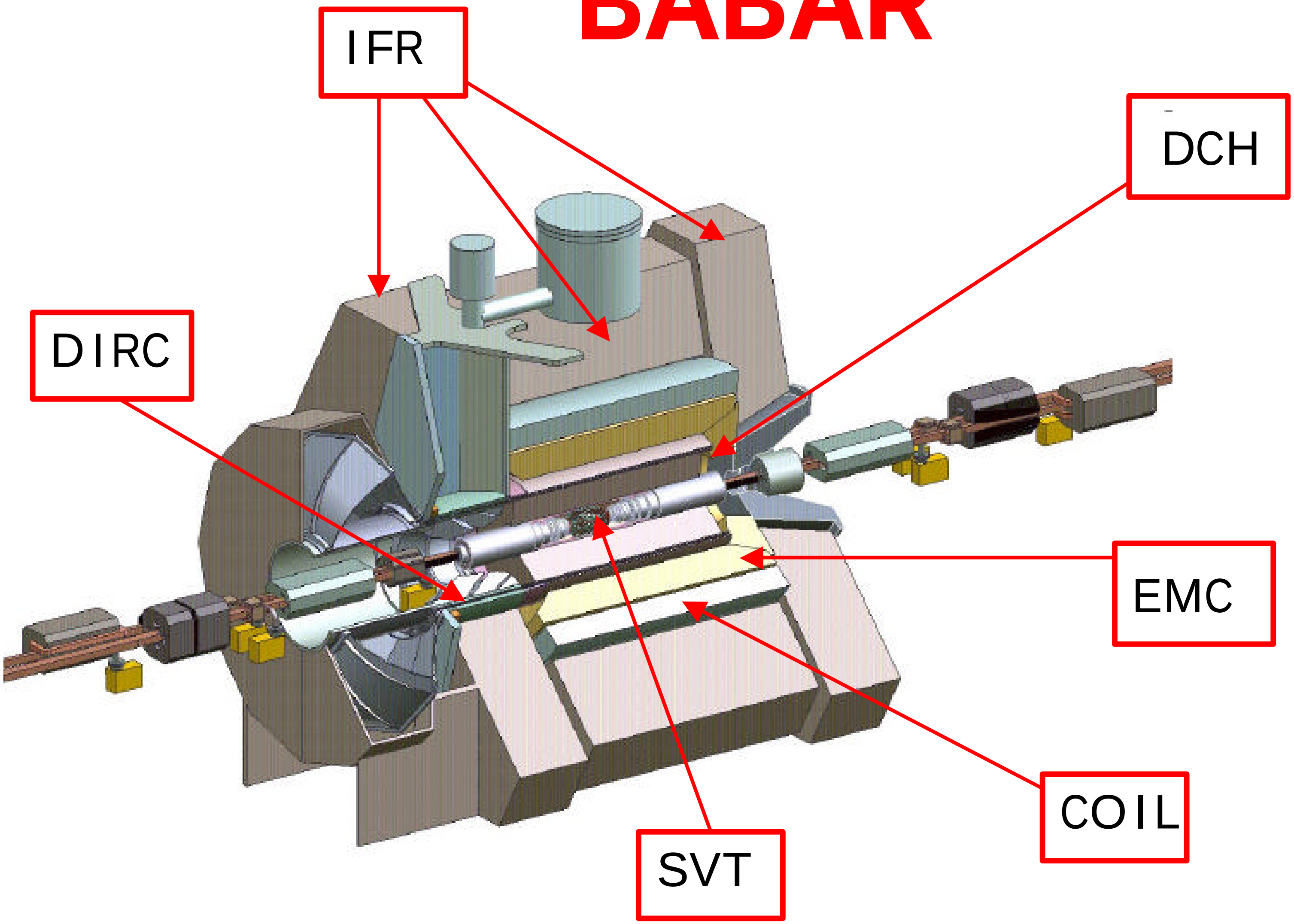
Norway [1/3]
U of Bergen

Russia [1/9]
Budker Institute, Novosibirsk

United Kingdom [10/66]
U of Birmingham
U of Bristol
Brunel U
U of Edinburgh
U of Liverpool
Imperial College
Queen Mary , U of London
U of London, Royal Holloway
U of Manchester
Rutherford Appleton Laboratory

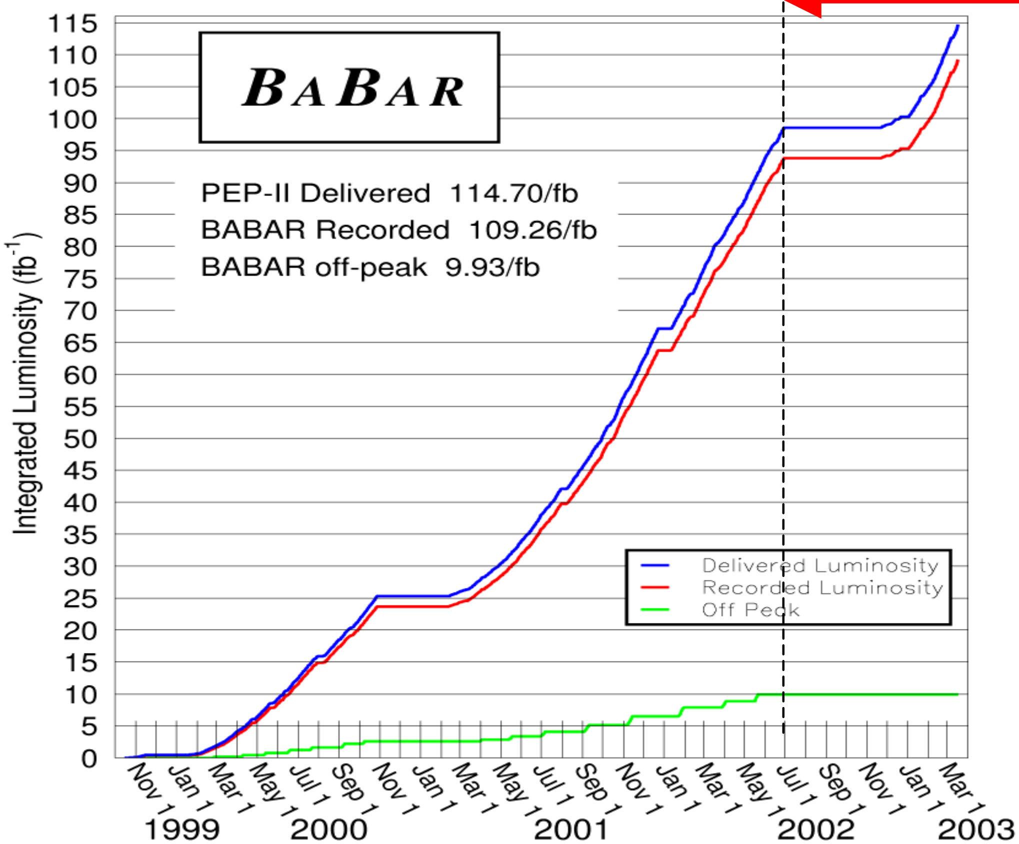
April 3, 2003

BABAR



Luminosity: Present and Future

So far in Run 3: On peak 19.03 fb^{-1}
Off peak 1.16 fb^{-1}



Summer 2002 and Winter 2003:
Run 1 + Run 2
On peak 83.9 fb^{-1}
Off peak 9.6 fb^{-1}
92 M BB pairs

FY2002

Summer 2003:
Run 3
add 40 fb^{-1}

FY2003

By end 2006:
500 fb^{-1}

Longer term

By the end of the decade:
1÷2 fb^{-1}

B pair collected (Run 1+2+3) ≈112 Million

BaBar Physics Mission

New environment: high luminosity asymmetric collider

1)Search for CP violation in B mesons decays largely predicted by the Standard Model

2)Test extensively at this low energy scale the Standard Model by measuring precisely enough quantities to impose constraints on the Standard Model parameters

~~CP~~ in b sector is **FOUND !**

TRY to open windows on new Physics beyond Standard Model

Rare B decays, Charm study, Tau rare decays

Flavour mixing and CP,T,CPT

CPV in Mixing Decay

CPV direct

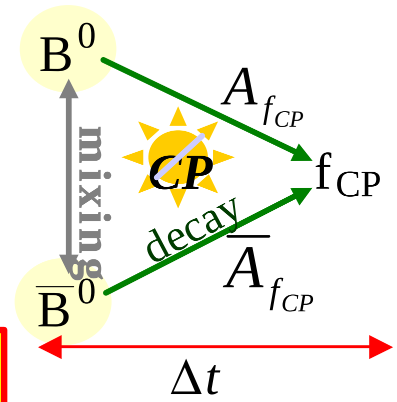
Time dependence:

$$dN \propto \exp(-|\Delta t|/\tau_B)\,(\,1 \pm D\,(S\sin(\Delta m\Delta t) - C\cos(\Delta m\Delta t))\,) \otimes R$$

$$\lambda = \eta_{cp}\,\frac{q}{p}\,\frac{\overline{A}_{cp}}{A_{cp}}$$

$$S = \frac{2\,\mathrm{Im}\,\lambda}{1+|\lambda|^2}$$

$$C = \frac{1-|\lambda|^2}{1+|\lambda|^2}$$



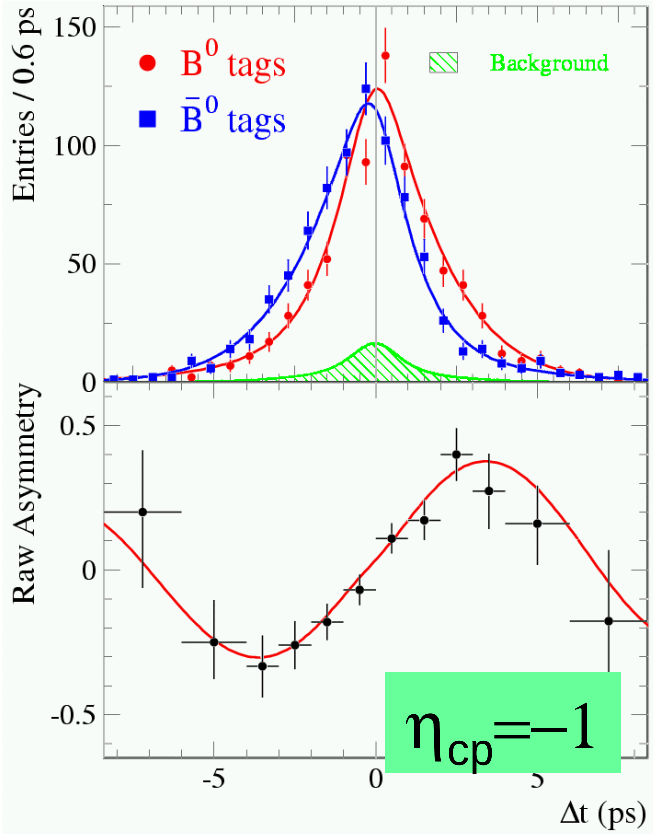
D is the mis-tag dilution

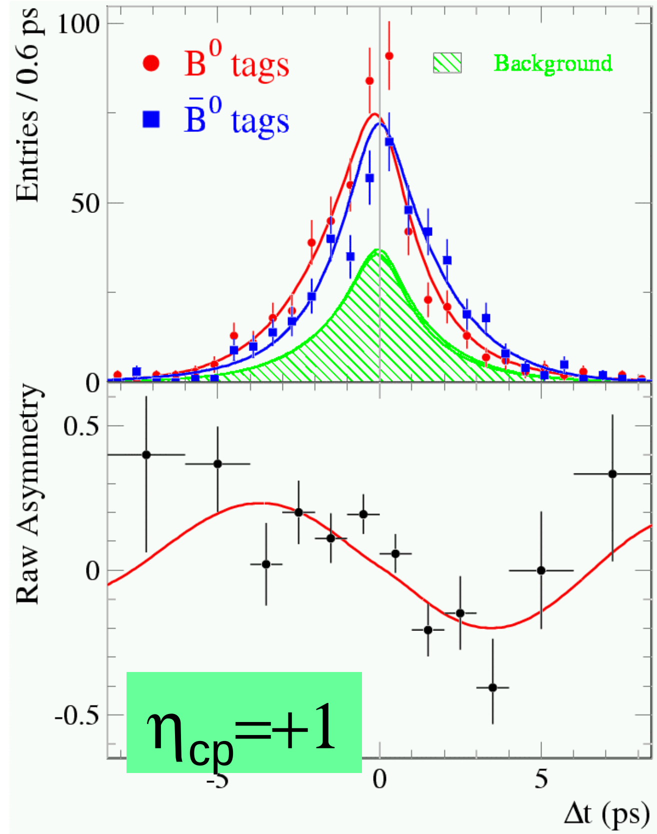
R is the time resolution

$$z = 2\,\frac{\delta M - (i/2)\delta\Gamma}{\Delta m - (i/2)\Delta\Gamma}$$

$z \neq 0$ CP & CPT violation

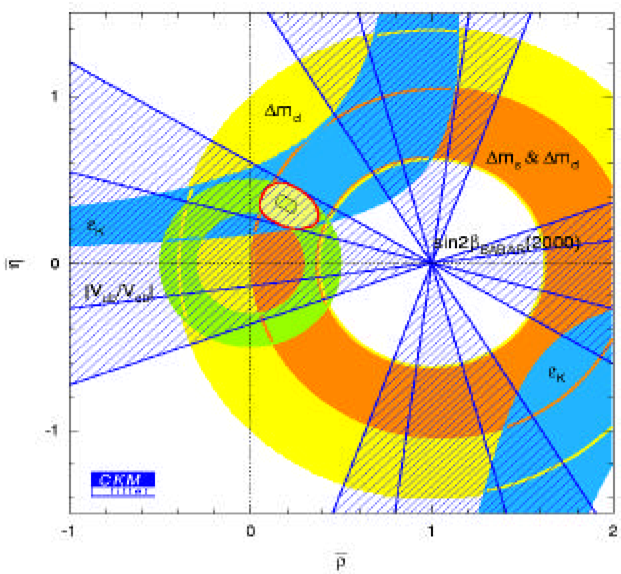
Measurement of sin2β=0.741 ± 0.067 ± 0.034





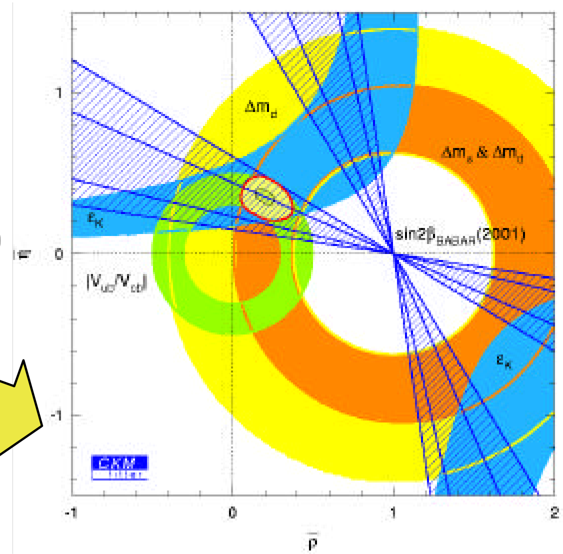
sin2b = 0.755 ± 0.074 **sin2b = 0.723 ± 0.158**

PRL 89 (2002) 201802

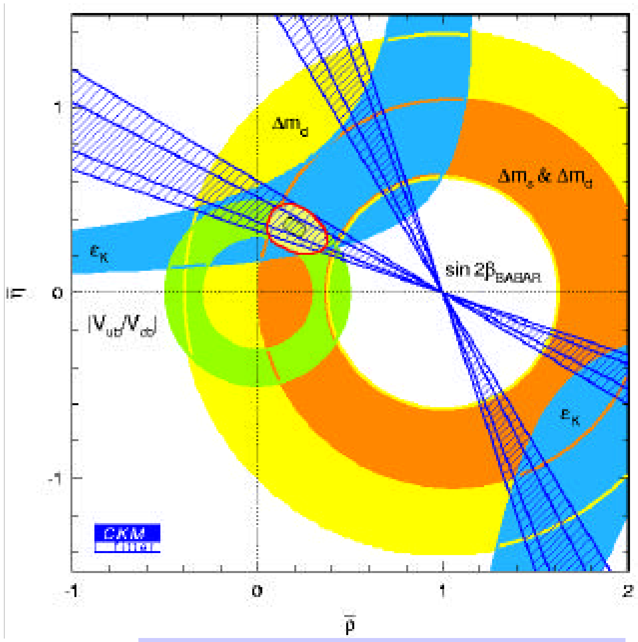


Osaka -2002

$\not{CP}$ discovery in B sector



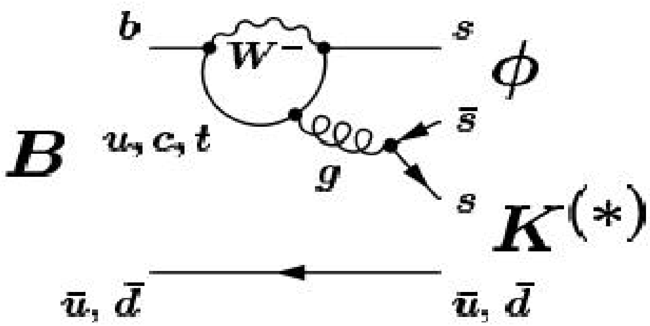
Rome- 2001

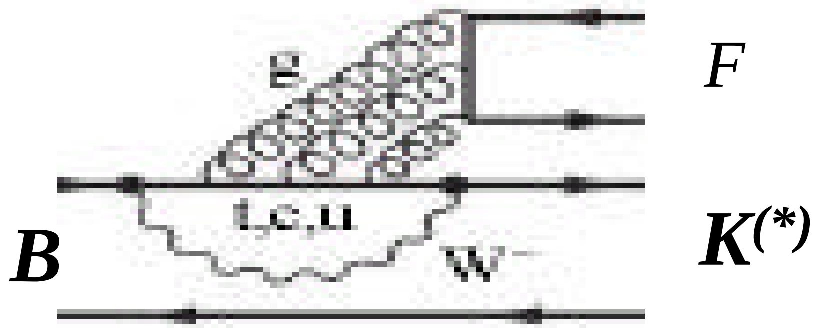


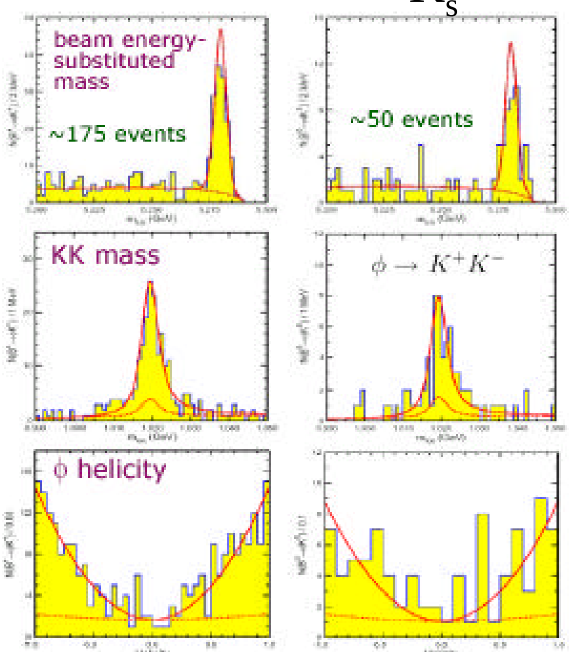
Amsterdam- 2002

(FY03) **What else on sin2b**

Measure sin2β also in ΦK (b→sss pure penguin)







$$\mathcal{B}(B^0 \to \phi K^0) = (7.6^{+1.3}_{-1.2} \pm 0.5) \times 10^{-6}$$

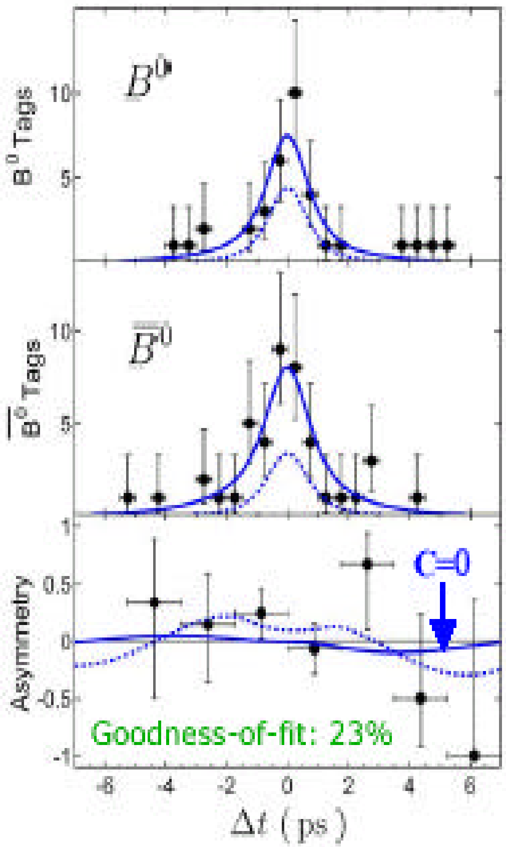
$$\mathcal{B}(B^+ \to \phi K^+) = (10.0^{+0.9}_{-0.8} \pm 0.5) \times 10^{-6}$$

$$\mathcal{A}_{CP}(B^\pm \to \phi K^\pm) = (3.9 \pm 8.6 \pm 1.1)\%$$

$$\mathcal{B}(B^+ \to \phi \pi^+) < 0.38 \times 10^{-6} \quad @90\%\,\mathrm{CL}$$

80 Million B pairs

(FY03) Time dependent analysis



Results:

$$S_{\phi K^0_S} = -0.18 \pm 0.51(\text{stat}) \pm 0.07(\text{syst})$$

$$C_{\phi K^0_S} = -0.80 \pm 0.38(\text{stat}) \pm 0.12(\text{syst})$$

Assuming C=0 (no direct CPV)

S=sin2β=-0.26±0.51 *stat.*

On control sample Charged K

expected S=0 Found S=0.26 ±0.27 *stat.*

(FY03) **CP, T, CPT**

A simultaneous fit to tagged and untagged data gives :

Δm , $\sin 2\beta$ (consistent with previous analysis)

$|A_{cp}/\bar{A}_{cp}|$ (consistent with no direct CP violation (4.5%)

(Wrong tag with K due to DCS allowed. $\Delta\Gamma/\Delta m$, z, λ, |q/p| left free!)

$$\mathrm{sign}(\mathrm{Re}\,\lambda_{CP}) \times \Delta\Gamma/\Gamma = -0.008 \pm 0.037 \pm 0.018 \quad [-0.084, +0.068]$$

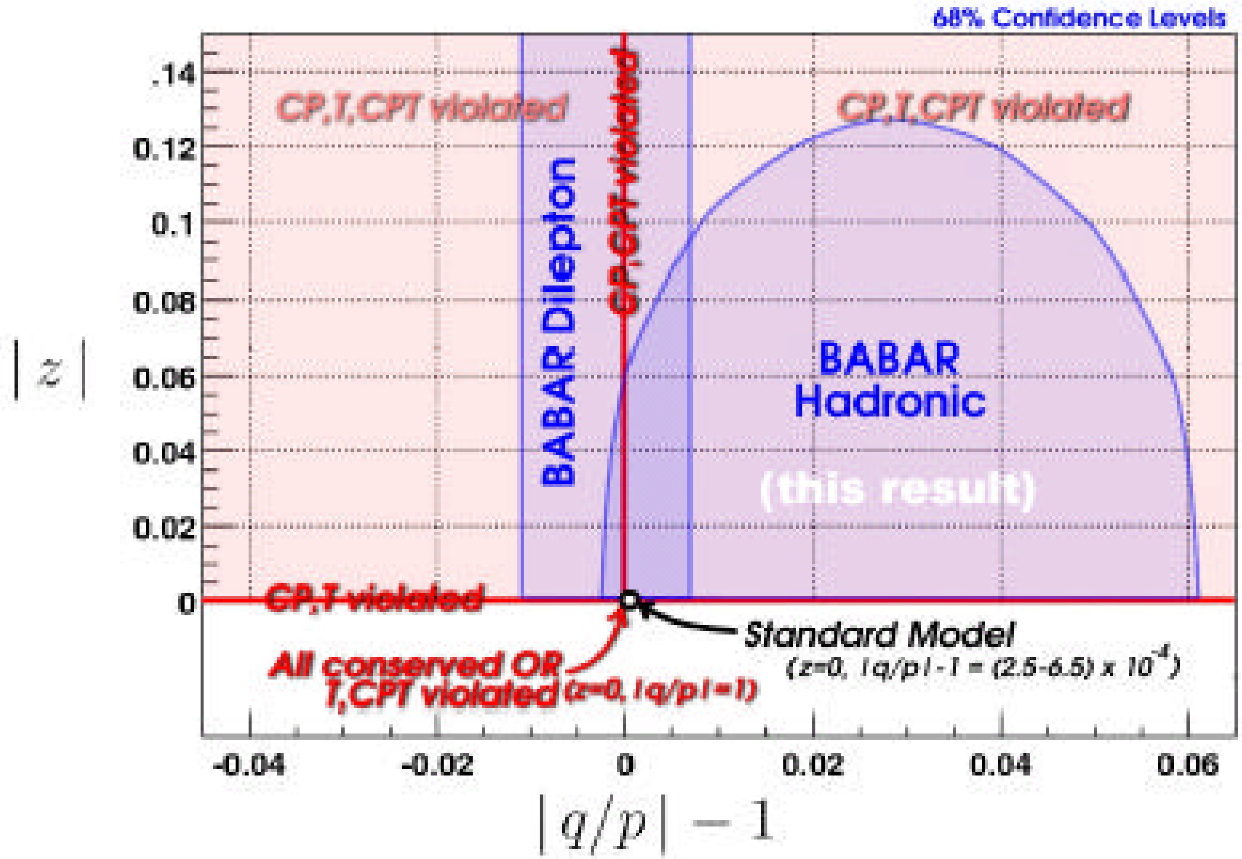
$$|q/p| = 1.029 \pm 0.013 \pm 0.011 \quad [+1.001, +1.057]$$

$$(\mathrm{Re}\,\lambda_{CP}/|\lambda_{CP}|) \times \mathrm{Re}\,z = 0.014 \pm 0.035 \pm 0.034 \quad [-0.072, +0.101]$$

$$\mathrm{Im}\,z = 0.038 \pm 0.029 \pm 0.025 \quad [-0.028, +0.104]$$

90% CL

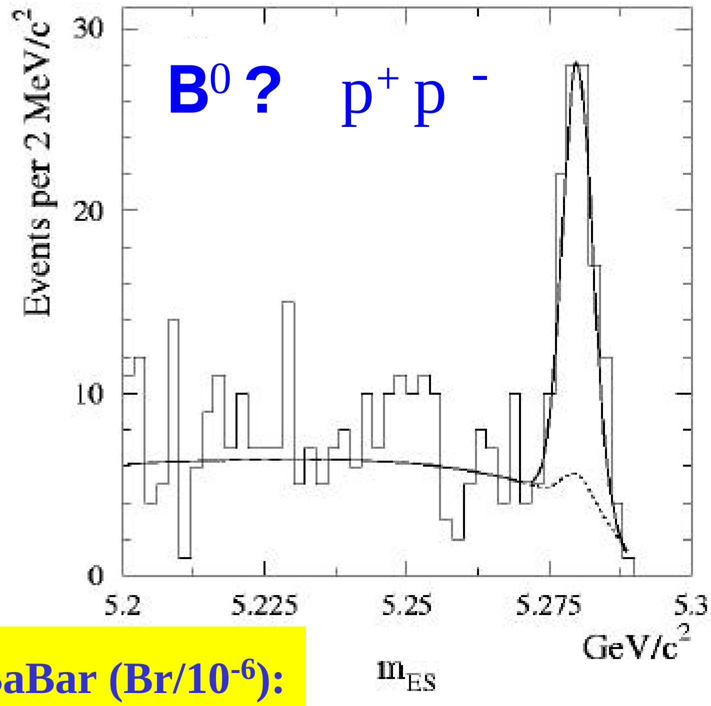
(FY03) **CP, T, CPT**

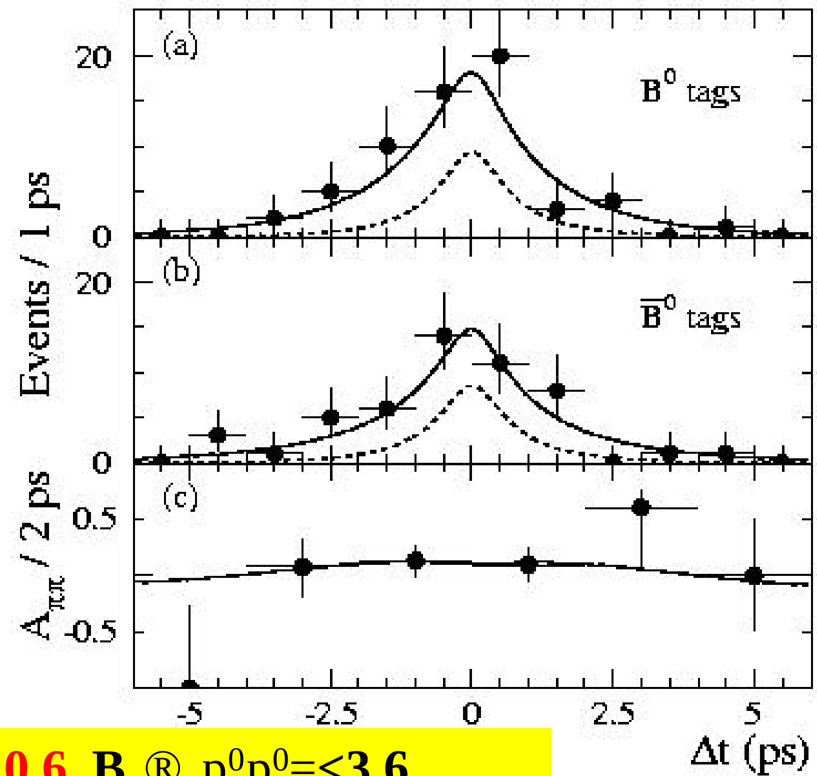


$$a_T = (0.5 \pm 1.2 \pm 1.4)\% \approx \frac{1-|q/p|^4}{1+|q/p|^4}$$

From dileptons

(FY02) Towards sin2a$_{eff}$: S$_{pp}$ and C$_{pp}$





BaBar (Br/10^{-6}):

B0 ® p$^+$p$^-$=4.7±0.6 ± 0.2 **B ® p$^+$ p^0=5.5 ± 1.0 ± 0.6** **B ® p^{0}p^0=<3.6**

$$l_{pp} = e^{2ia} \frac{1+|P/T|e^{id}e^{ig}}{1+|P/T|e^{id}e^{-ig}}$$

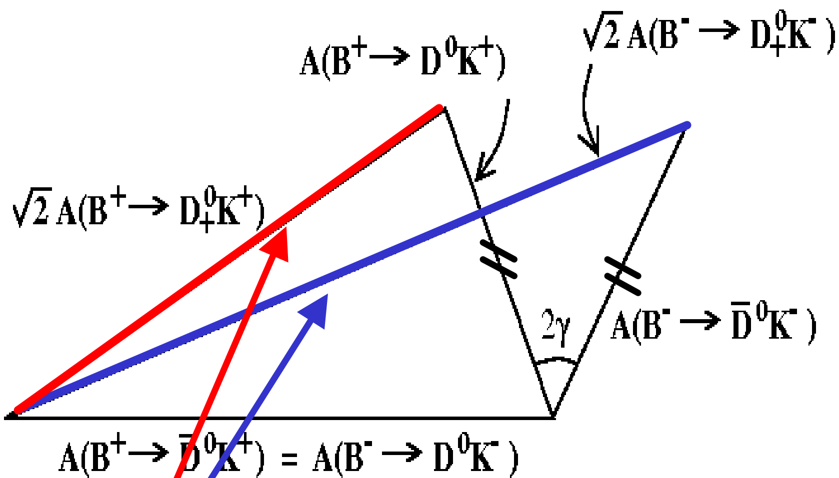
$$C_{pp} \propto \sin(d)$$

$$S_{pp} = \sqrt{1-C_{pp}^2}\ \sin(2a_{\text{eff}})$$

$$S_{pp} = 0.02 \pm 0.34(stat) \pm 0.05(syst)$$

$$C_{pp} = -0.30 \pm 0.25(stat) \pm 0.04(syst)$$

Measuring γ with $B^+ \to D^0 K^+$



$$n_1 \equiv \frac{\Gamma(B^- \to D_1 K^-)}{\Gamma(B^- \to D_0 K^-)} = \frac{1+r^2}{2} + r\cos(\Delta d - g)$$

$$p_1 \equiv \frac{\Gamma(B^+ \to D_1 K^+)}{\Gamma(B^- \to D_0 K^-)} = \frac{1+r^2}{2} + r\cos(g + \Delta d)$$

$$n_2 \equiv \frac{\Gamma(B^- \to D_2 K^-)}{\Gamma(B^- \to D_0 K^-)} = \frac{1+r^2}{2} - r\cos(\Delta d - g)$$

$$p_2 \equiv \frac{\Gamma(B^+ \to D_2 K^+)}{\Gamma(B^- \to D_0 K^-)} = \frac{1+r^2}{2} - r\cos(g + \Delta d)$$

$$\Delta p_i = \Delta n_i = a_i \sqrt{n_i}\sqrt{\frac{100\ fb^{-1}}{\int Ldt}} \oplus 0.01$$

actual detector: a_i=0.177
"perfect" vertex detector: a_i=0.133 (no Bkg)

stat. errors $\to \sqrt{N}$

$$r \equiv \left|\frac{A(B^- \to \overline{D}_0 K^-)}{A(B^- \to D_0 K^-)}\right| = O(0.1)$$

$$n_1 \equiv \frac{\Gamma(B^- \to D_1 K^-)}{\Gamma(B^- \to D_0 K^-)} = 1.02 \pm 0.29 \pm 0.02$$

$$p_1 \equiv \frac{\Gamma(B^+ \to D_1 K^+)}{\Gamma(B^- \to D_0 K^-)} = (0.72 \pm 0.26 \pm 0.02)$$

(FY03) New results with full statistics 80/fb

$$R_{CP} \equiv \frac{Br(B^- \to D^0_{CP} K^-) + Br(B^+ \to D^0_{CP} K^+)}{Br(B^- \to D^0_{CP} \pi^-) + Br(B^+ \to D^0_{CP} \pi^+)}$$

$$R_{CP}(\mathrm{KK}) = (8.0 \pm 1.7 \pm 0.6)\%$$

$$R_{CP}(\pi\pi) = (12.9 \pm 4.0^{+1.1}_{-1.5})\%$$

$$\text{combined } R_{CP}(hh) = (8.8 \pm 1.6 \pm 0.5)\%$$

$$A_{CP} \equiv \frac{Br(B^- \to D^0_{CP} K^-) - Br(B^+ \to D^0_{CP} K^+)}{Br(B^- \to D^0_{CP} K^-) + Br(B^+ \to D^0_{CP} K^+)}$$

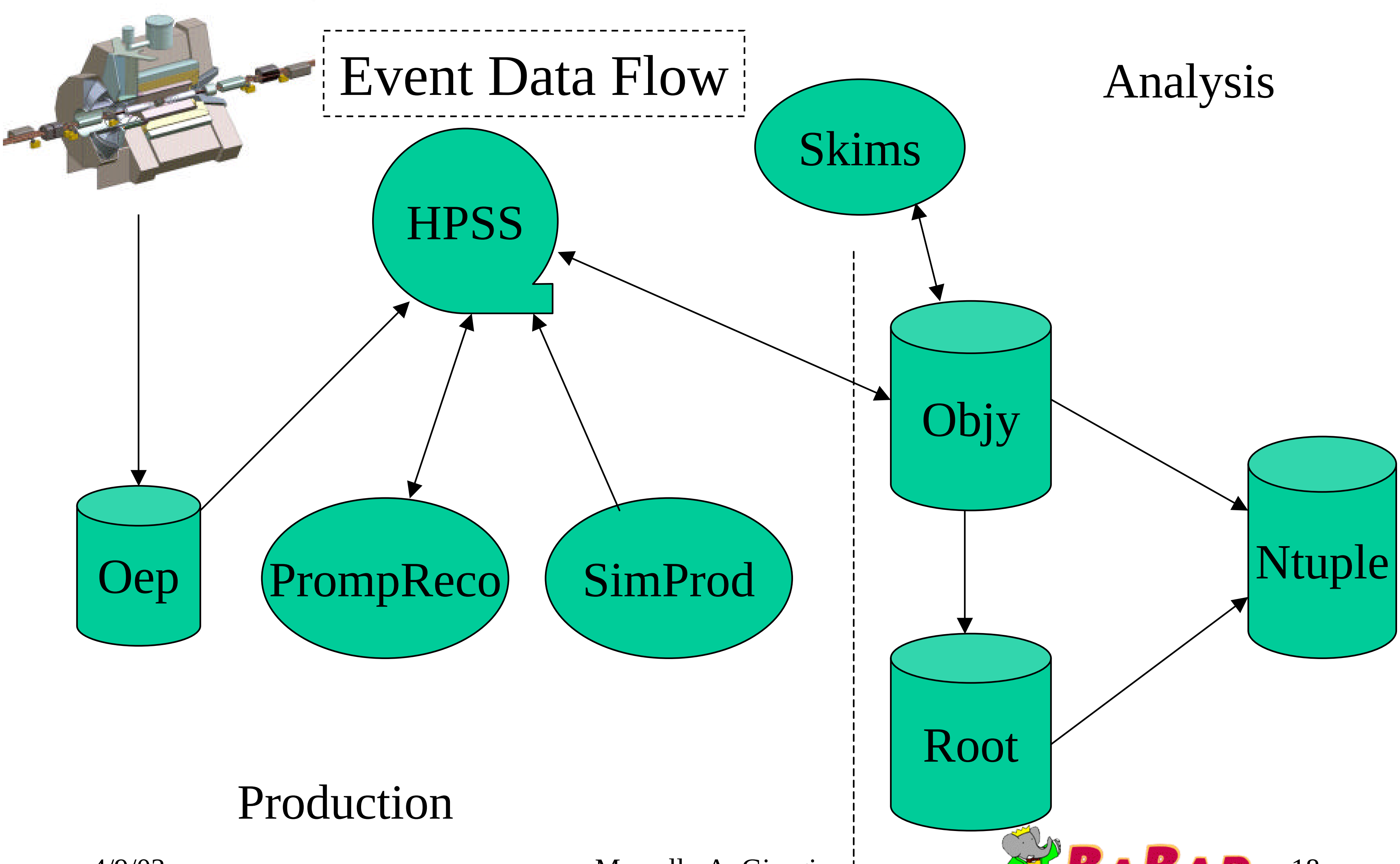
$$A_{CP}(\mathrm{KK}) = 0.25 \pm 0.20 \pm 0.07$$

$$A_{CP}(\pi\pi) = -0.44 \pm 0.34 \pm 0.06$$

$$\text{combined } A_{CP}(hh) = 0.06 \pm 0.17 \pm 0.06$$

To complete the measurements odd CP eigenstates are needed as Ks π^0 and Cabibbo suppressed modes

COMPUTING


Event Data Flow
Analysis
Skims
HPSS
Objy
Ntuple
Oep
PrompReco
SimProd
Root
Production

Computing Model Discussions (FY02)

- Current Model defined in 2000 **(April review suggested an update)**
- BaBar has 4 Tier-A sites (France, Italy, UK, US)
  - Looking at how to best exploit these distributed resources (BaBar GRID is one tool for this)
- Multiple analysis formats (now)
  - Objectivity, ROOT and Ntuples
  - Multi-step process
  - Problems found at any level need fixes propagated to other formats
- An ad hoc committee has evaluated the computing model with increased luminosity within a limited resource scenario **(in both people and money)**

Simulation Production (SP)

Since August 2001 (start of SP4) have gone from 7 sites to 25 (5 new in last 6 months)

First large experiment to utilise GEANT4 toolkit

Simulated 276 fb^{-1} BB and 75 fb^{-1} continuum

We adjusted the ratio of Bs to continuum to optimise analysis errors

Prompt Reconstruction

Now have two types of farms

Prompt Calibration (PC) Process about 600pb^{-1}/day

Event Reconstruction (ER) Process about 150pb^{-1}/day

PC keeps pace with data taking Accepts constant Hz of data should scale

Currently 2 ER farms Add another shortly

New Computing Model (FY03)

BaBar will adopt ROOT Eventstore Coupled with new analysis methodology

BaBar should consider the complete phaseout of Objectivity.

Analysis and production testing milestones through September FY2003

Many areas should see improvements Current user job management is poor

Tools to manage running and bookkeeping out user output to be developed, initial versions foreseen in FY2003

FY2002 shutdown (DETECTOR)

Down period in summer 2002 motivated by the PEPII replacement of vacuum chamber and by a major intervention to improve the muon/Klong detection in the forward direction.

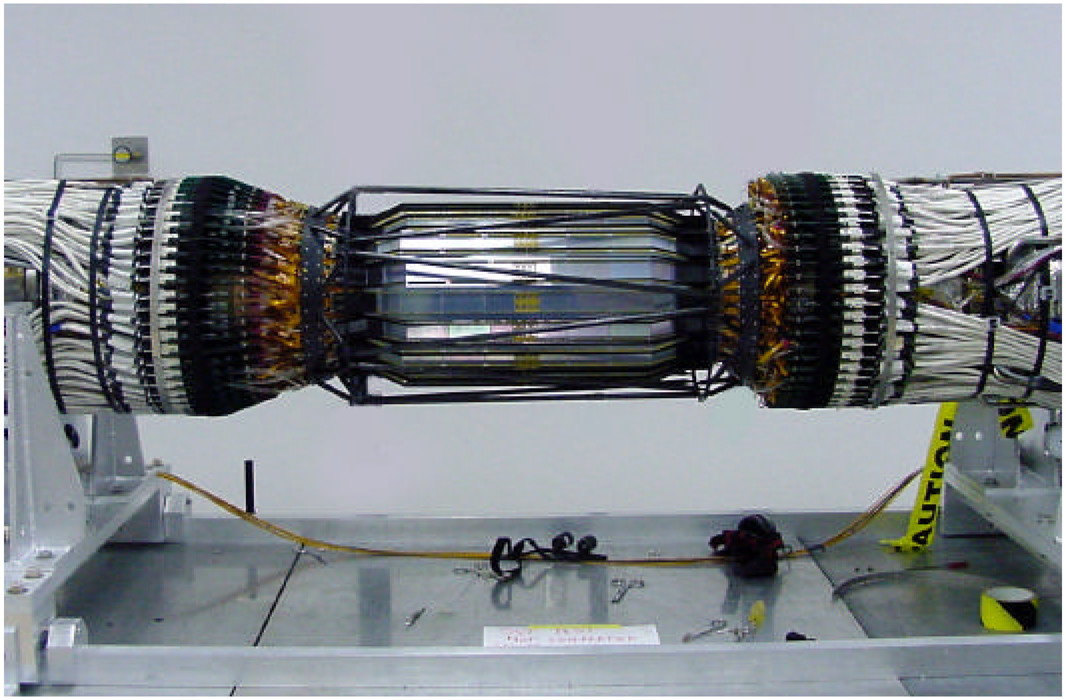
RPC newly built have been installed in the forward endcap together with new absorbers to improve the performance.

Down period Activity (DETECTOR)

- The main and programmed activities on the BABAR Detector:
  - the intervention on the IFR End Cap (muon/K_L detector).
  - The installation of new TDC in the Dirc .
  - The maintainance of SVT (possible because of the extraction from BABAR of Support Tube containing SVT, beam pipe and magnetic elements of interaction region)

SVT

- SVT has been un-cabled, taken to the clean room, split in two halves and removed from the B1 magnets
- Once the SVT was exposed electrical tests and visual inspections were performed. We discovered the reason for some of the failures of the 9 non functioning readout sections, some modules fixed! Now only 4 out of 208 sections are not readable.

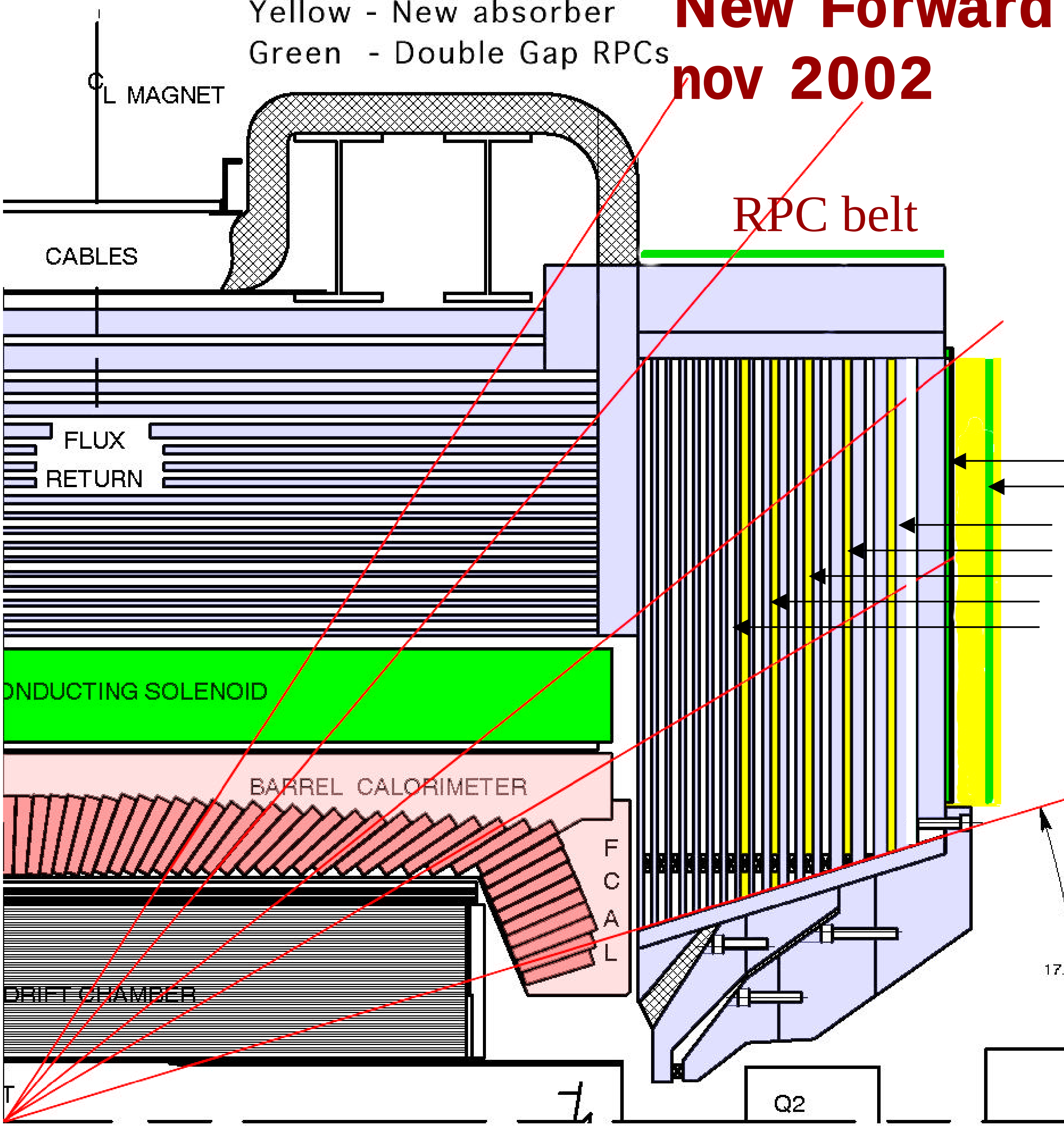


SVT so far tested for rad hardness up to 4 Mrad (OK!) rad tests are going on.

Partial SVT replacement of modules already built, tested and soon ready in Pisa and UCSB is considered by 2005

New Forward EndCap from nov 2002

Yellow - New absorber
Green - Double Gap RPCs



Terminology:
19 slots
and 15 RPC layers

Slot18/19
5 brass layers
(slot 8,10,12,14,16)

Absorber Segmentation

7 layers 2 cm

1 layer 7 cm

2 layers 9 cm

2 layers 13 cm

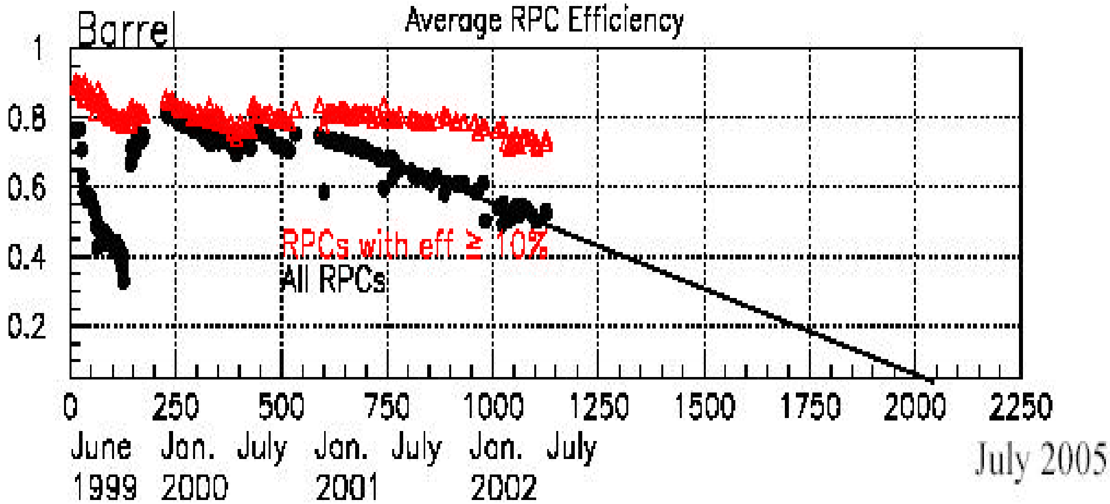
2 layers 10cm

total 85 cm

Barrel IFR Upgrade

Decreasing efficiency
Some RPC completely off

The problem: dying RPCs.



REMEDIATION attempt made in 2002 ⇨ **NO SUCCESS!**

Can BABAR program survive without the IFR Barrel ?

Decision taken in FY2003 to increase the thickness of the absorber and to replace the bakelyte RPC with a more robust detector (LST).

Physics Motivation for the IFR Barrel Replacement

- We have reviewed the long-term physics program in BaBar from the perspective of muon and K_L identification in the IFR.
- The barrel IFR represents about half of our muon acceptance.

Region	Lab frame polar angle (radians)	Fraction of CM coverage (with ϕ acceptance)	Frac. of IFR coverage
Pure barrel	$1 < \theta_{lab} < 2$	0.413 (0.380)	0.51
Barrel/endcap overlap	$0.7 < \theta_{lab} < 1$	0.185 (0.170)	0.23
Pure endcap	$0.3 < \theta_{lab} < 0.7$	0.215 (0.197)	0.26
Sum	$0.3 < \theta_{lab} < 2$	0.814 (0.748)	1.0

Physics Program for the IFR

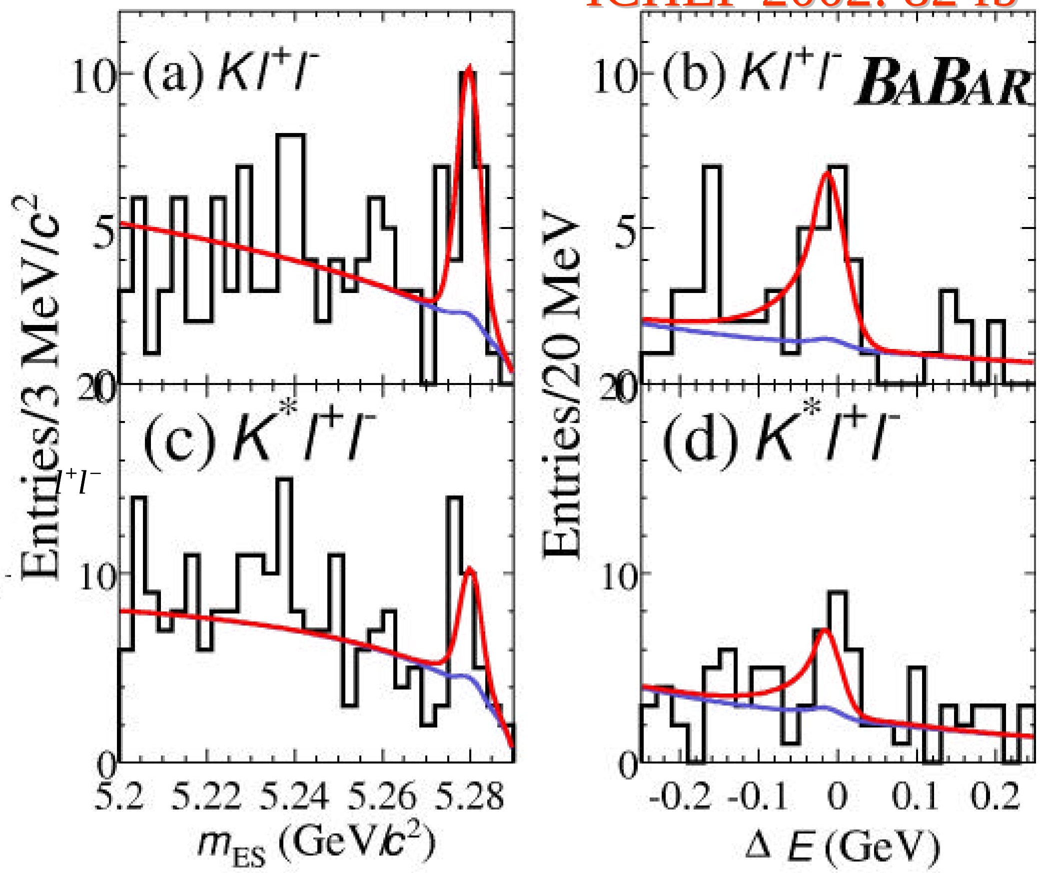
- The IFR has been used in about 30 BaBar physics analyses.
  - Semileptonic decays (*B*→*Dln, B*→*D*ln, rln, pln,* X_u*ln,* X_c*ln, ...*)
  - Leptonic decays (*B*→*t n, mn,* m^+m^-, D_s→*mn,..)*
  - Electroweak penguins (*B*→*K*l^+l^-, *K**l^+l^-, $X_s\,l^+l^-$)
  - Processes involving *J/y* or *y(2S)* (*B*→*J/y* K_s, new rare modes, e.g., evidence for ***J/****y* ***p***$^+$*L.*)
  - Lepton tagging (CP, CPT studies, mixing, certain rare decays)
  - Reconstruction of *B*→*D*ln* on one side of the event
  - K_L identification (*B*→*J/y* K_L)
- We forsee many analyses involving muons for the long-term BaBar physics program. Now look at examples, focusing on need for statistics. (Different e/μ systematics also important!)

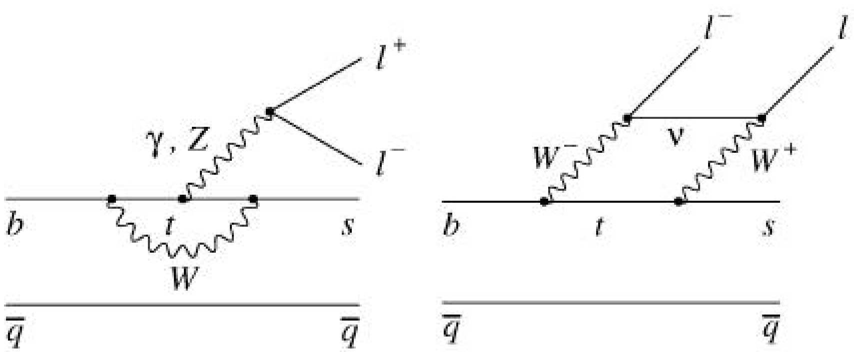
$B \rightarrow K l^+ l^-$, $K^* l^+ l^-$, $X_s\, l^+ l^-$

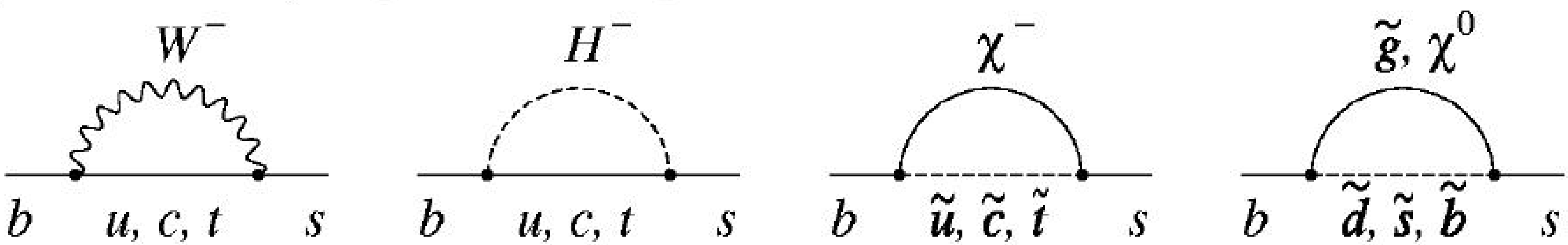
ICHEP 2002: 82 fb^{-1}

Rare FCNC modes

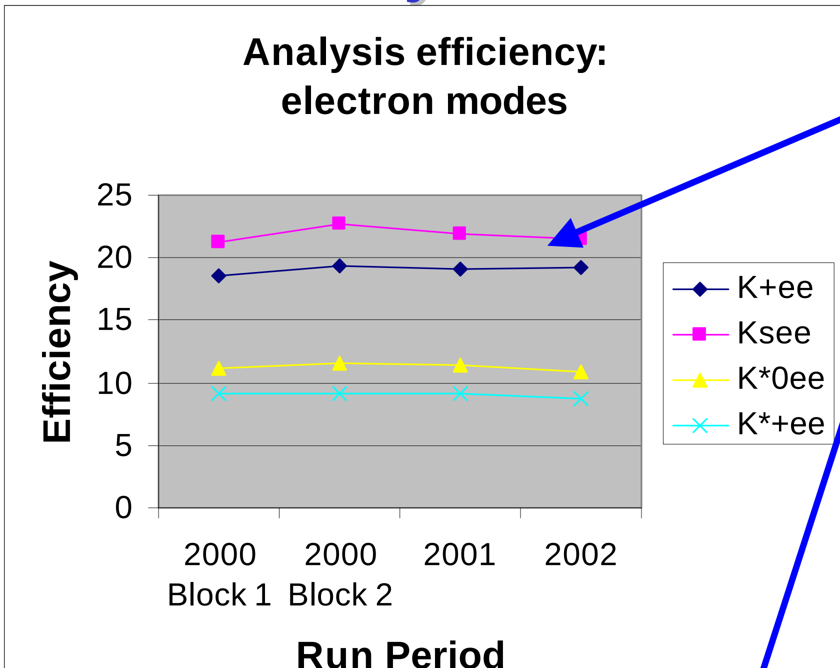
- Sensitive to IFR performance (2μ)
- *Kll* observed (4.4σ)
- *K*ll* at 2.8σ



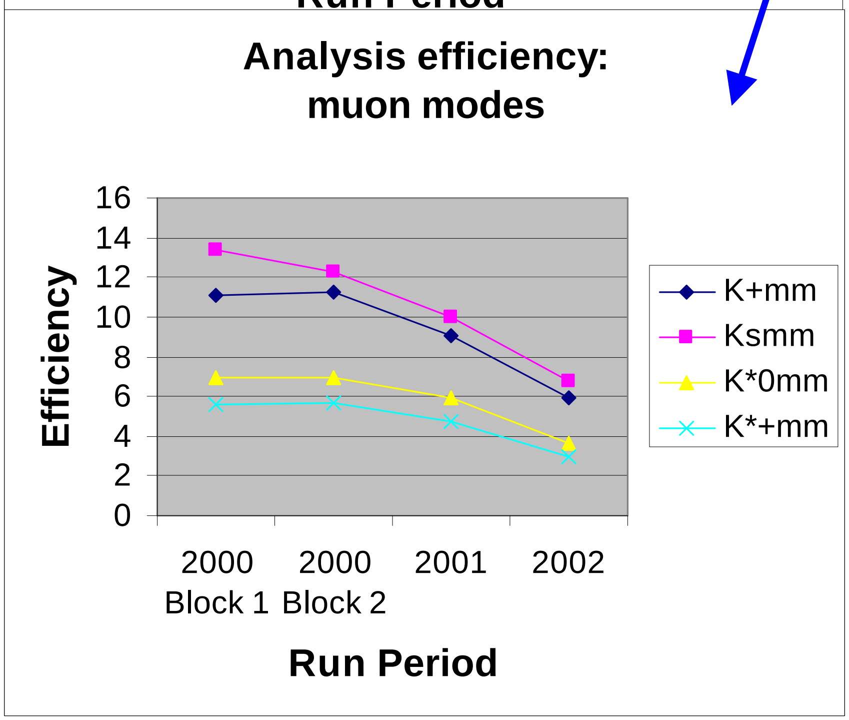


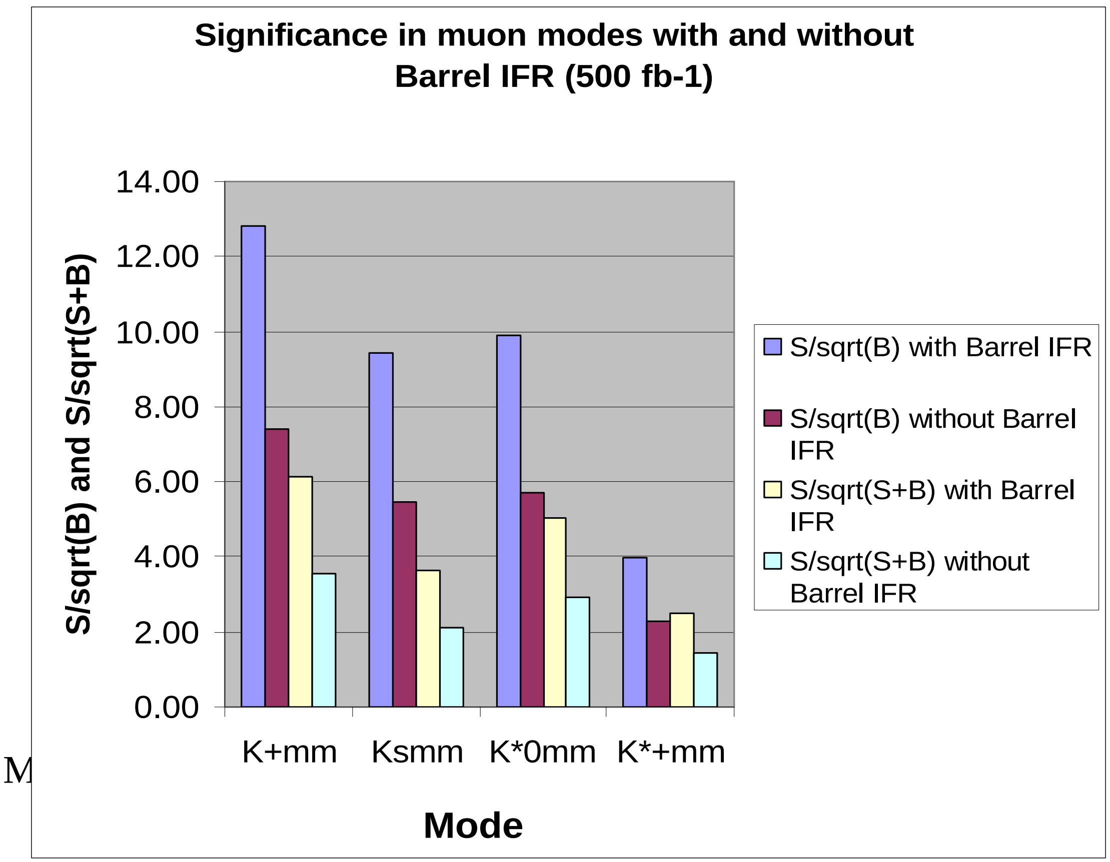


Efficiency vs. time & effect of IFR barrel replacement



- K(*)ee modes: ε stable vs. run
- K(*)μ+μ– modes: ε low & falling with time
- Lose 2/3 $\mu^+\mu^-$ events w/o IFR barrel



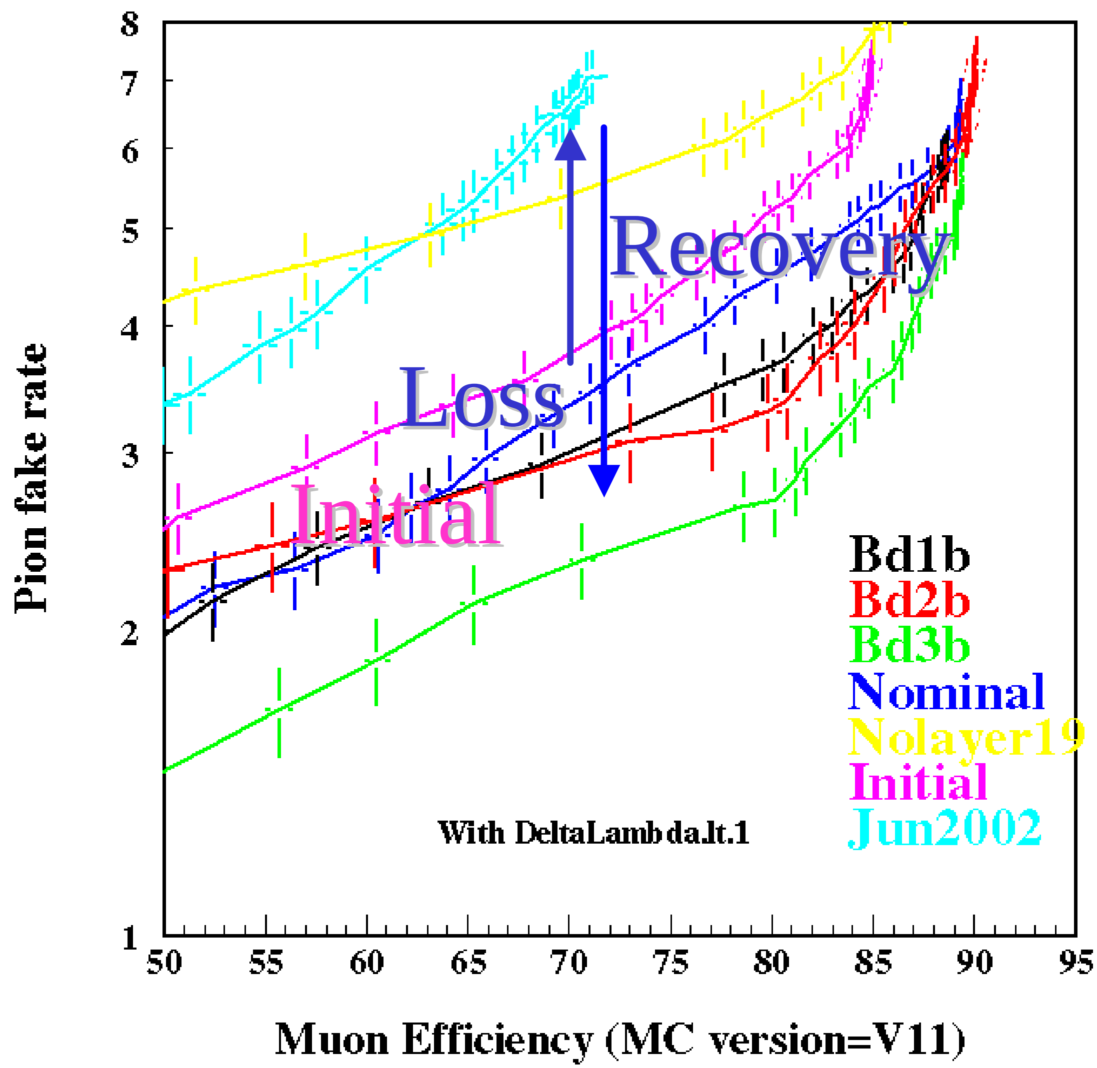


Two paths to $|V_{ub}|$

- The uncertainty on |Vub| will soon limit tests of the unitarity triangle.
- Challenges:
  1. Small branching fractions, large $b \rightarrow cln$ backgrounds
  2. Theoretical uncertainties associated with strong interaction effects
- Focus on experimental approaches with potential to reduce theoretical errors
  - Exclusive $B \rightarrow \pi\, l\, \nu$ at high q^2 with theory from lattice QCD; experiment uses "neutrino reconstruction"
  - Inclusive $B \rightarrow X_u\, l\, \nu$ with theory from heavy quark expansion; experiment uses fully reconstructed *B* sample
  - Both methods need large event samples!

New IFR Hadron Absorber

- Replacing the IFR barrel gives us the opportunity to improve the absorber design.
- IFR barrel layer 19 cannot be replaced➔ we effectively lose 10 cm (0.6 λ_{int}) of absorber. (But this layer did not have full coverage.)
- layers (0.75 λ_{int}) ; Insert 5 brass detector/absorber configuration will emphasize muon detection more than original design, but will still preserve reasonable K_L efficiency



Plot based on depth cut only.p rejection contribution :X 0.6

The Barrel improvement is motivated…..

- Physics with muons is an essential part of BaBar's long-term physics program.
- The barrel IFR provides about 50% of our muon acceptance.
  - The main effect of not replacing the barrel would be loss of statistics.
  - Muons are also valuable because they have very different systematics from electrons (Different detectors, radiation from electrons)
  - Modes with 2 leptons, such as *B→Kll, B→K*ll, and B→Xsll,* would be severely affected without the barrel replacement.
- Physics with K_L's will probably be less important than in the initial stage of BaBar, when B→J/ψ K_L was very important.
  - Can redesign the absorber to be more optimal for muon ID
  - Still retain significant K_L capability
- With strong competition from Belle and soon from CDF, BaBar needs IFR Barrel replacement

IFR Barrel Upgrade **(DETECTOR FY03 ….)**

- Decision on technology made during Dec Collaboration Meeting.
- Project based on LST will be ready (WBS) by end of may 2003 and will be reviewd in June.
- Access for replacement of current RPCs is mechanically complex: significant engineering needed. Expect to upgrade in 2004 and 2005 to avoid an extremely long shutdown.

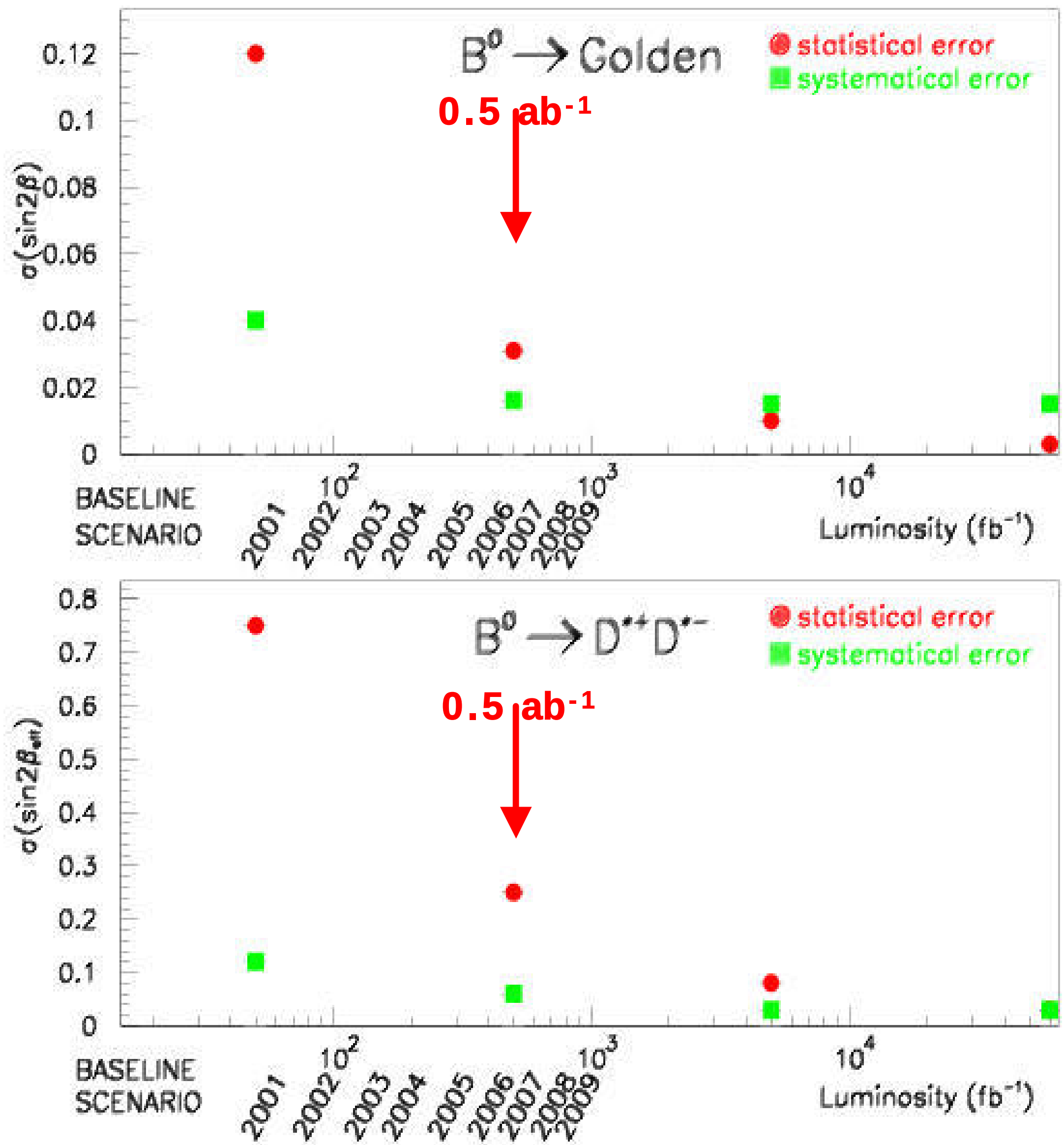
(>FY03) What next for Sin 2b

We can improve the expt. error on sin2β with luminosity in time dependent asimmetry for channels as:

$b \to ccs$ $O(\lambda^2)$ (golden as $J/\psi K_s$) or

$b \to ccd$ $O(\lambda^3)$ (as $D^{(*)+} D^{(*)-}$) ,

where the leading term gives sin2β



(>FY03) What next for Sin 2b

Pure penguin process B ⟶ Φk

NEW PHYSICS ?

New quanta in the loop?

The present value with 80 / fb is:

$$S=\sin 2\beta=-0.26\pm 0.51\ \mathit{stat.}$$

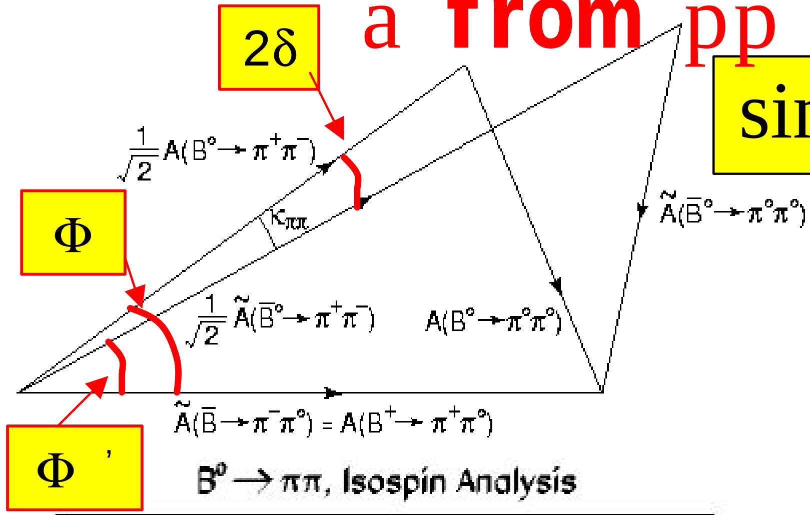
But also B ⟶ ηk and B ⟶ K K K

How from a_{eff} to a ?

ππ channel with isospin analysis?

ρπ with Dalitz plot analysis?

a from pp ISOSPIN ANALYSIS



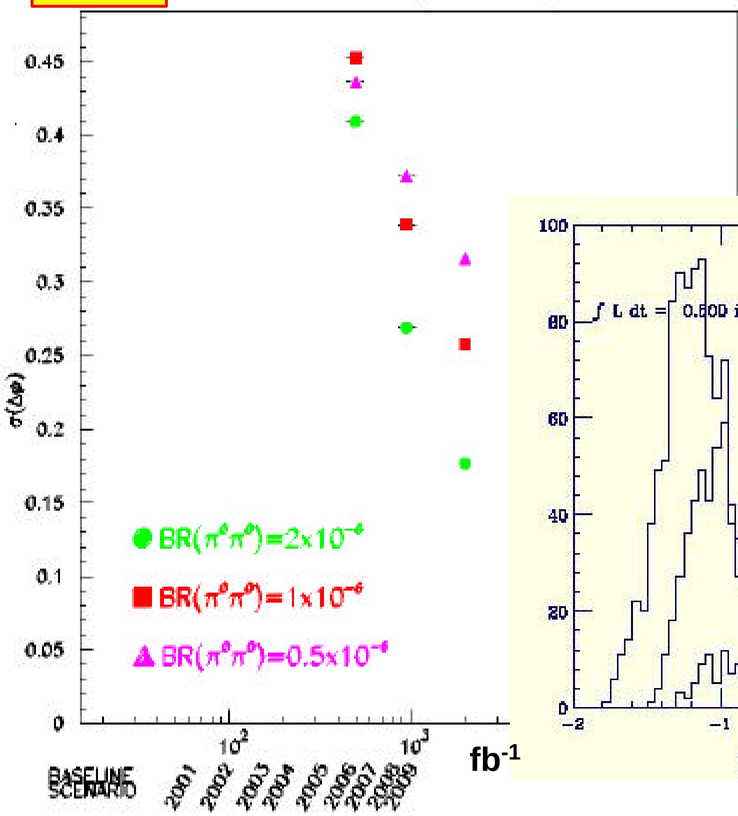
$$\sin 2a_{eff} = \sin(2a - 2d) = 0.2 \pm 0.34 \pm 0.05$$

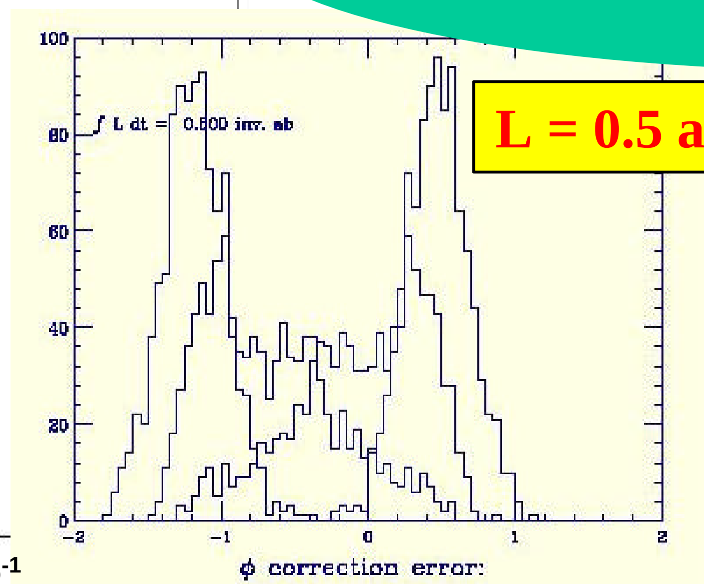
In a full isospin analysis one can measure Φ and Φ' from B and B decays with a 4-fold ambiguity

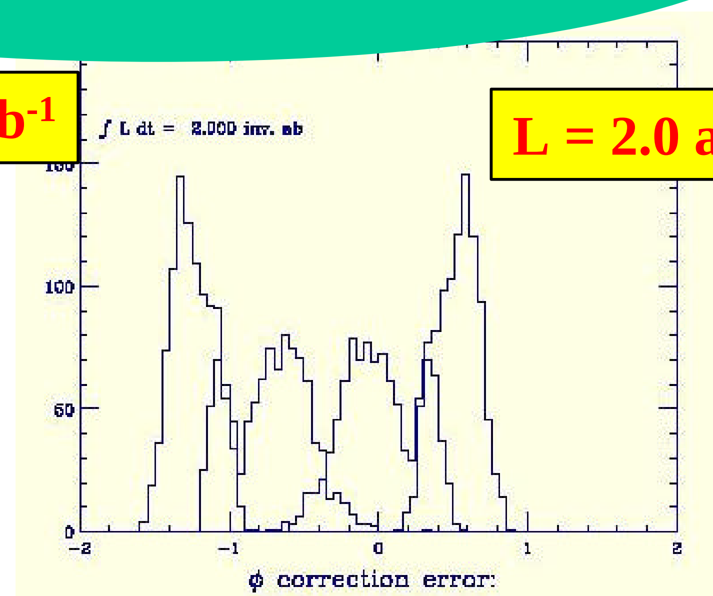
$$\cos\phi = \frac{Br(\pi^+\pi^0) + \frac{1}{2}Br(\pi^+\pi^-) - Br(\pi^0\pi^0)}{\sqrt{2Br(\pi^+\pi^-)\,Br(\pi^+\pi^0)}}$$

Fix :BR($\pi^+\pi^-$) = 4.7x10^{-6}, BR($\pi^-\pi^0$) = 4.1x10^{-6}

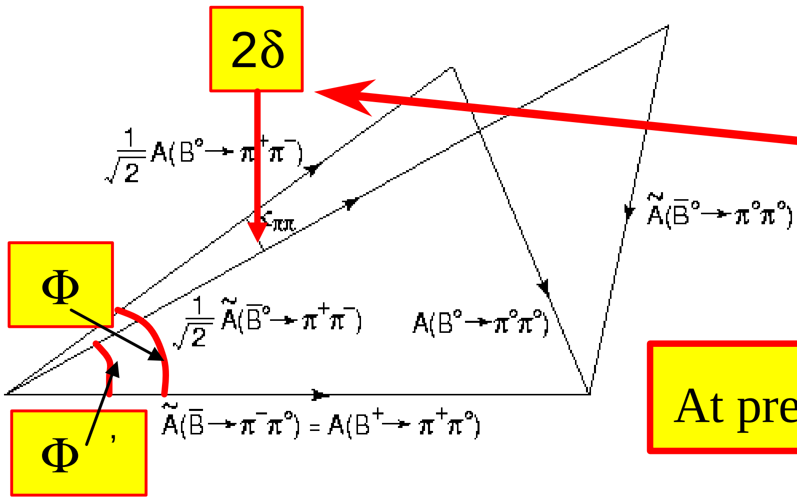
and assuming BR($\pi^0\pi^0$)$\leq$ 1.0 x10^{-6}







Bound on δ

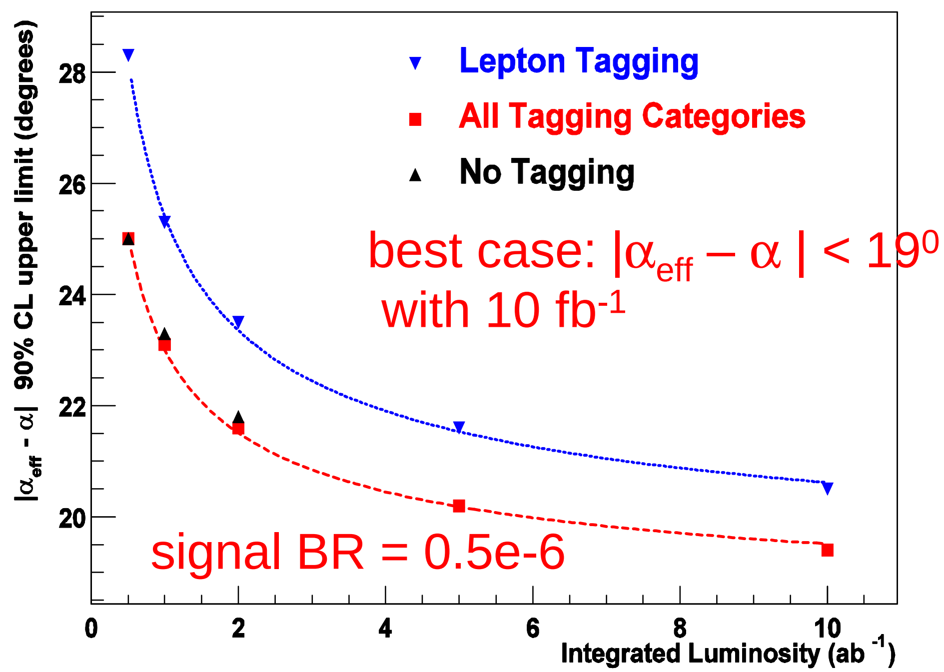


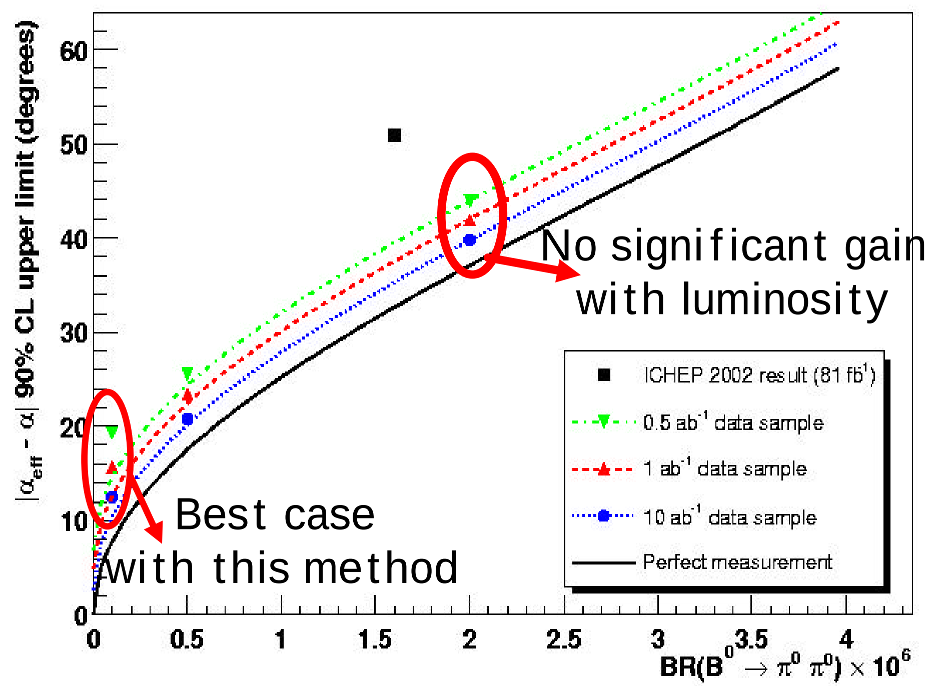
$\sin 2\alpha_{eff} = -0.02 \pm 0.34 \pm 0.05$

with $2\alpha_{eff} = 2\alpha + 2\delta$

Grossman-Quinn bound: $\sin^2\delta \leq \frac{Br(B^0 \to \pi^0\pi^0)}{Br(B^+ \to \pi^+\pi^0)}$

At present BR(B^0? $\pi^0\pi^0$) < 3.6×10^{-6} (81 /fb) ⇨ $\delta = |\alpha_{eff} - \alpha| < 51^o$

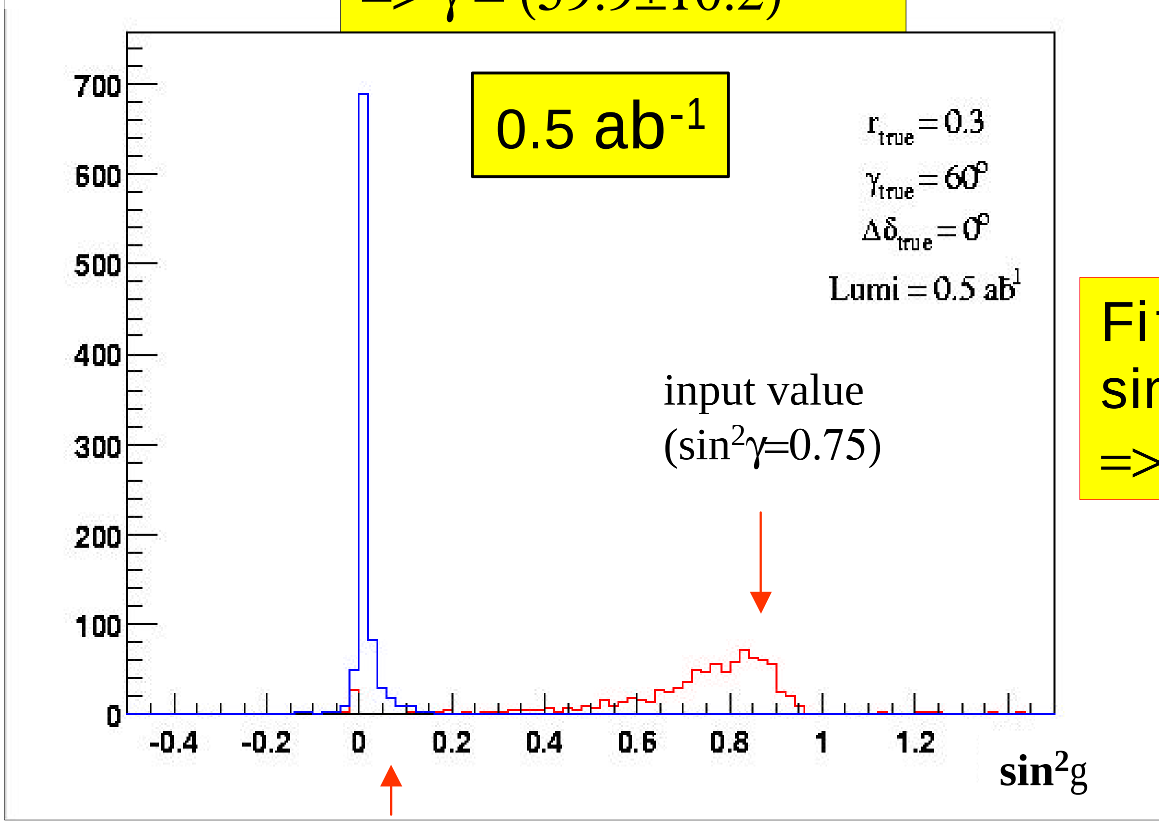




g from $B^+ \to D^0 K^+$

Fit: $\sin^2\gamma = 0.72 \pm 0.23$
=> $\gamma = (59.9 \pm 10.2)^o$

Toy MC: results for r=0.3



input value
($\sin^2\Delta\delta$=0)

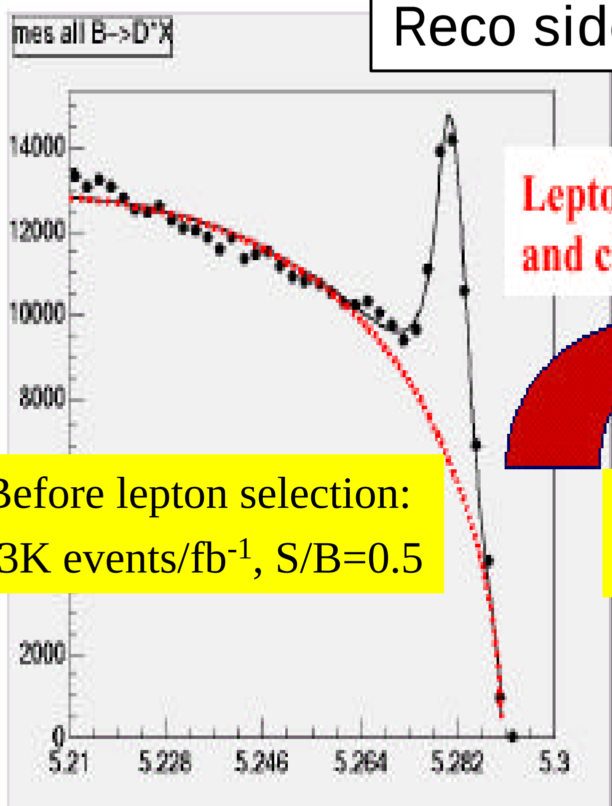
Fit with $2ab^{-1}$ (perfect):
$\sin^2\gamma = 0.71 \pm 0.14$ ($\sin^2\gamma = 0.73 \pm 0.09$)
=> $\gamma = (58.5 \pm 7.4)^o$ ($\gamma = (58.8 \pm 5.5)^o$)

Measuring V_{ub}

Measure $Br(b \to u l \nu)$ on the recoil of fully reconstructed B.

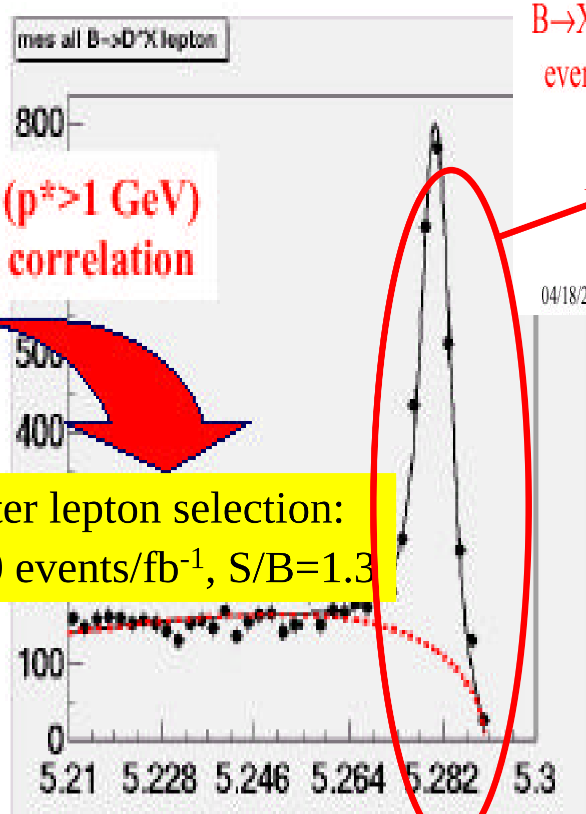
Close kinematics: P^*_l, Q^2 and M_x available

Reco side

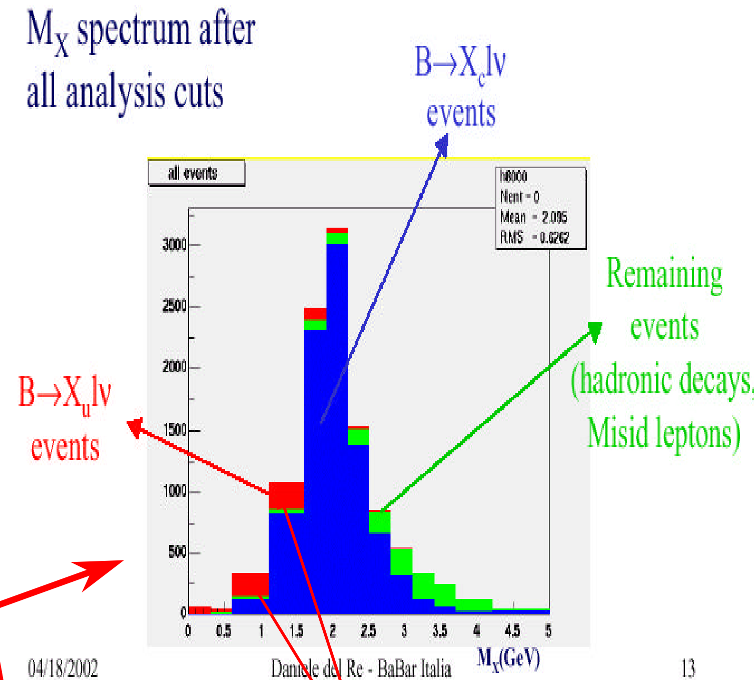


Before lepton selection:
>3K events/fb^{-1}, S/B=0.5

Lepton cut (p*>1 GeV)
and charge correlation



After lepton selection:
~500 events/fb^{-1}, S/B=1.3



We are after the red part and one want to go as close as the D mass

- M_X spectrum depends on the Fermi motion of the b quark in the B meson

$$F(x) = N(1-x)^a e^{(1+a)x}$$

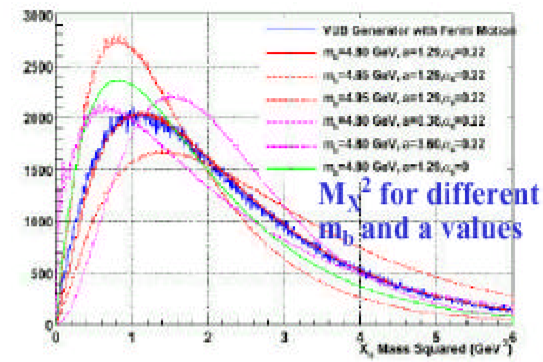
where $x = k_+/\overline{\Lambda}$ and $\overline{\Lambda} = m_B - m_b$

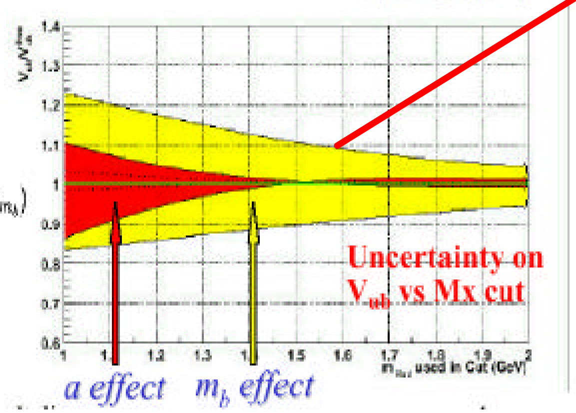
(see De Fazio, Neubert JHEP 9906:017,1999).

- The fraction of signal events removed by a cut on M_X is then affected by a large uncertainty
- V_{ub} can be determined from:

$$|V_{ub}| = 0.00445\left(\frac{\mathcal{B}(B\to X_u l\nu)}{0.002}\frac{1.55ps}{\tau_b}\right)^{1/2} \times \left(1.0 \pm 0.020_{pert} \pm 0.030_{1/m_b^3} \pm 0.035_{m_b}\right)$$

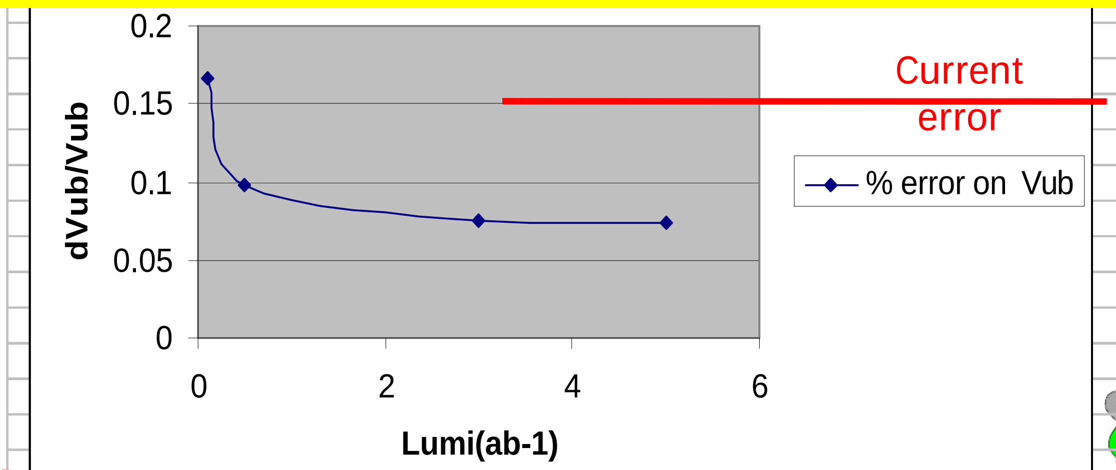
- ~10% theoretical uncertainty with a cut at 1.6 GeV





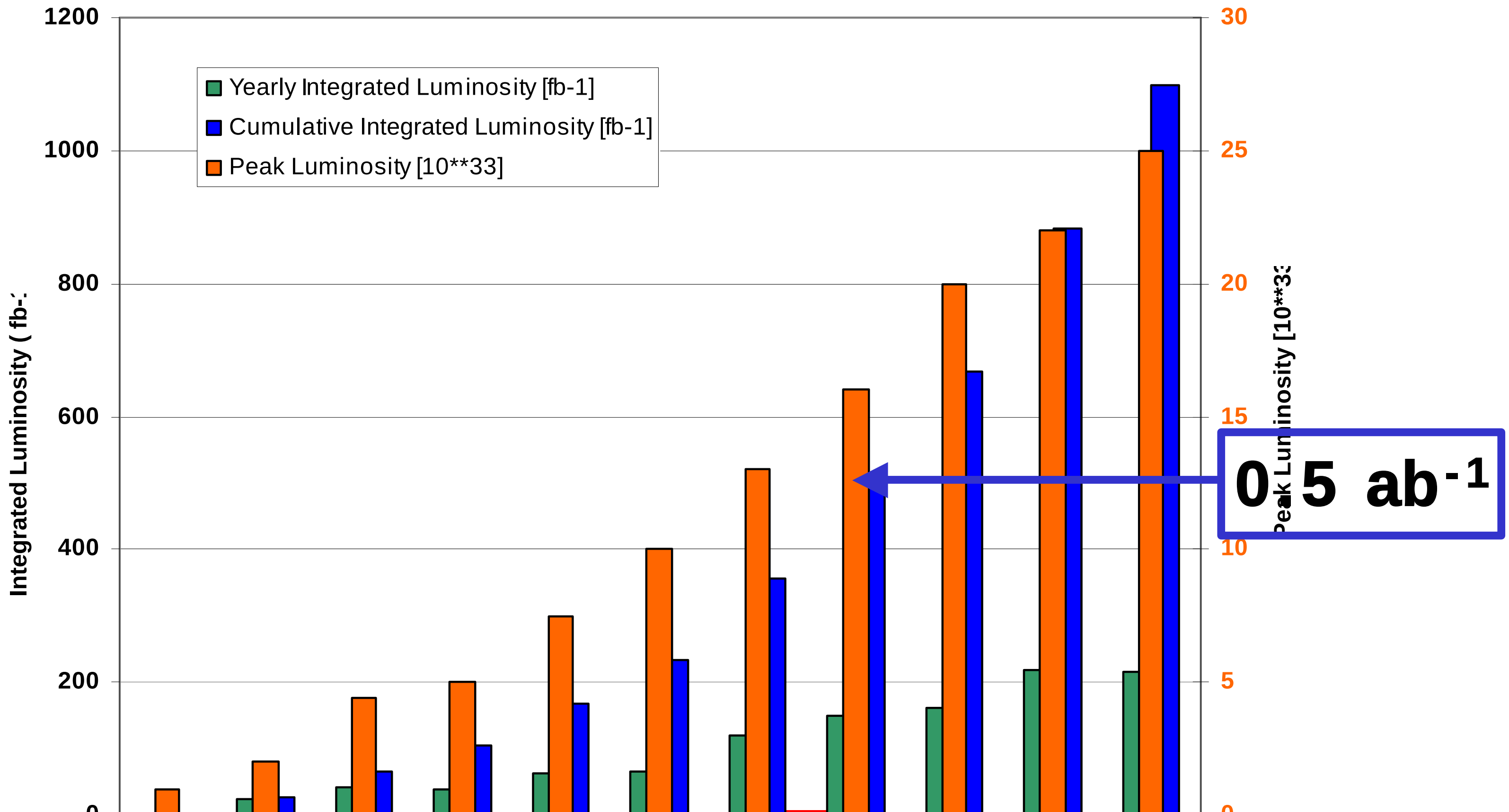
The theoretical error of 10% can be further reduced at the 5% level using all information P^*_l, Q^2 and M_x

Assuming a 5% theoretical error and a 5% experimental systematic error, here are the projections of the error as a function of the luminosity



N.B. this estimate neglects the fact that the full fledged theorethical extraction becomes feasible only with enough statistics

PEP II – “adiabatic” scenario



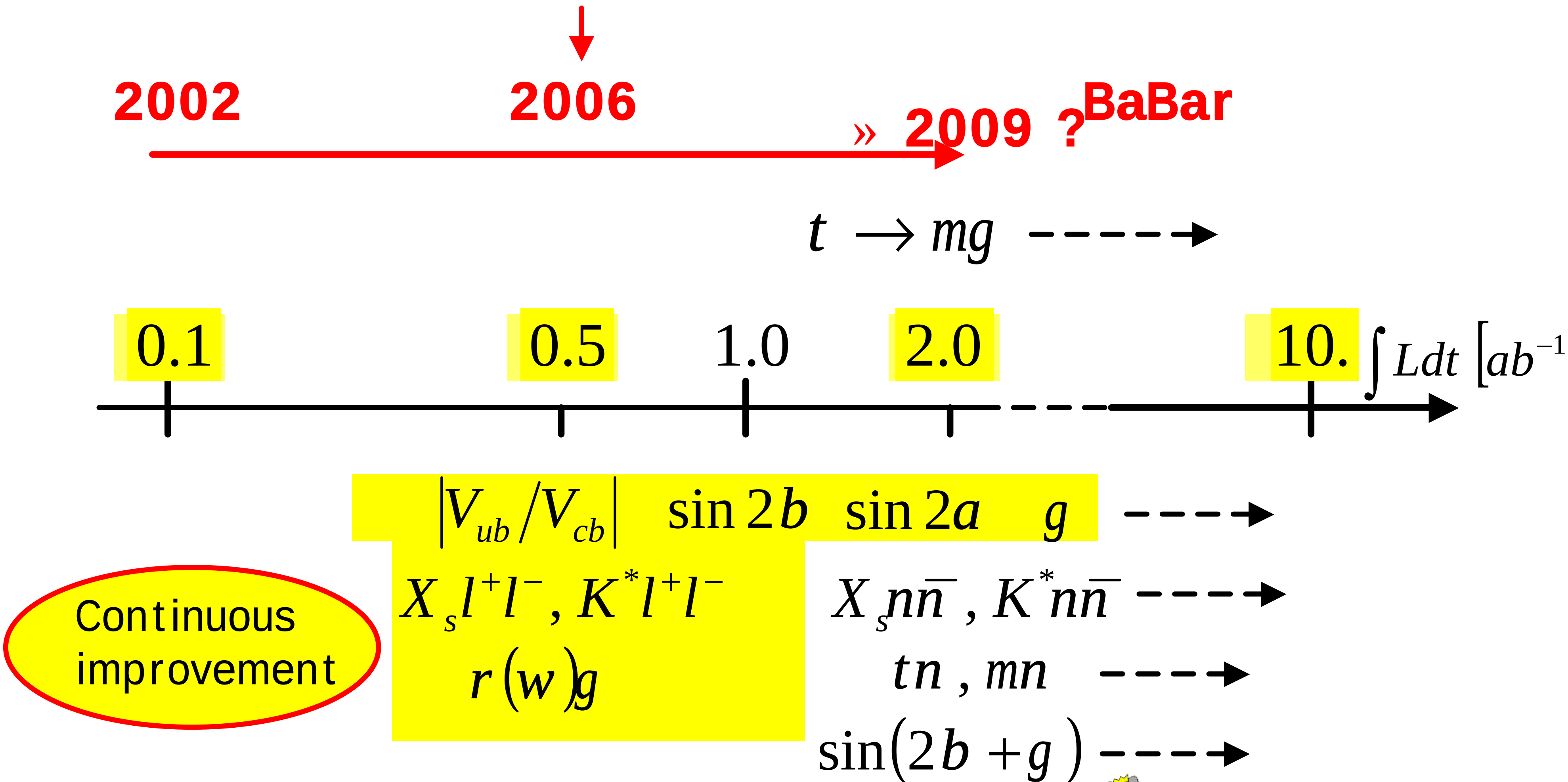
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Yearly Integrated Luminosity [fb-1]	3	23	41	39	62,6	66,1	120,1	151	160,1	217	216
Cumulative Integrated Luminosity [fb-1]	3	26	67	106	168,6	234,7	354,8	505,8	665,9	882,9	1098,9
Peak Luminosity [10**33]	1	2	4,4	5	7,5	10	13	16	20	22	25

Year

1.6×10^{34}

2006

Integrated luminosity vs physics



Summary

FY2002-Precise measurement of sin2β, preliminary measurement of sin2αeff

New IFR Endcap installed, SVT improved !

Decision to move toward a new computing model,several Tier-A in operation (Lyon,Padova,Rutherford)

FY2003-Starts the implementation of the new computing model, Karlsruhe in operation.

Decision taken to rebuild the IFR Barrel with a new technology (LST)

Preliminary measurements of pure penguin processes for sin2b, preliminary measurements of Vub, B->DK, B-$\rho\pi$.

Summary

FUTURE – In 2005 install IFR Barrel and Spare modules of SVT, to replace the heavily irradiated on horizontal plane.

New computing model based on Root files in operation in a distributed system with 4 active Tier-A centers beside SLAC.

Approach the precision measurement with 0.5/ab of integrated luminosity and towards more than 1.0/ab to explore possible openinings for new physics.

Study of CP asymmetries but also rare decays in b, c and tau sectors.