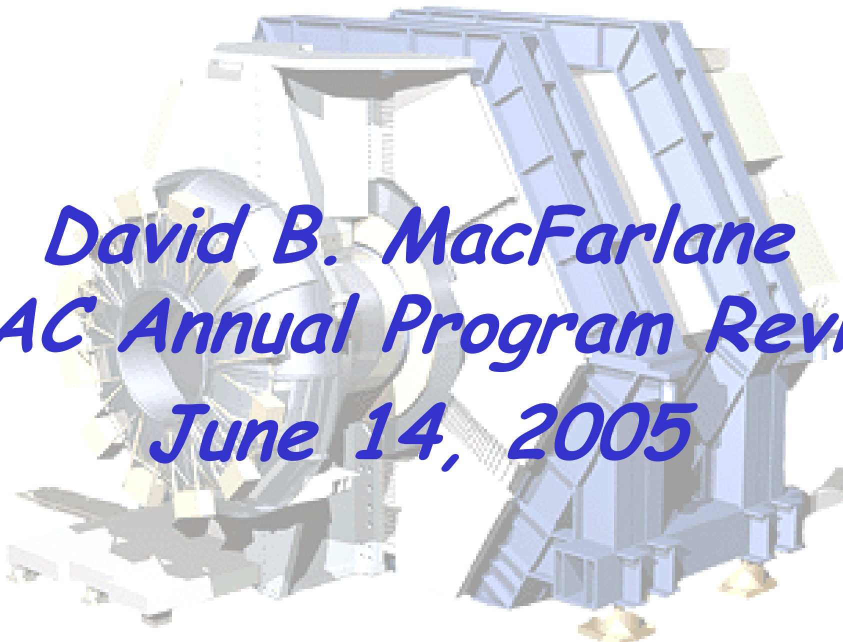
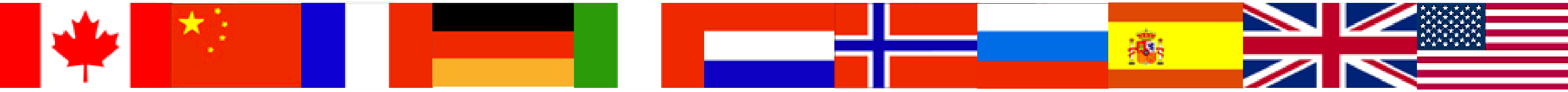
BABAR Update and Plans



David B. MacFarlane
SLAC Annual Program Review
June 14, 2005

Stanford Linear Accelerator Center



The *BABAR* Collaboration

11 Countries

80 Institutions

623 Physicists

USA [38/311]

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
Harvard U
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 [4/24]

U of British Columbia
McGill U
U de Montréal
U of Victoria

China [1/5]

Inst. of High Energy Physics, Beijing

France [5/53]

LAPP, Annecy
LAL Orsay
LPNHE des Universités Paris VI et VII
Ecole Polytechnique, Laboratoire Leprince-Ringuet
CEA, DAPNIA, CE-Saclay

Germany [5/24]

Ruhr U Bochum
U Dortmund
Technische U Dresden
U Heidelberg
U Rostock

Italy [12/99]

INFN, Bari
INFN, Ferrara
Lab. Nazionali di Frascati dell' INFN
INFN, Genova & Univ
INFN, Milano & Univ
INFN, Napoli & Univ
INFN, Padova & Univ
INFN, Pisa & Univ & Scuola Normale Superiore
INFN, Perugia & Univ
INFN, Roma & Univ "La Sapienza"
INFN, Torino & Univ
INFN, Trieste & Univ

The Netherlands [1/4]

NIKHEF, Amsterdam

Norway [1/3]

U of Bergen

Russia [1/13]

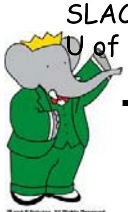
Budker Institute, Novosibirsk

Spain [2/3]

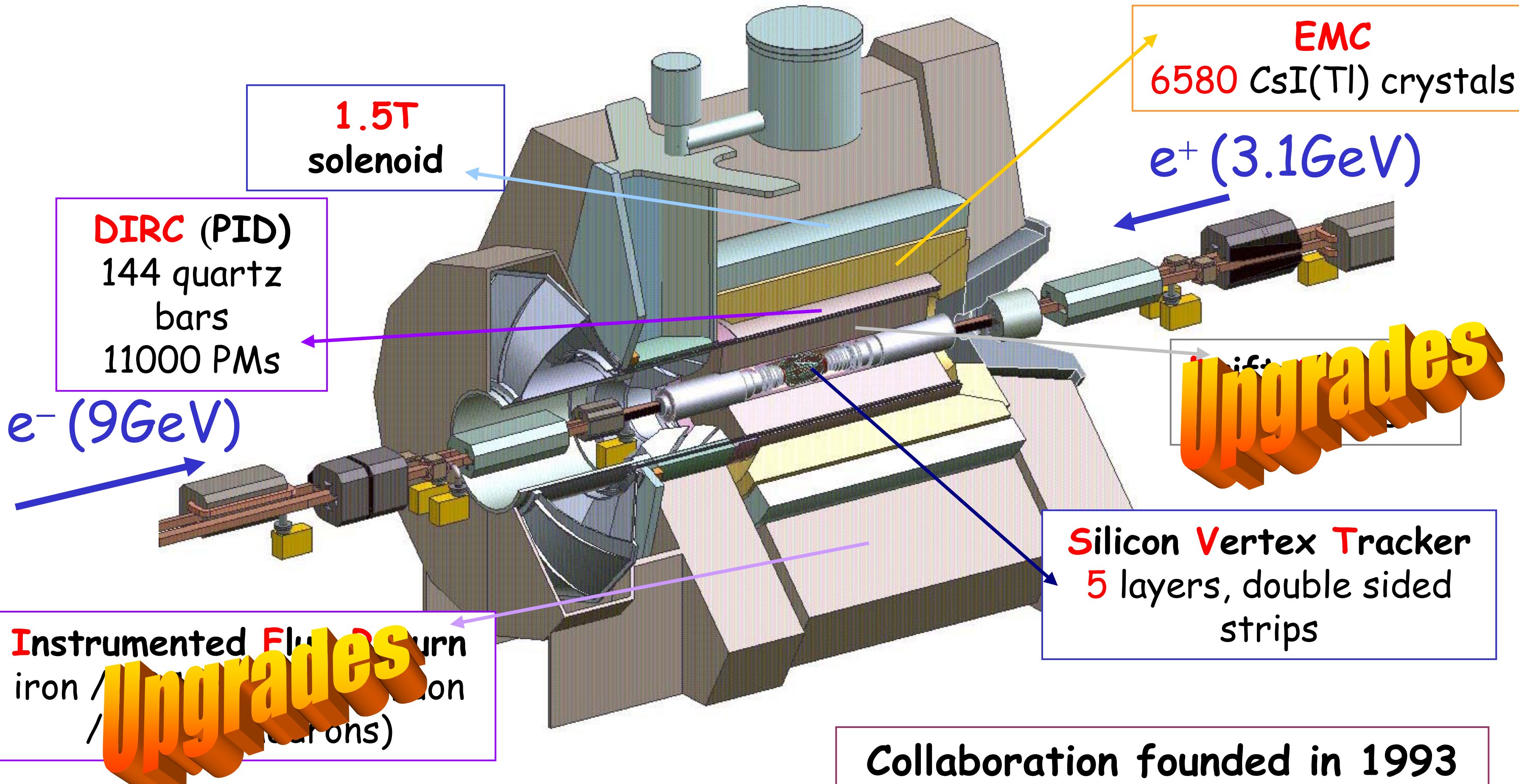
IFAE-Barcelona
IFIC-Valencia

United Kingdom [11/75]

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
U of Warwick



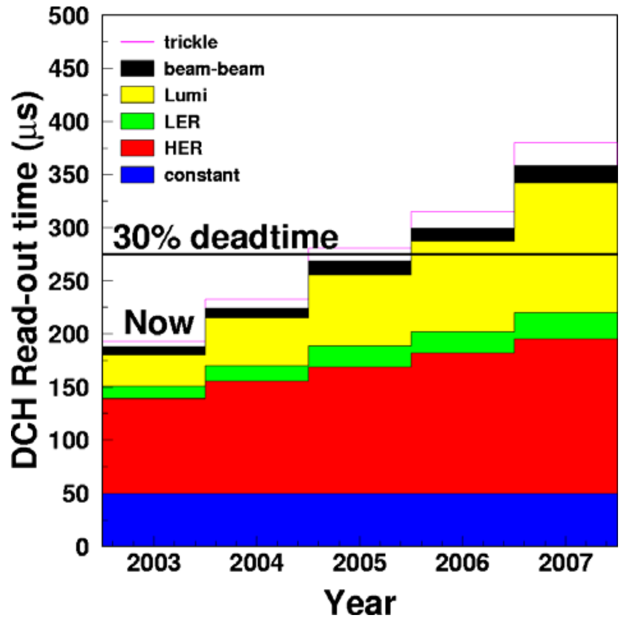
BABAR Detector

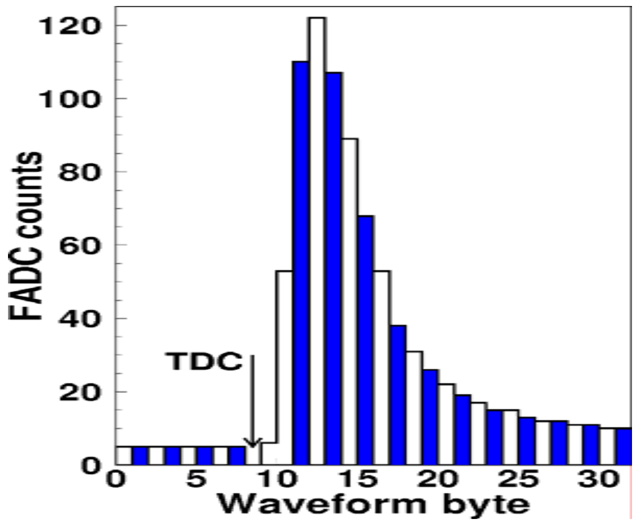


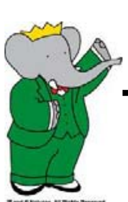
Collaboration founded in 1993
Detector commissioned in 1999

DCH electronics upgrade

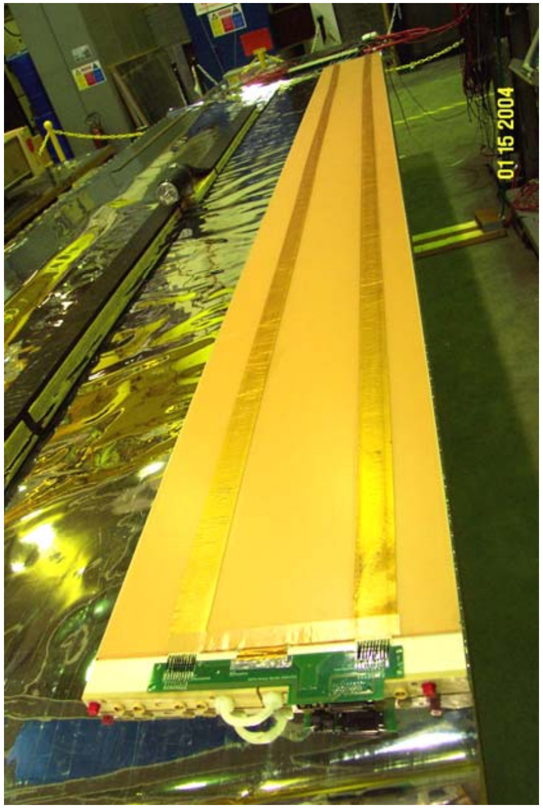
- **Motivation:**
  - Reduce deadtime due to serialization and shipping of data from DIOM to ROM
- **Upgrade in two steps:**
  - Phase 1 (summer 2004)
    - Ship only 1/2 waveform information (32→16 bytes) from frontends
    - No change observed with data
  - Phase 2 (Oct 2005)
    - Larger FPGA for feature extraction before transmission → hardware change
    - New boards in production

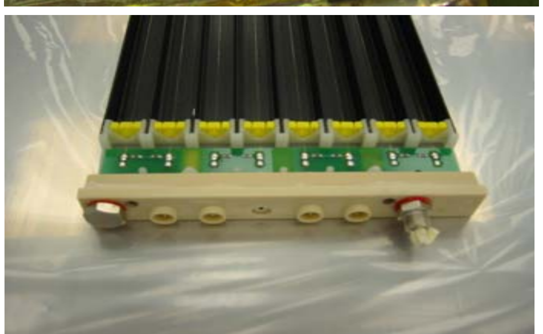


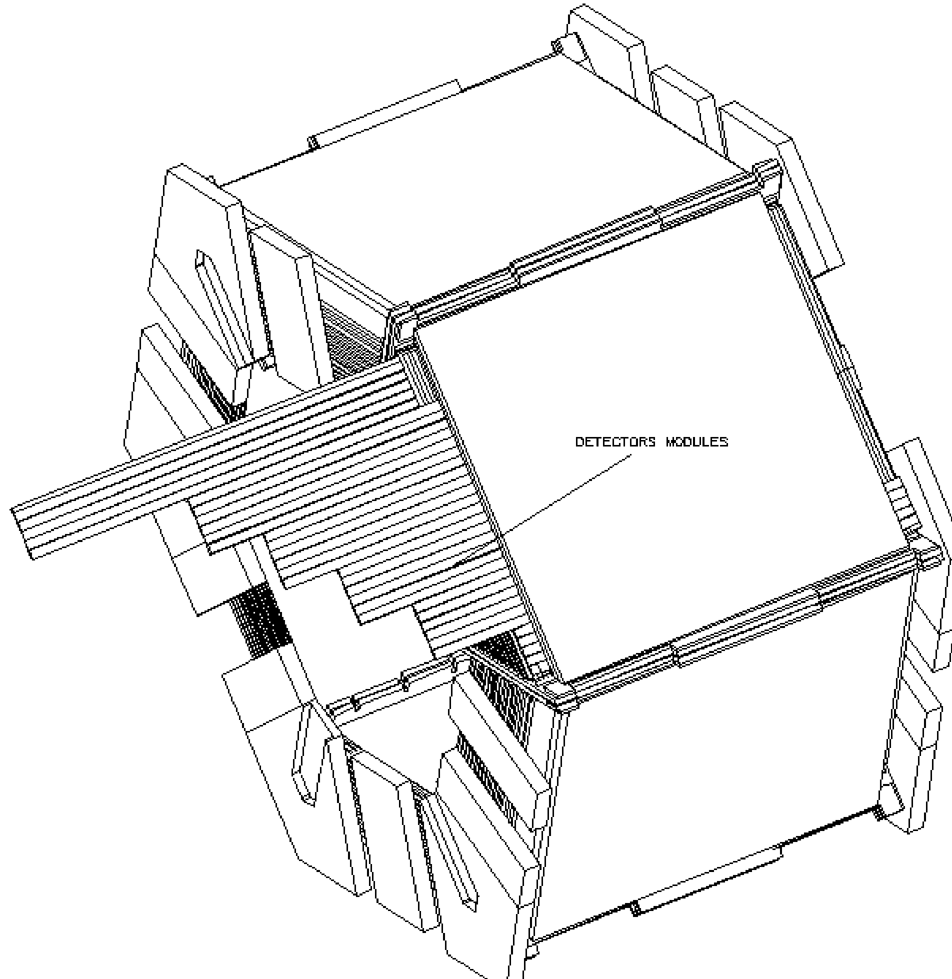




IFR upgrade with LSTs

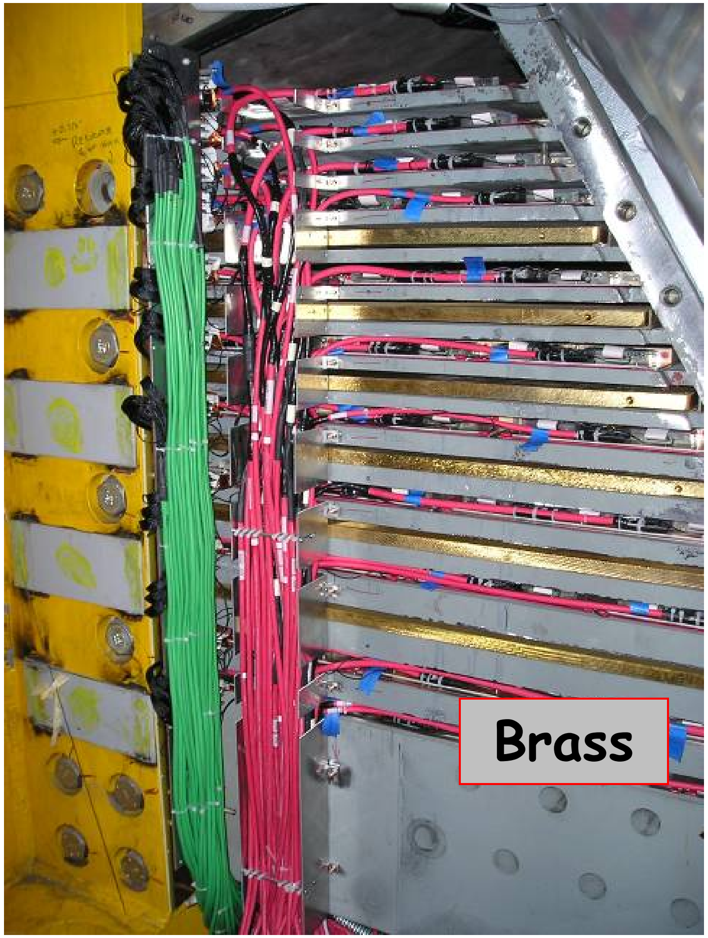






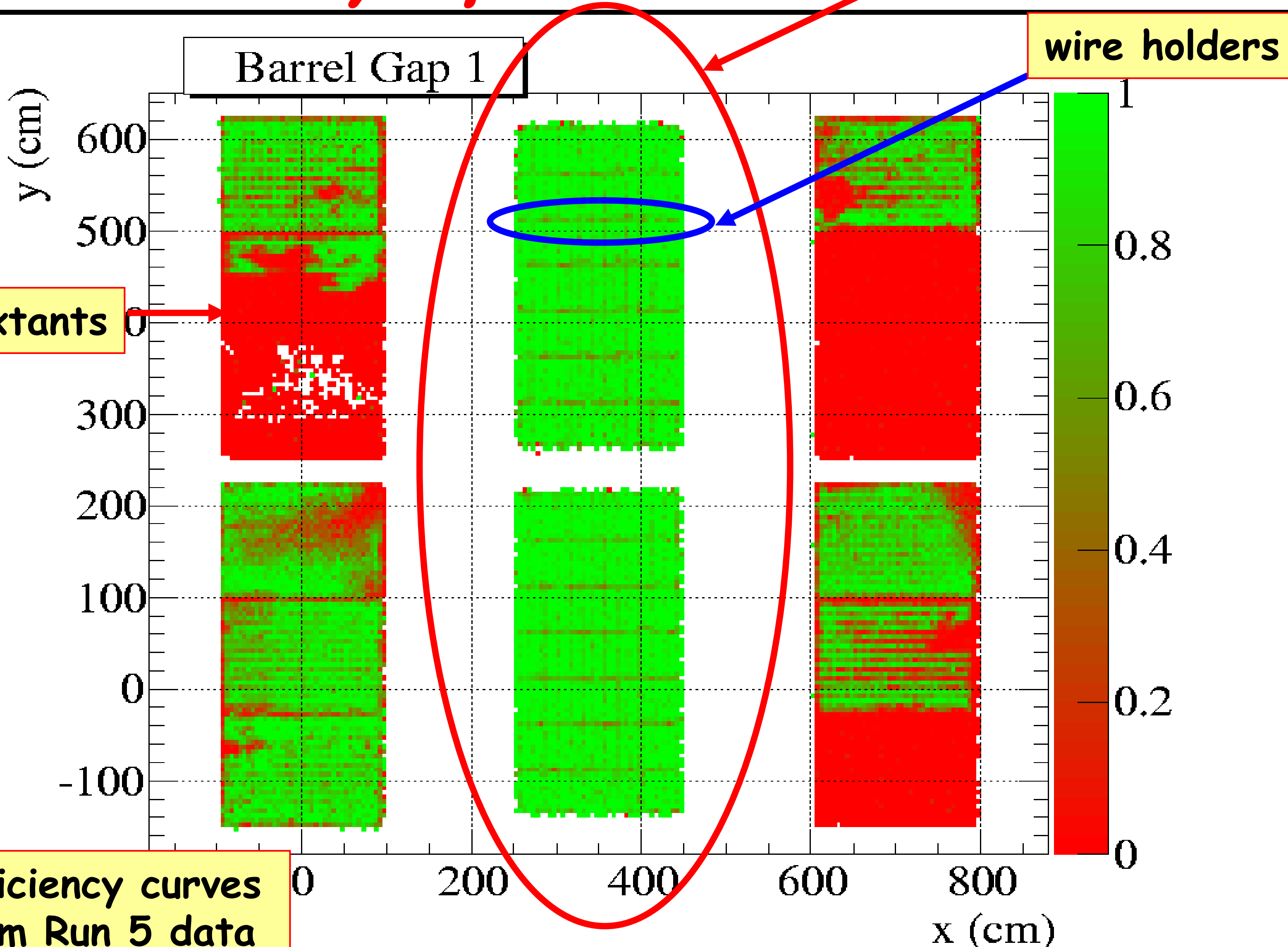
Bottom & top sextants installed summer 2004
Remaining sextants delayed until summer 2006

LST installation summer 2004



Bottom sextant: Aug 15-Sep 4
Top sextant: Sep 16-29

LSTs are fully operational



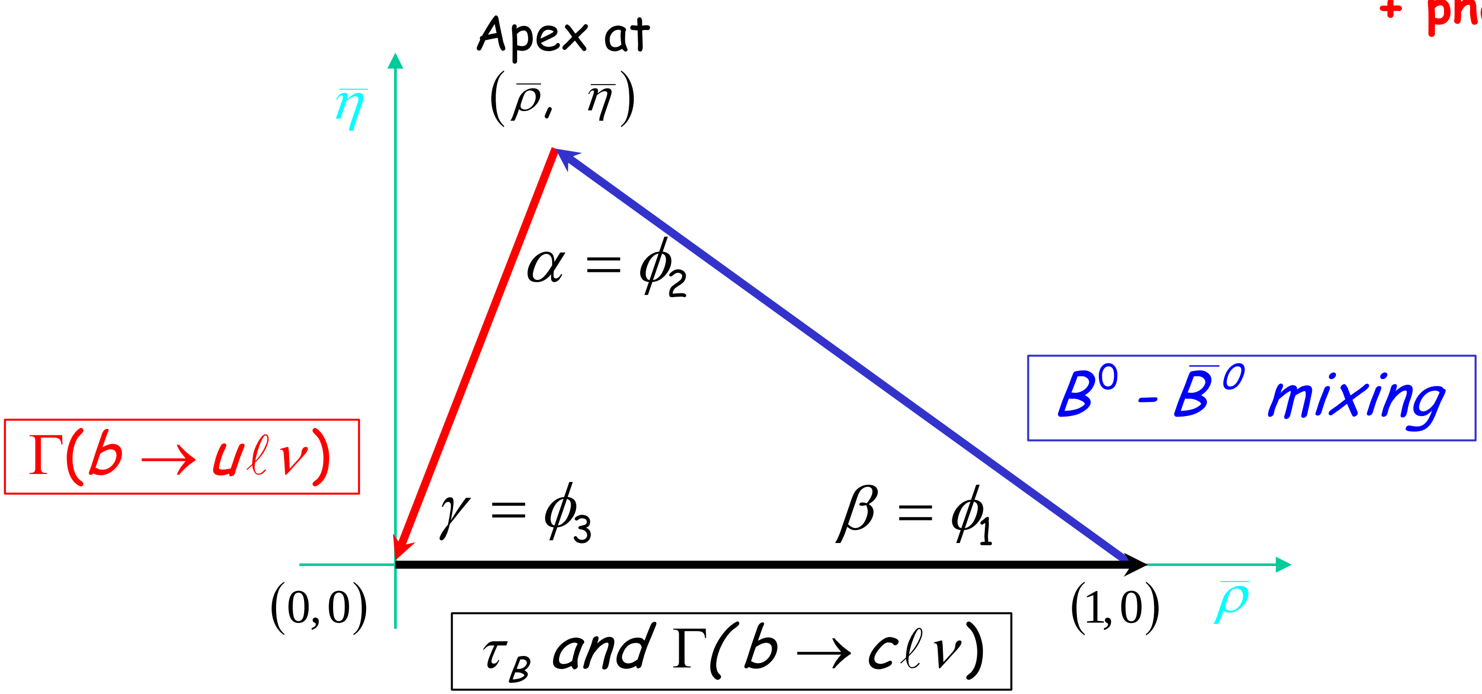
Efficiency curves from Run 5 data

Weak Interaction in Standard Model

Unitarity Triangle as a summary of Standard Model *b* physics

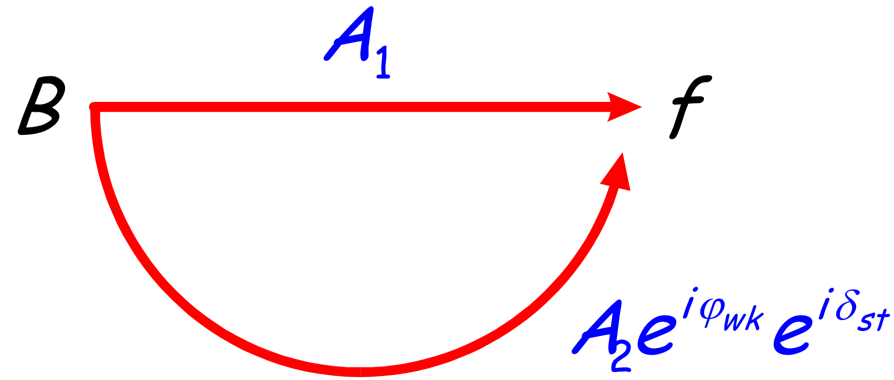
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

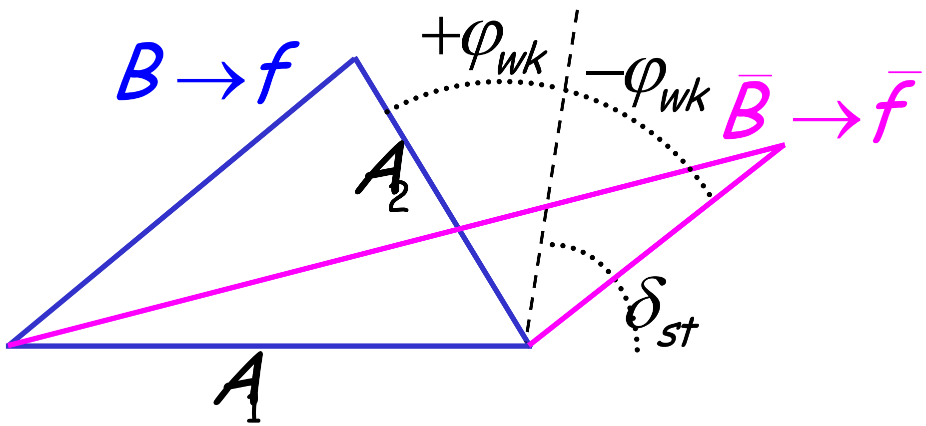
+ phases



CP violation in B decays

- CPV through interference of decay amplitudes



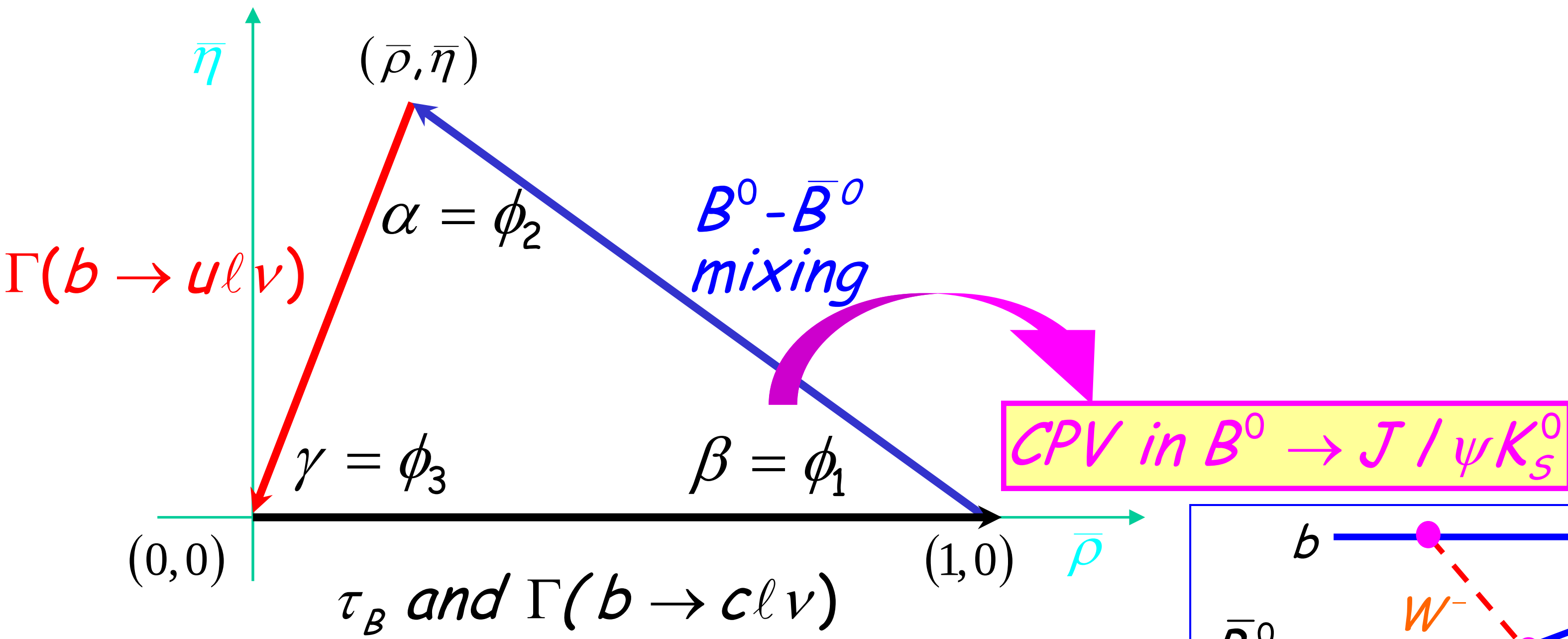


$$\Gamma(B \to f) = \left| A_1 + A_2 e^{i\varphi_{wk}} e^{i\delta_{st}} \right|^2$$

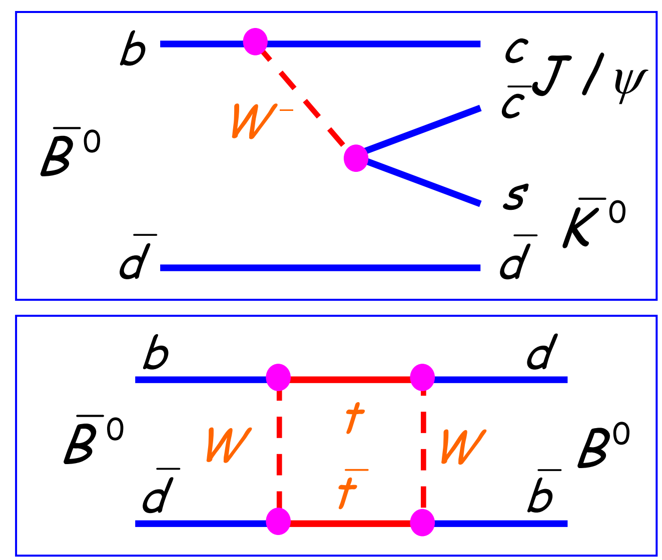
$$\Gamma(\bar{B} \to \bar{f}) = \left| A_1 + A_2 e^{-i\varphi_{wk}} e^{i\delta_{st}} \right|^2$$

$\Gamma(B \to f) \neq \Gamma(\bar{B} \to \bar{f})$
for $\varphi_{wk} \neq 0$ and $\delta_{st} \neq 0$

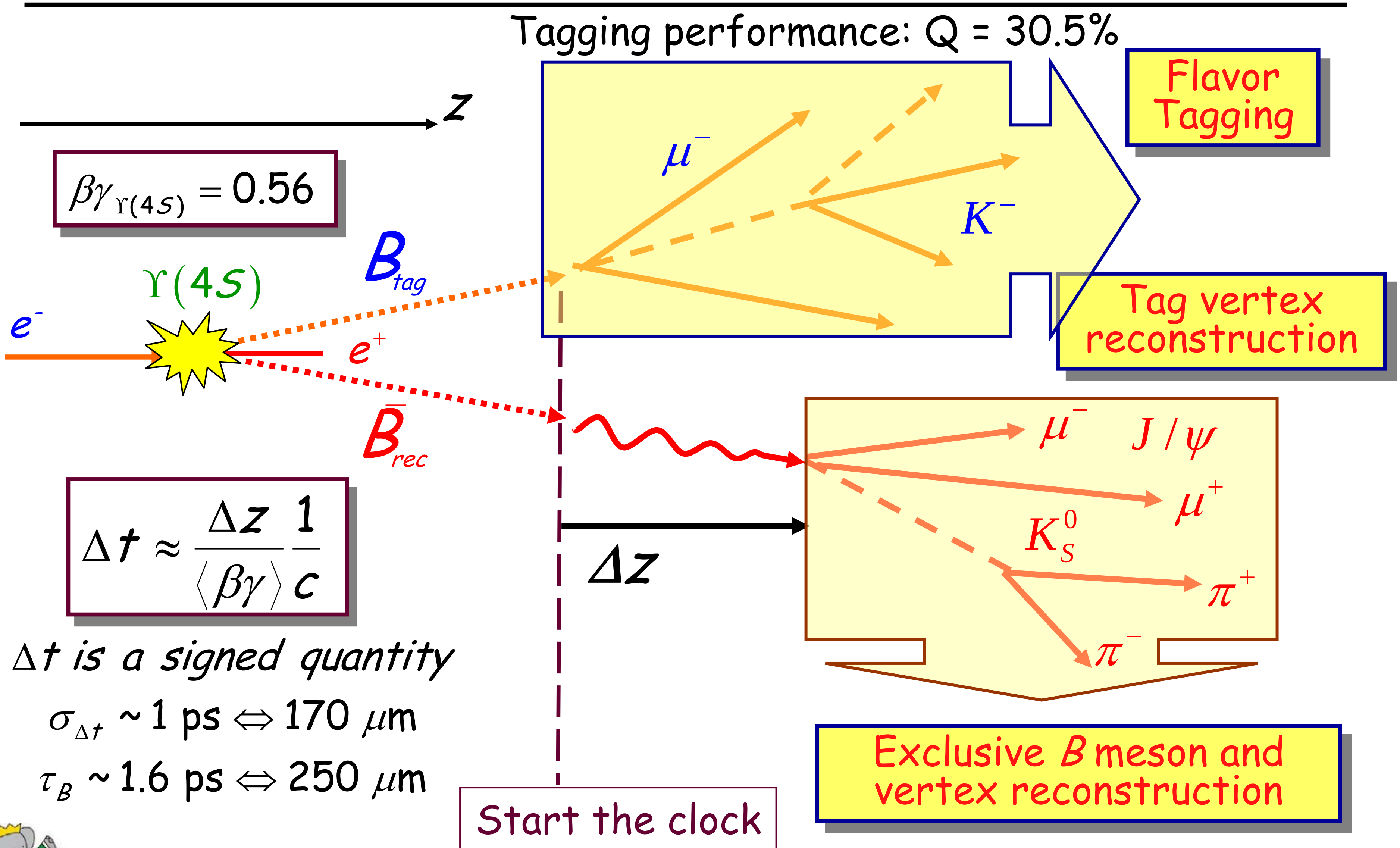
CPV in charmonium modes



Interference of $b \to c$ tree decay with mixing



Measuring time-dependent CP asymmetries



$$\Delta t \approx \frac{\Delta z}{\langle\beta\gamma\rangle}\frac{1}{c}$$

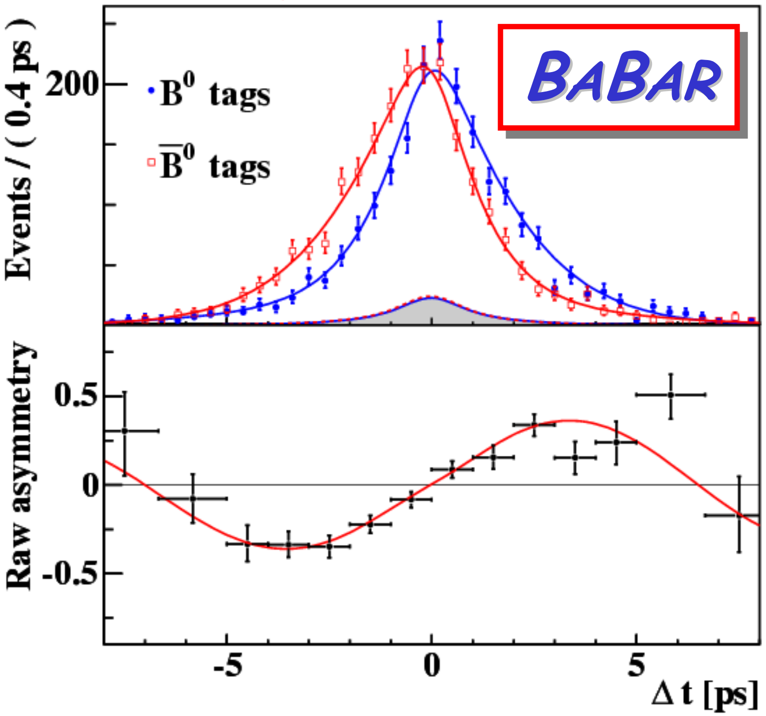
Δt is a signed quantity

$\sigma_{\Delta t} \sim 1$ ps $\Leftrightarrow$ 170 μm

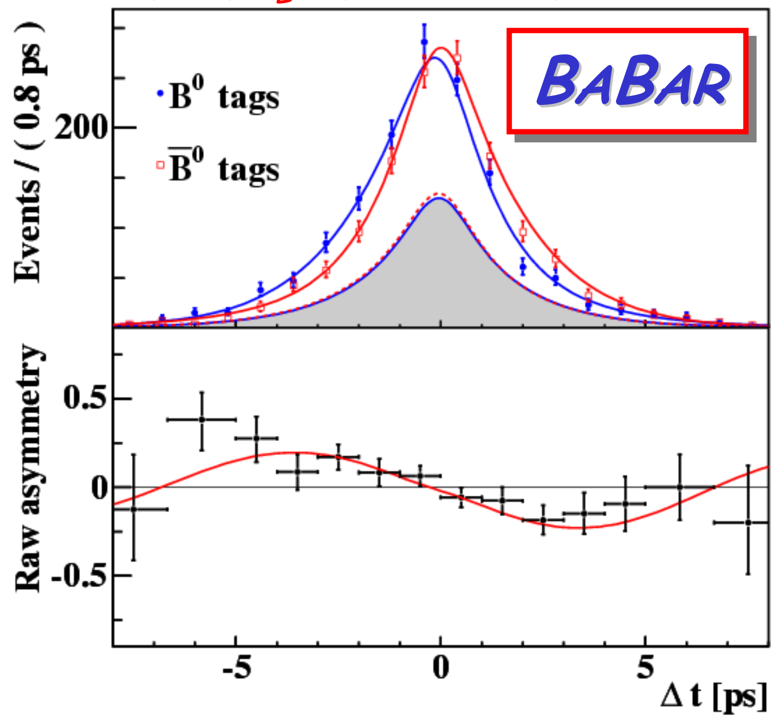
$\tau_B \sim 1.6$ ps $\Leftrightarrow$ 250 μm

$\sin 2\beta$ results from charmonium modes

$(c\bar{c})K_S^0$ (CP odd) modes



$(c\bar{c})K_L^0$ (CP even) modes



Update for ICHEP04

BABAR PUB-04/038

$$\sin 2\beta = +0.722 \pm 0.040 \pm 0.023$$

$$|\lambda| = |\bar{A}/A| = 0.950 \pm 0.031 \pm 0.013$$

$(c\bar{c})K_S^0 +$ $(c\bar{c})K_L^0$

Limit on direct CPV

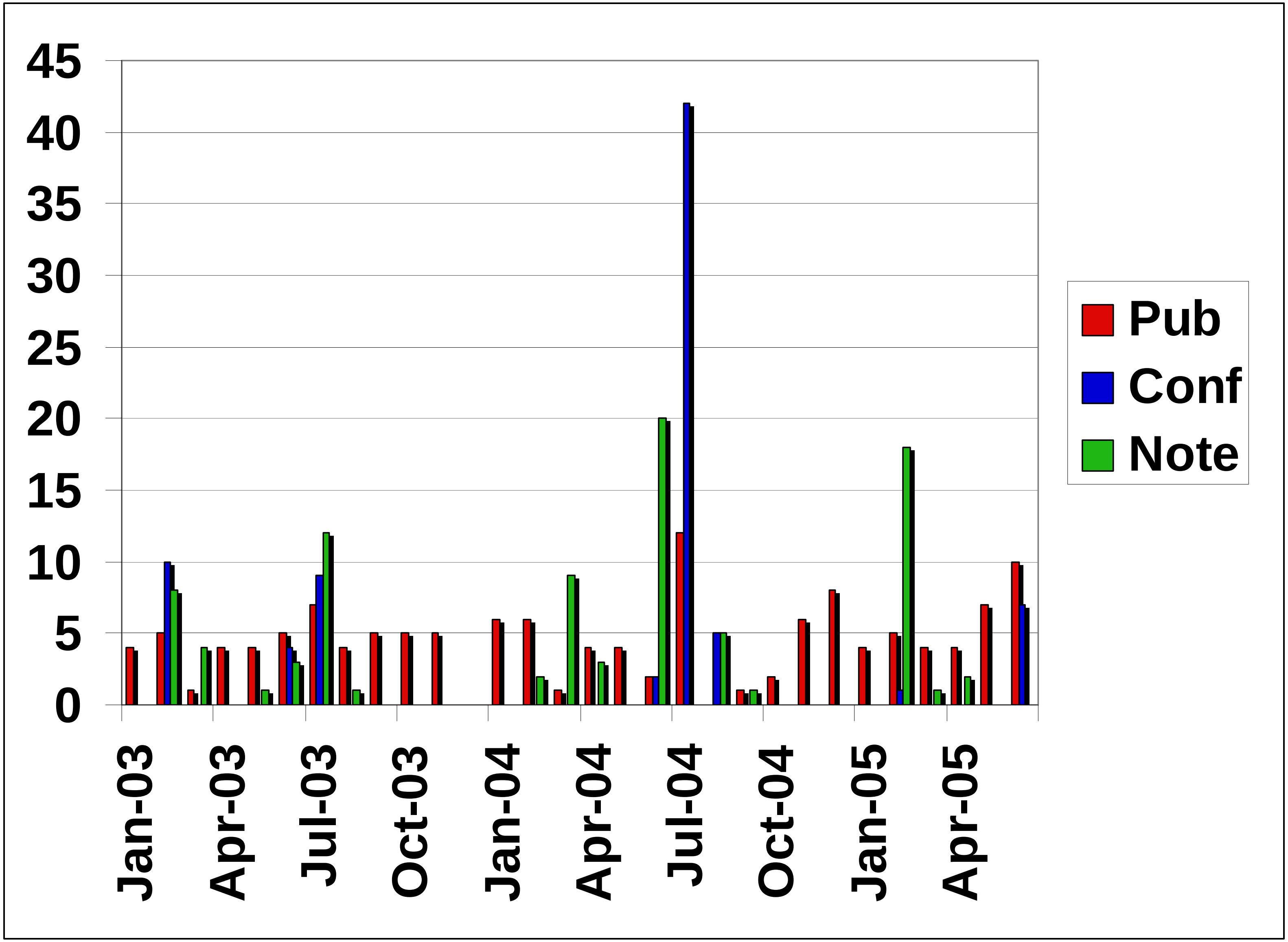
$205 fb^{-1}$ on peak or $227M$ $B\bar{B}$ pairs
7730 CP events (tagged signal)

BABAR & Belle physics results

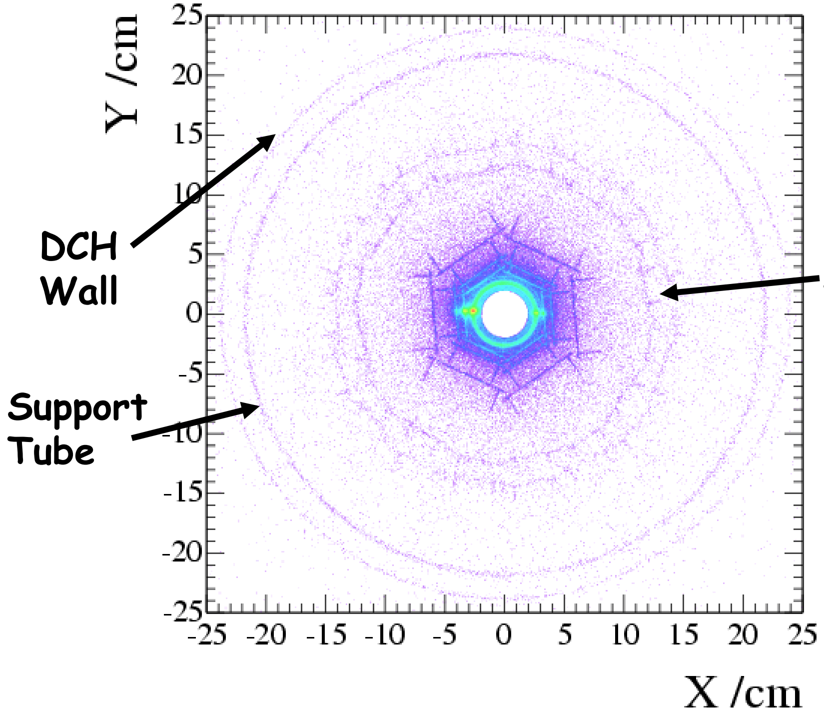
Journal Papers	BABAR	Belle
<2003	32	54
2003	39	28
2004	52	35
June 2005	26	23
Total	149	140

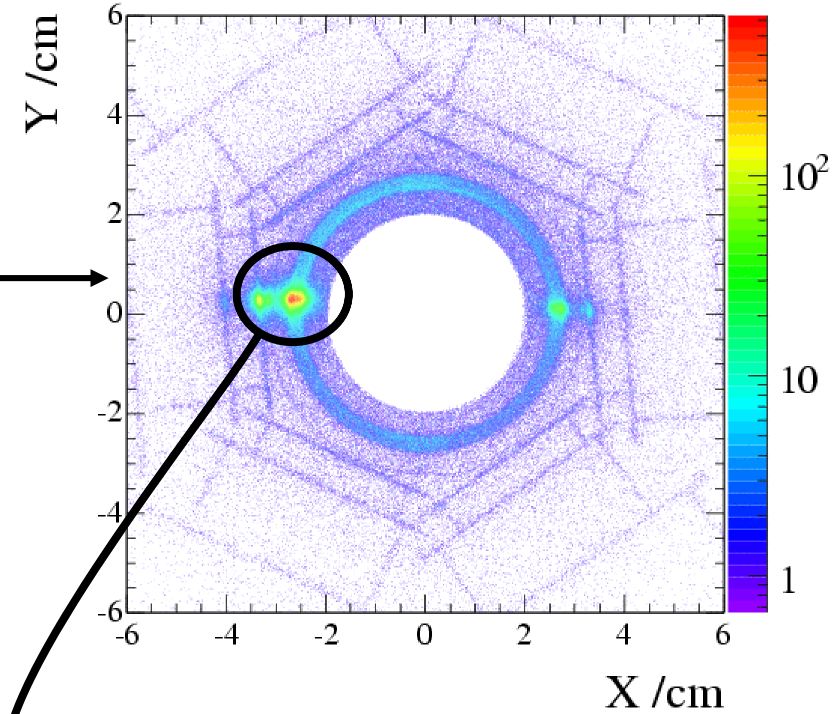
Conference Contributions	BABAR	Belle
Papers submitted to ICHEP04	72	63
Abstracts submitted to LP05	75	73

BABAR publication history

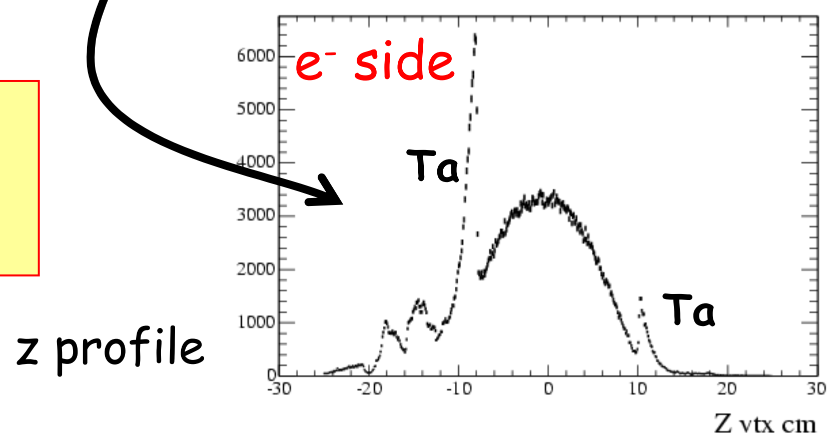


Even our backgrounds yield physics!

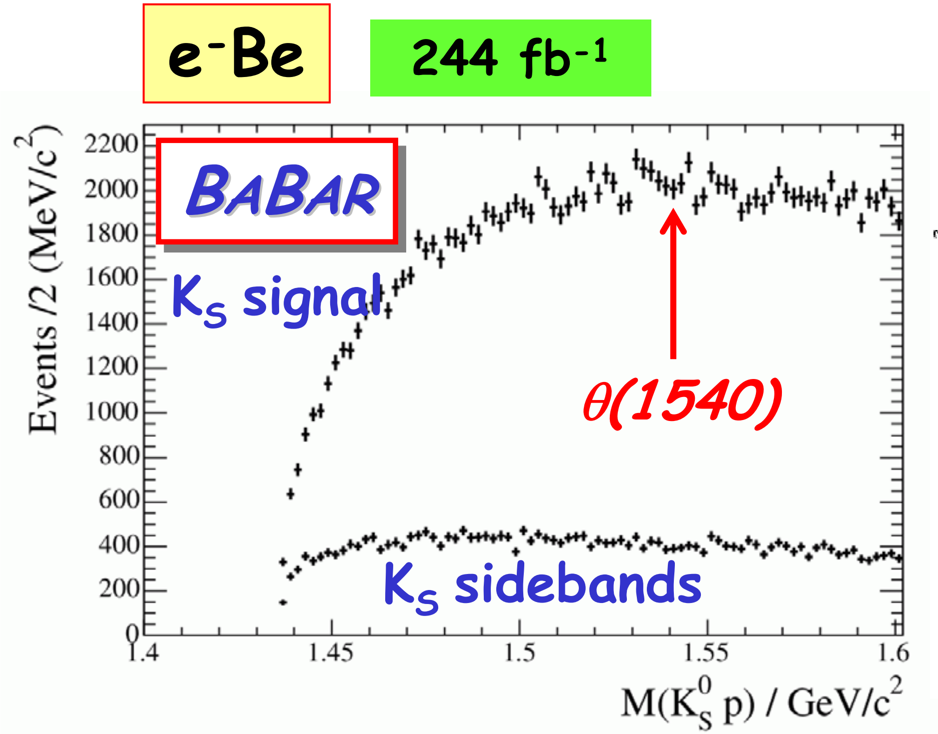


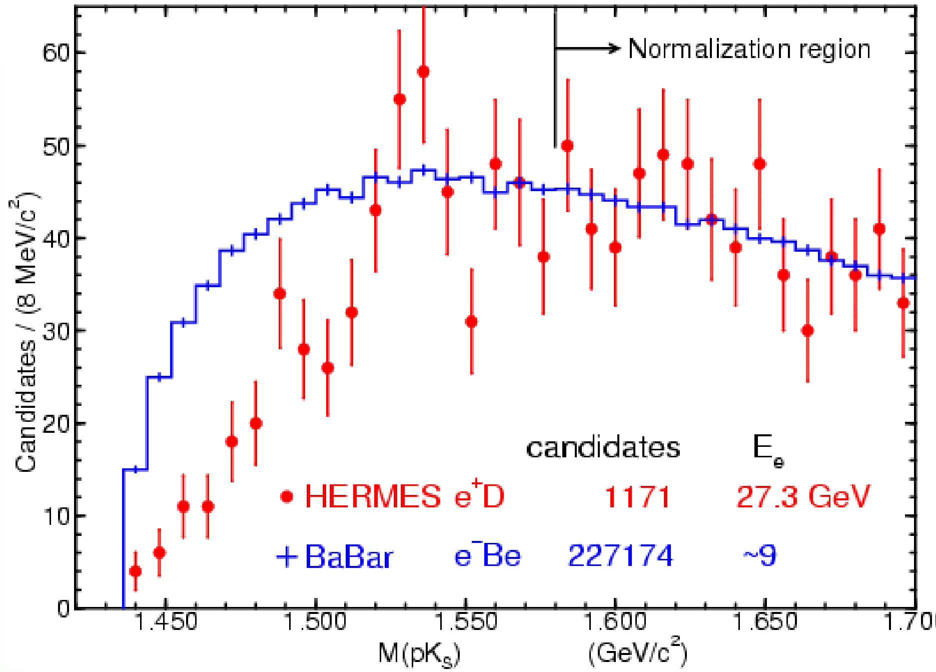


Inner detector tomography with pK_s vertices from elctro- and hadro-production events



Searches for the θ(1540) pentaquark



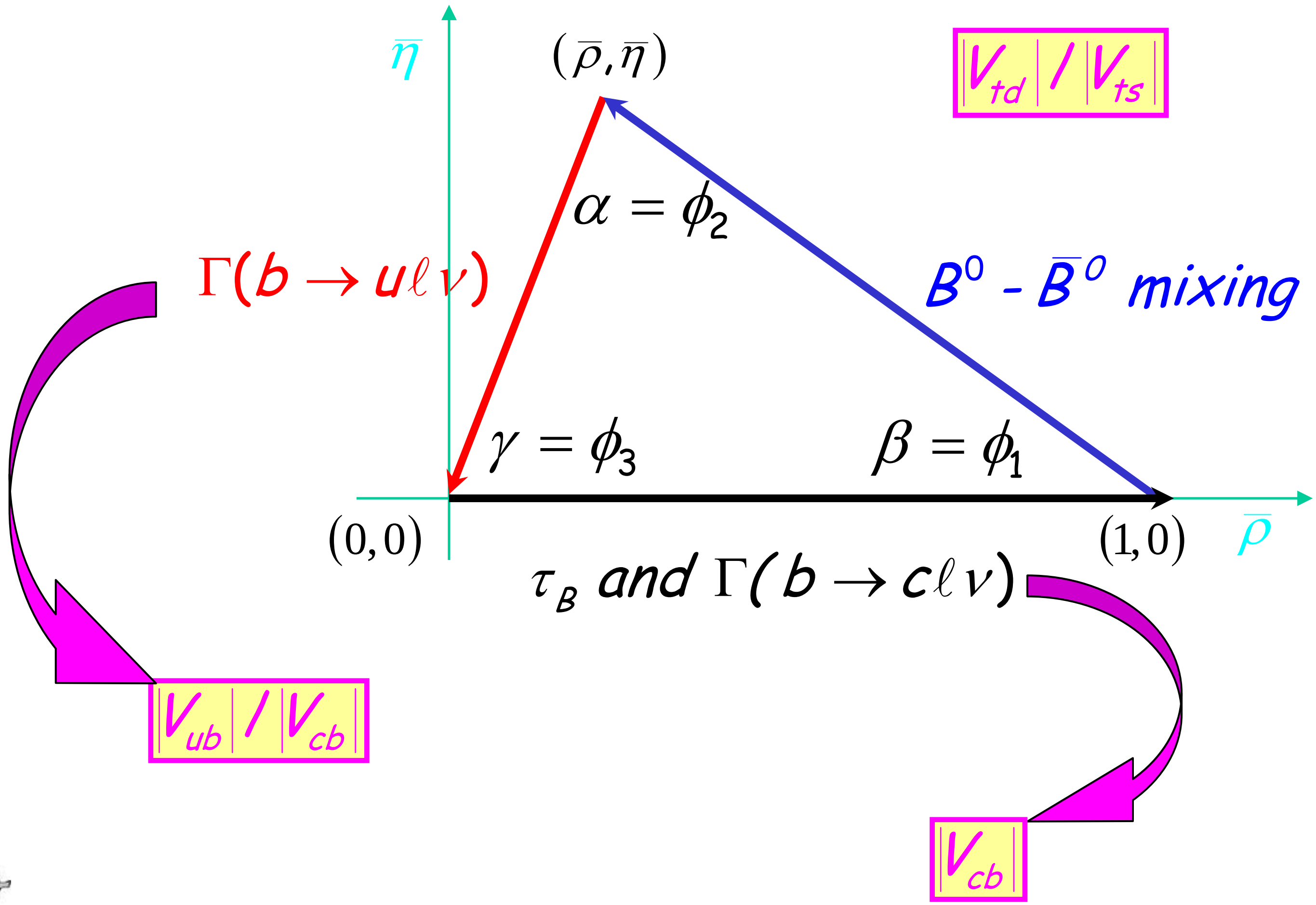


Object lesson: with data in hand, clever analysis ideas will emerge

HERMES: possible acceptance loss at low mass (PID on proton > 4.1 GeV/c)

***BABAR* is also a tau, charm, ISR, and $\gamma\gamma$ Factory**

Progress on b quark couplings



Search for $B \to \rho\gamma, \omega\gamma$

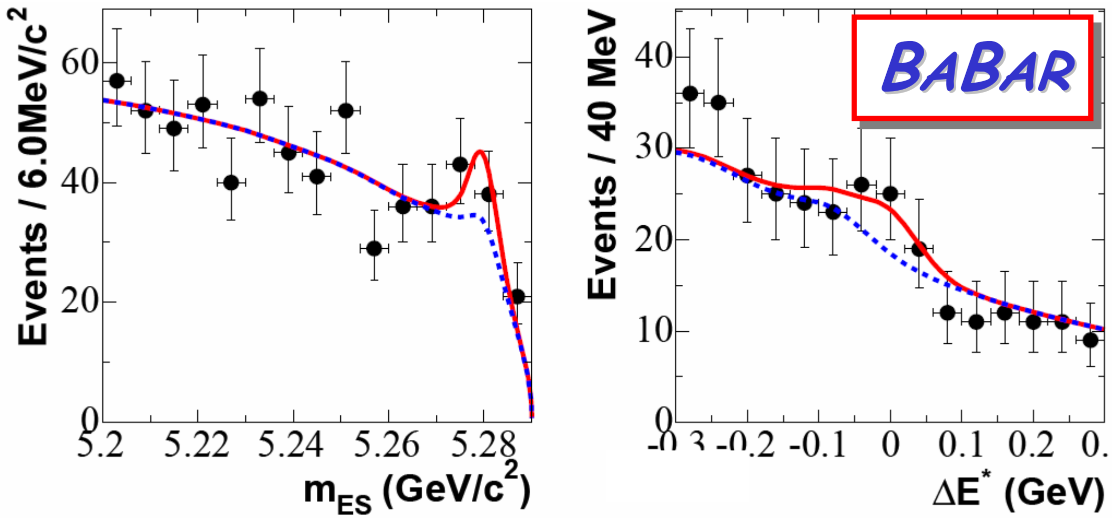
BABAR-PUB-04/035

$211M\ B\bar{B}$ pairs

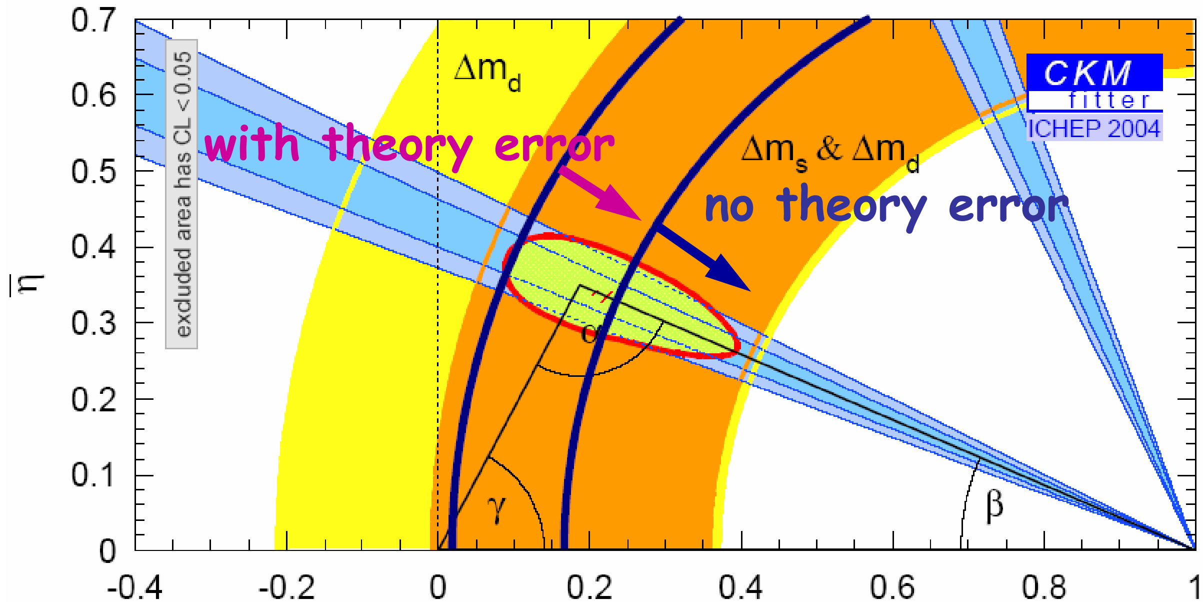
Simultaneous fit to

$B \to \rho^{+}\gamma, \rho^{0}\gamma, \omega\gamma$

$BF < 1.2 \times 10^{-6}$ (90% CL)



Penguins are starting to provide meaningful CKM constraint

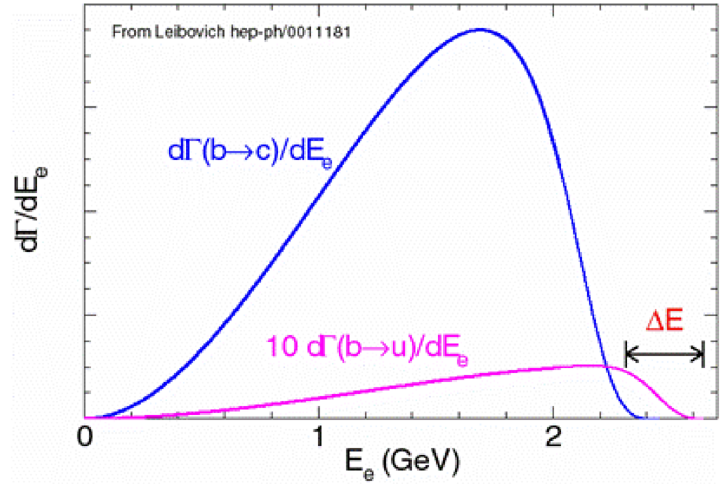


ργ 95% CL BABAR allowed region (inside the blue arc)

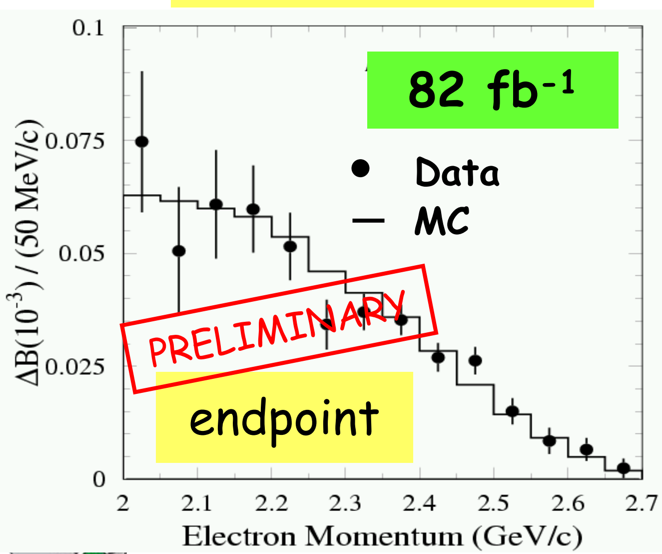
Inclusive $|V_{ub}|$ measurements

Different approaches available to extract partial rates

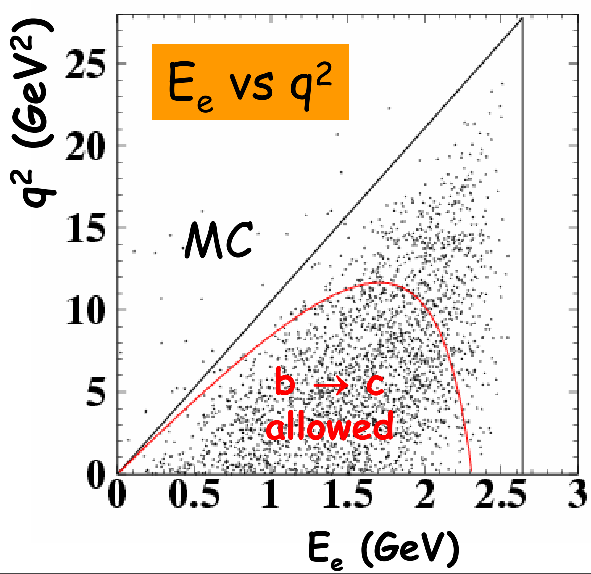
$$\frac{\Gamma(b \to u \ell \bar{\nu})}{\Gamma(b \to c \ell \bar{\nu})} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$



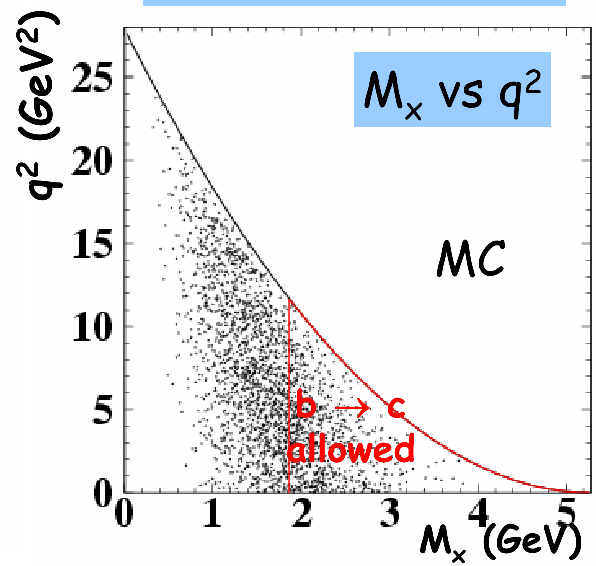
hep-ex/0408075



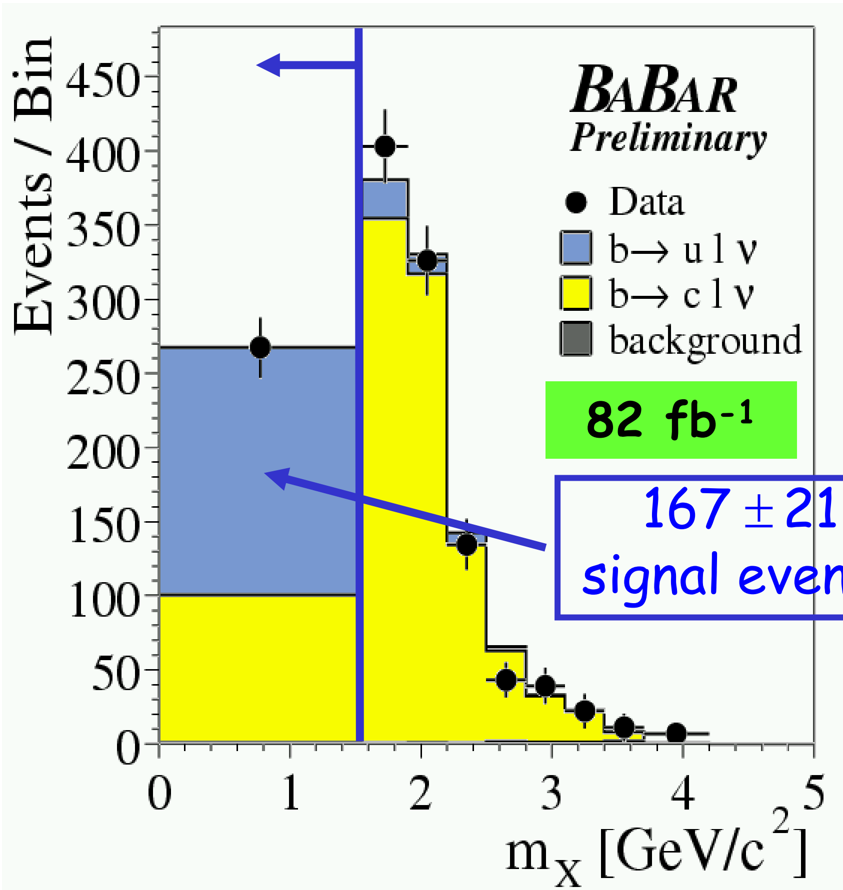
hep-ex/0408045



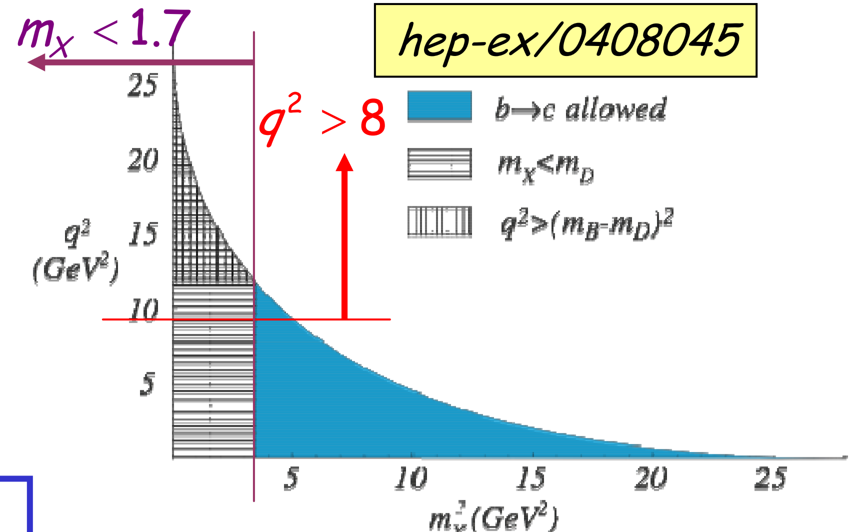
hep-ex/0408068



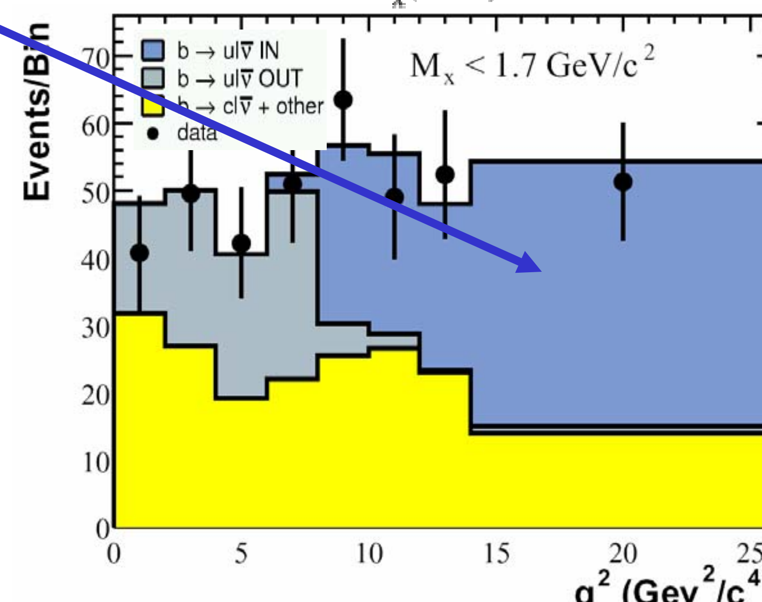
V_{ub} from B_{reco}-tagged M_x-q^2 analysis



hep-ex/0408045

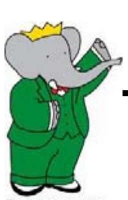


167 ± 21
signal events

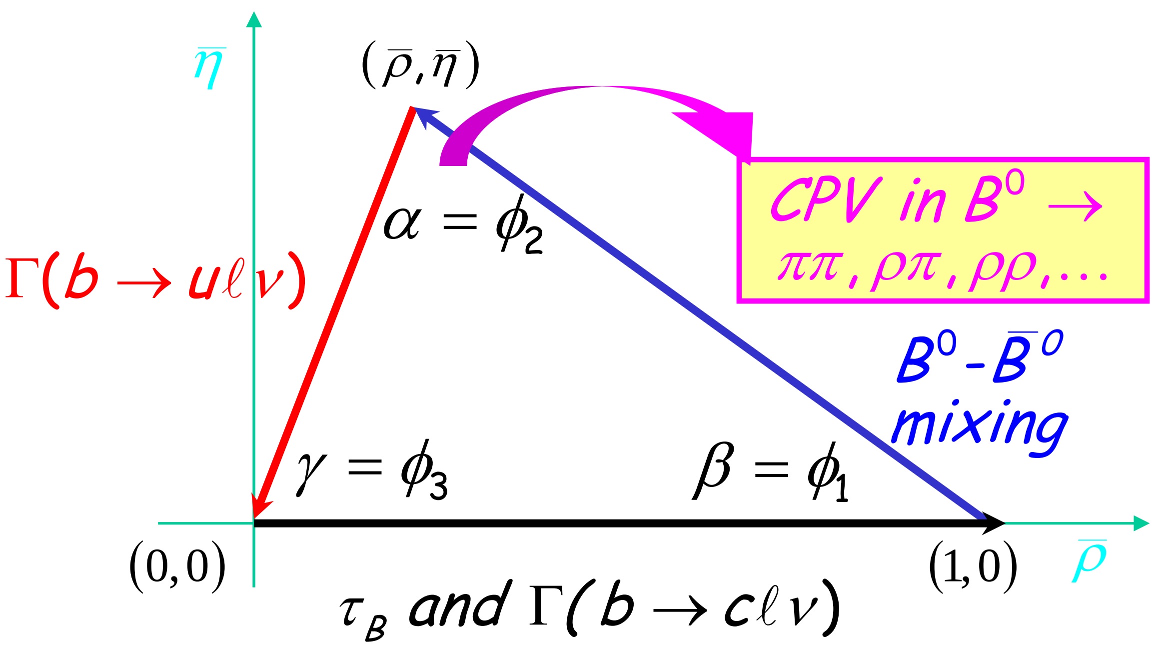


Inclusive methods now: $\sigma(V_{ub}) = 11.5\%$

Imagine what this will look like with 10x data in 2008!

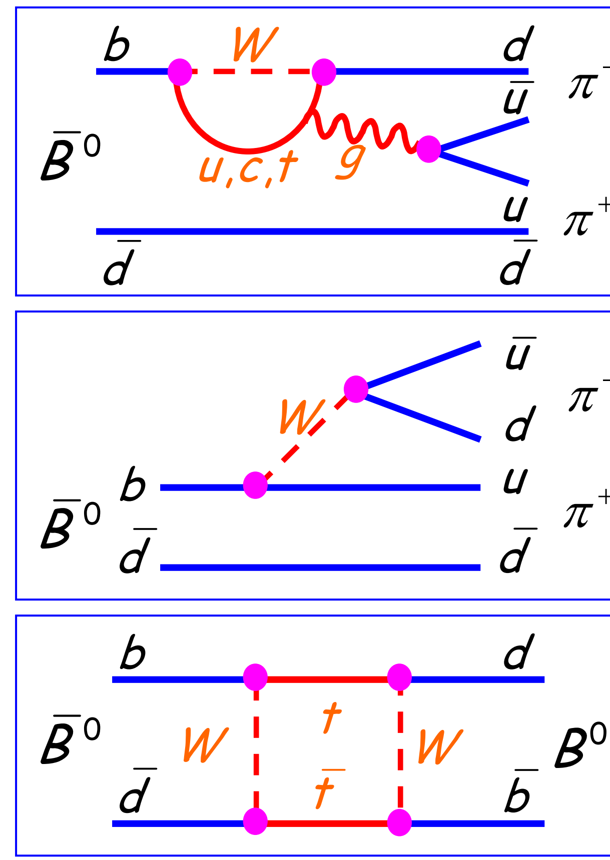


CPV in charmless modes



Interference of suppressed $b \to u$ tree decay with mixing

3rd component: sizable Penguin diagram



Very promising: $B \to \rho\rho$ decays

Extraction of α similar to $\pi\pi$, but with advantage of smaller Penguin pollution:

$\frac{|A^{00}|}{|A^{+0}|}, \frac{|A^{00}|}{|A^{+-}|}$ found small: $\Delta\alpha_{peng}$ small

BABAR PUB-04/048

$$|\alpha - \alpha_{eff}| < 11^0 \ \ (90\% CL)$$

Potentially $\rho^+\rho^-$ could be mixed *CP*, but is found to be almost pure $CP = +1$

$B^0 \to \rho^+\rho^-$ (232*M* $B\bar{B}$ pairs)

Signal: 617 ± 52 events

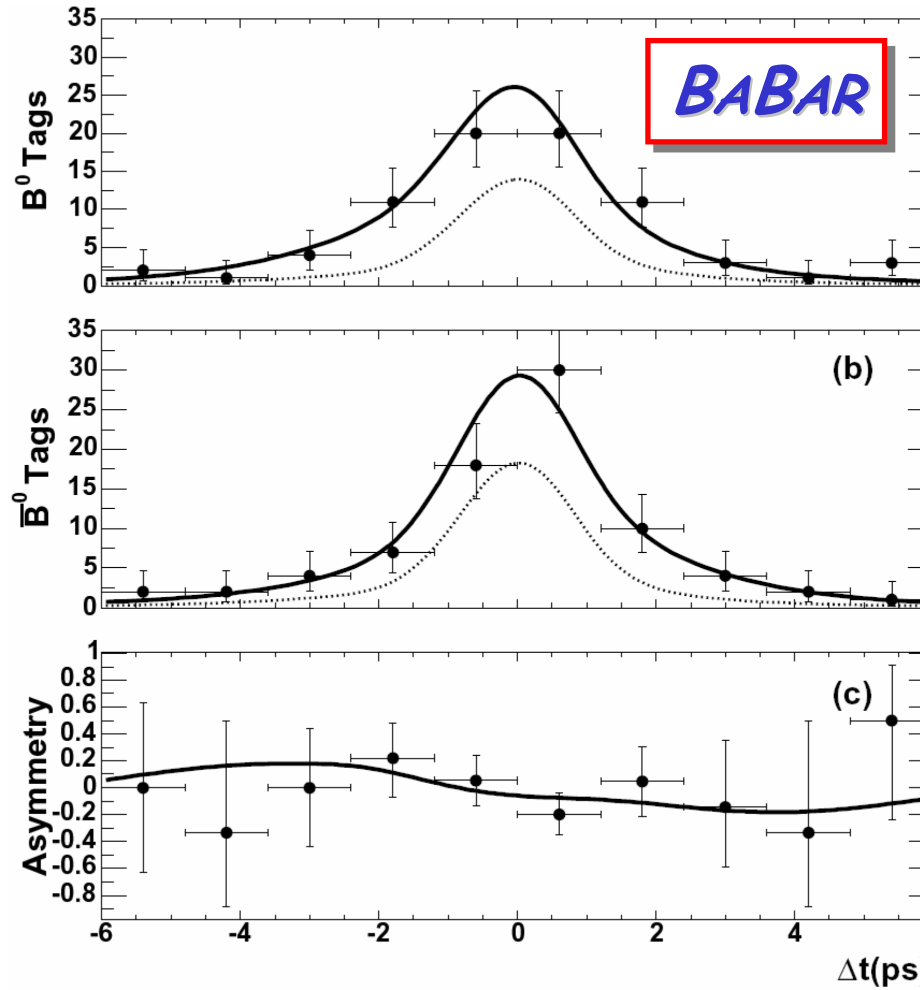
$$f_{long} = 0.978 \pm 0.014 \begin{smallmatrix} +0.021 \\ -0.029 \end{smallmatrix}$$

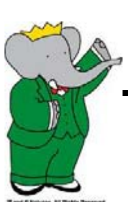
$$S_{long} = -0.33 \pm 0.24 \begin{smallmatrix} +0.08 \\ -0.14 \end{smallmatrix}$$

$$C_{long} = -0.03 \pm 0.18 \pm 0.09$$

BABAR PUB-05/007

Moriond EW05





Summary of constraints on α

BABAR only

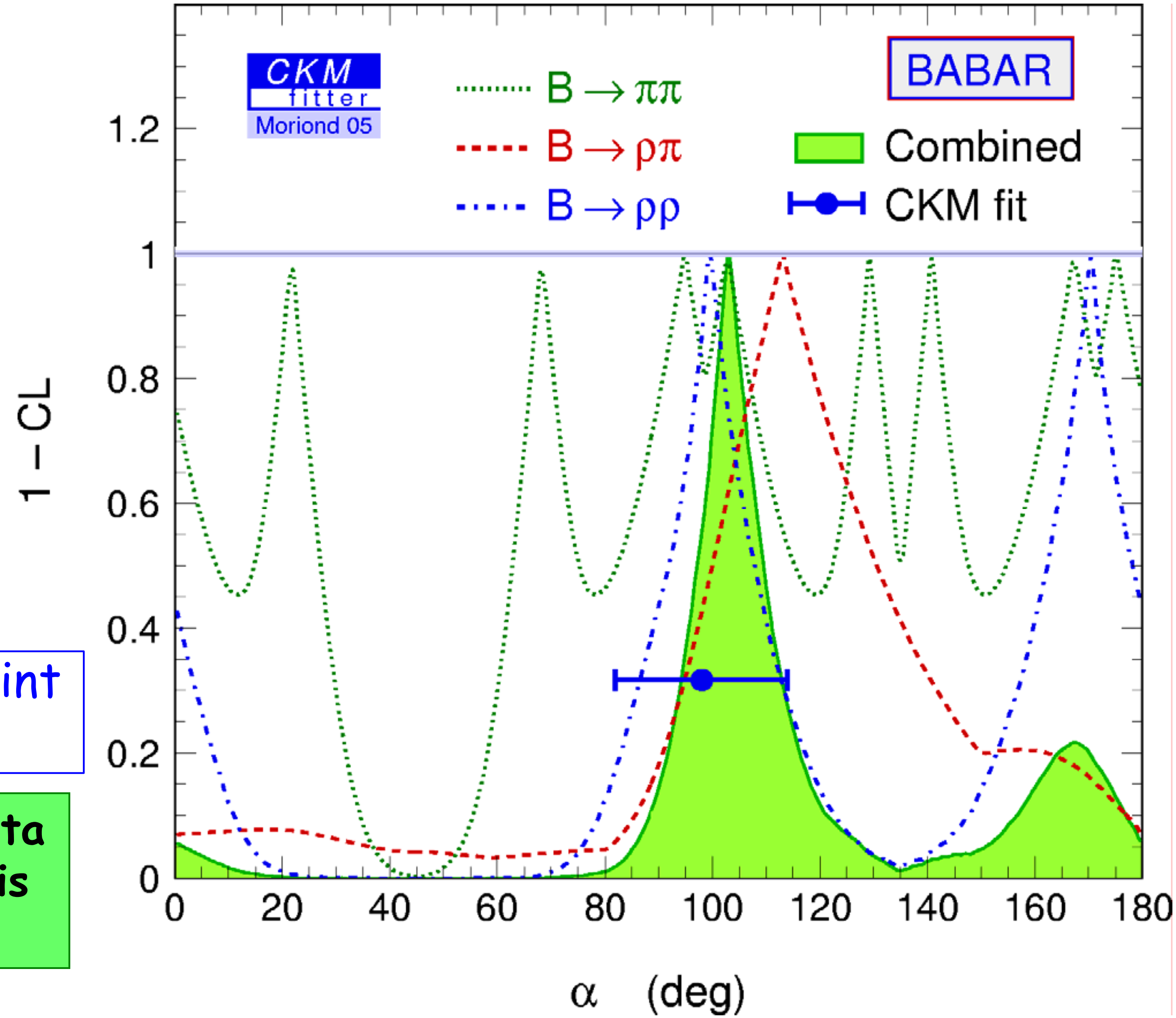
Mirror solutions disfavored

From combined $\pi\pi, \rho\pi, \rho\rho$ results:

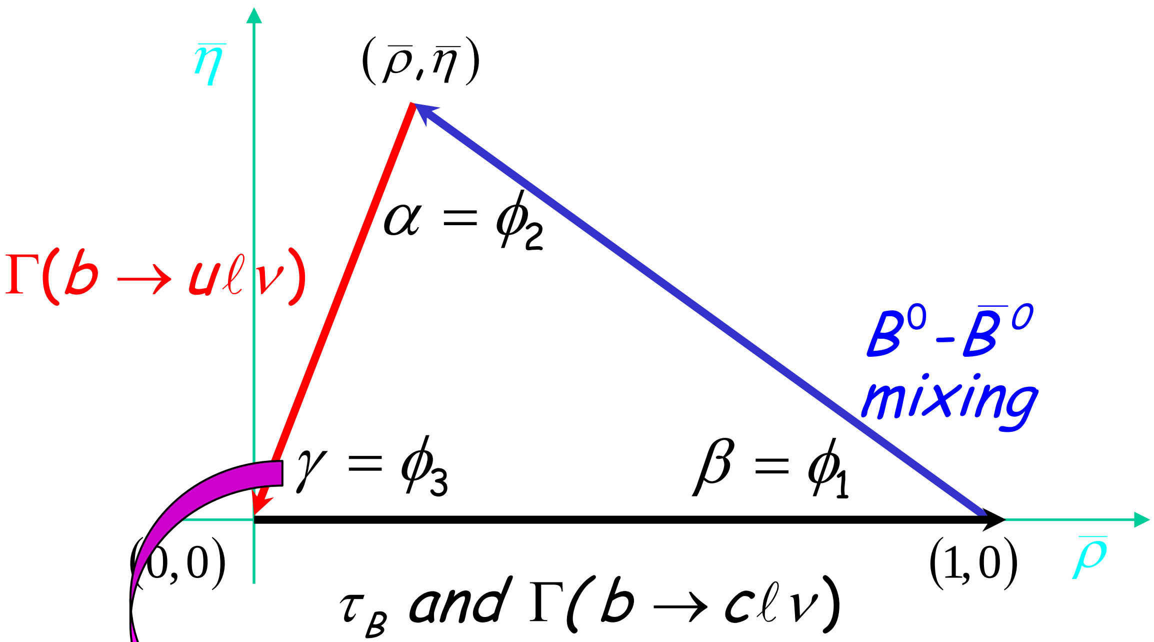
$$\alpha = \left[100 \, ^{+9}_{-10}\right]^{\circ}$$

CKM indirect constraint fit: $\alpha = 98 \pm 16^{\circ}$

Object lesson: with data in hand, clever analysis ideas will emerge



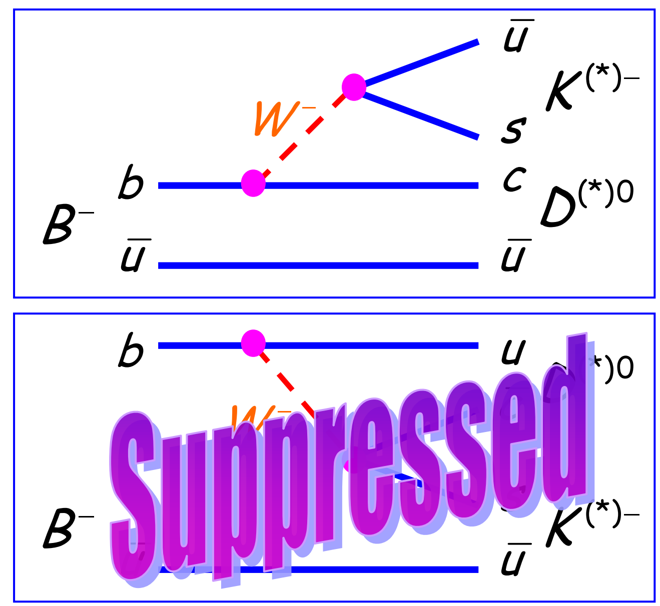
Unexpectedly good progress on gamma!



γ : CPV in $B^0 \to D_{CP}K, D_{DCS}K, \ldots$

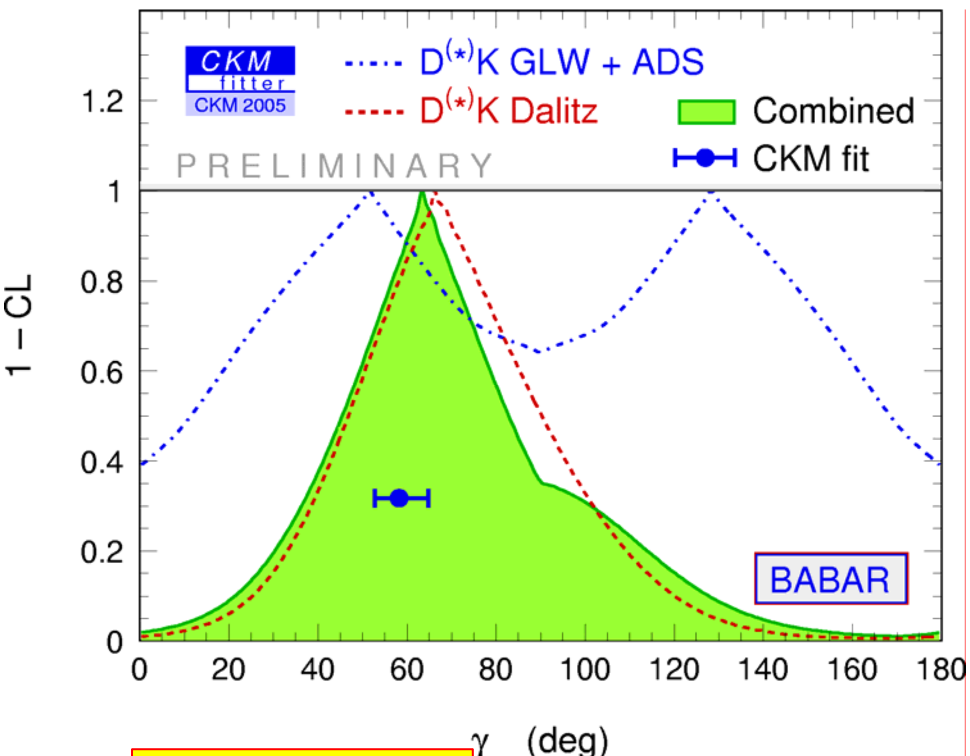
Interference of color-allowed and color-suppressed tree decays

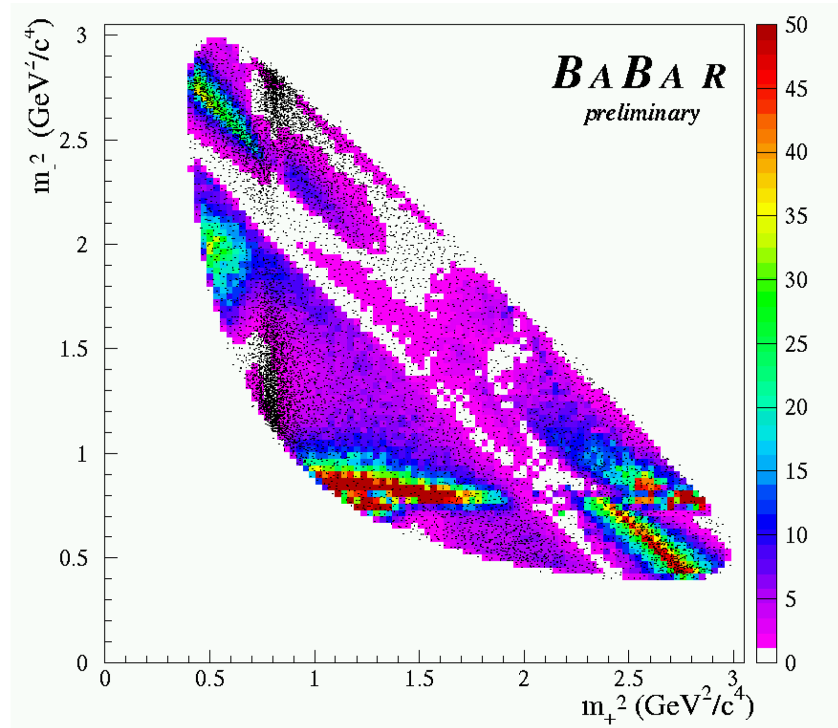
Effect depends on ratio of two diagrams



Dalitz plot analysis for gamma

Idea: Increase *B* decay interference through *D* decay Dalitz plot





$B^+ \to D^{(*)0}\left[\to K_S^0\pi^+\pi^-\right]K^+$

From Dalitz analysis:

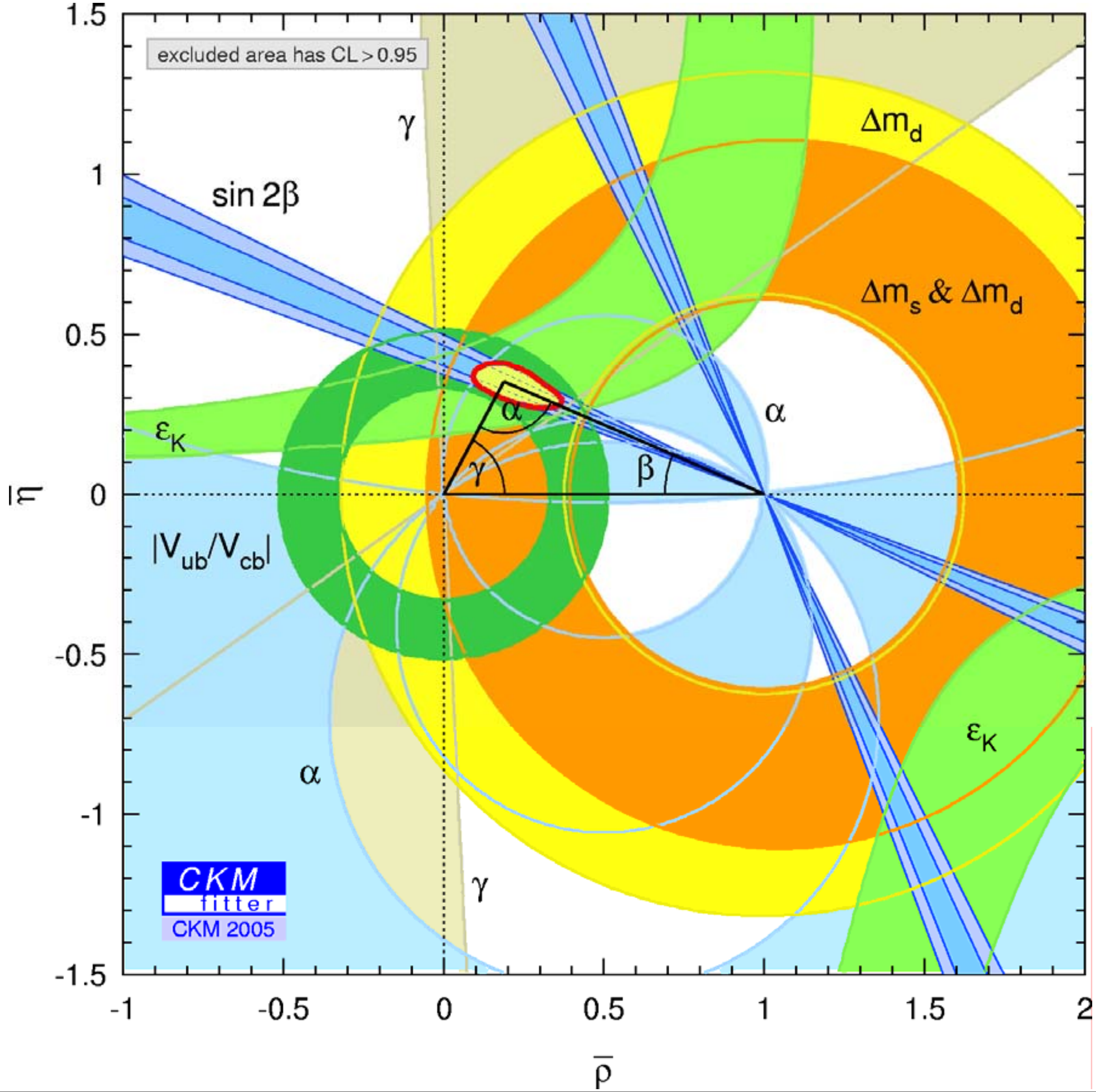
$\gamma = \left[63^{+34}_{-26}\right]^\circ$

Indirect constraint:

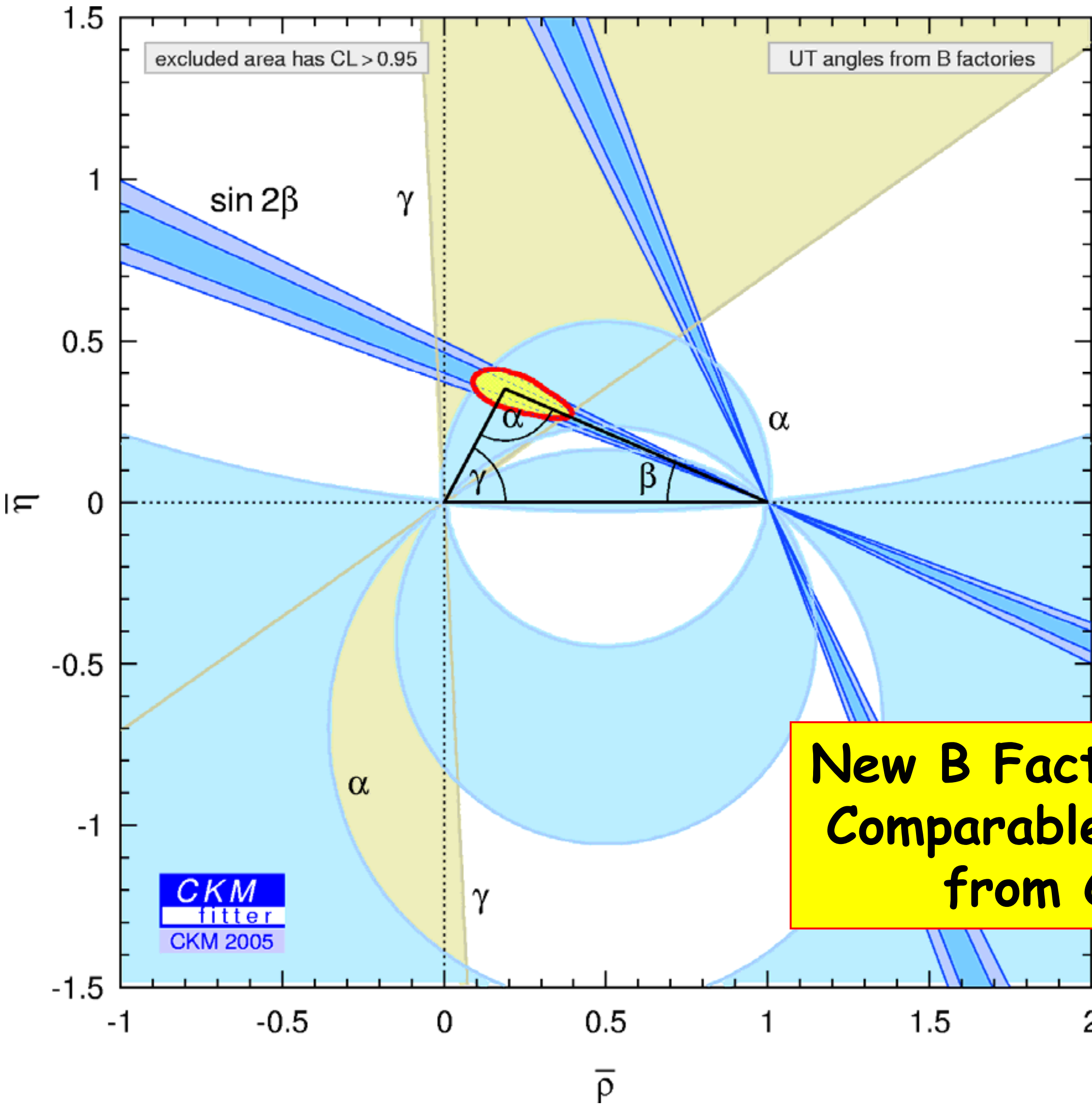
$\gamma = \left[58^{+8}_{-7}\right]^\circ$

Object lesson: with data in hand, clever analysis ideas will emerge

UT from sin2β & indirect constraints



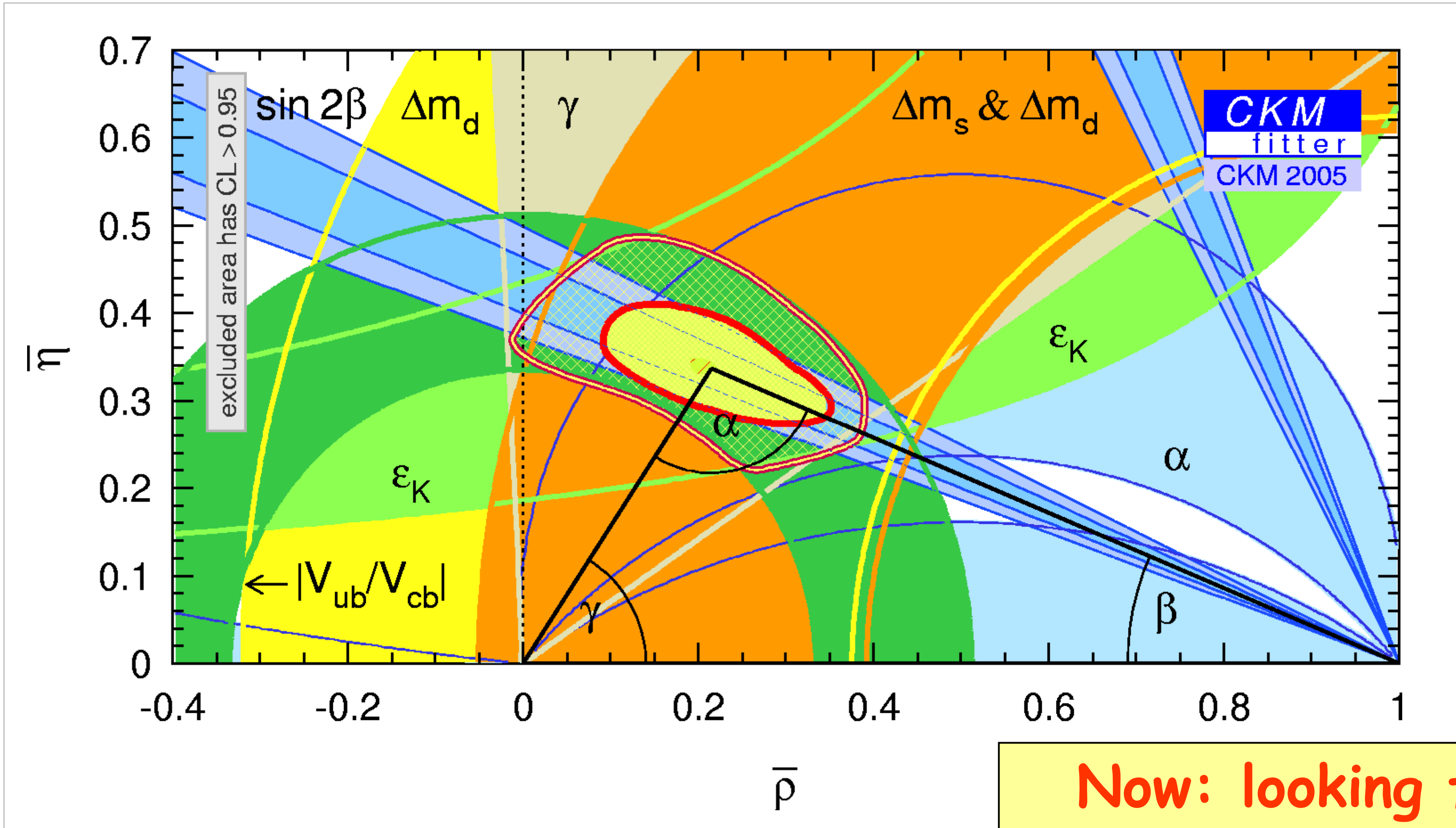
UT from CP violation measurements alone



New B Factory milestone: Comparable UT precision from CPV alone

Global CKM fit: 2005

95% contours



Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

Δm_d

Δm_s

$B \to \tau\nu$

$|\varepsilon_K|$

$\sin 2\beta$

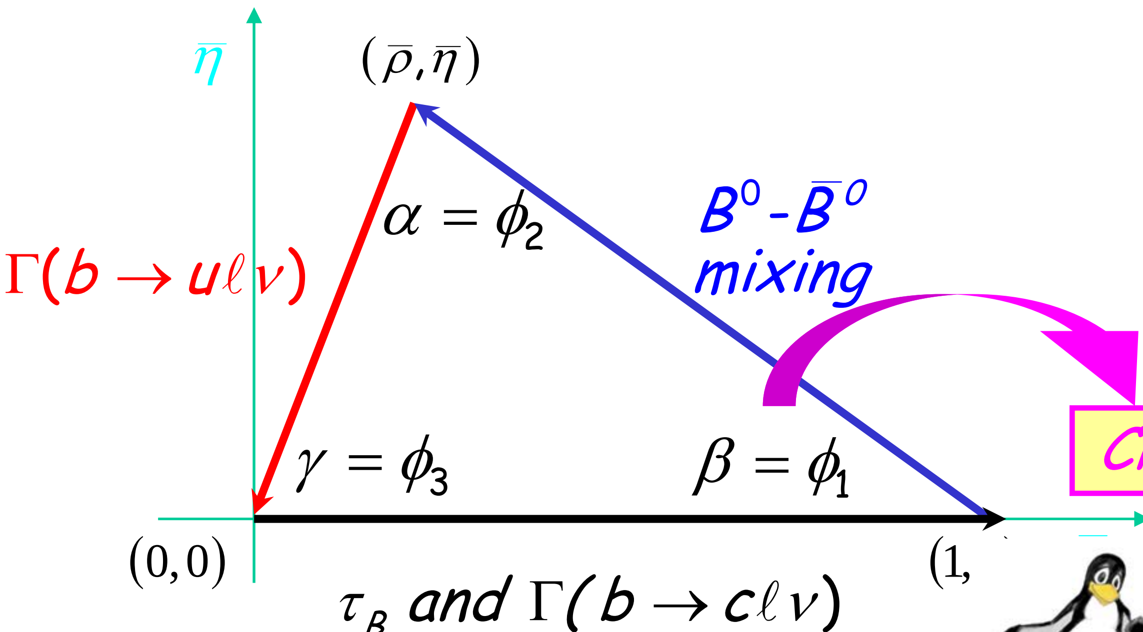
α

γ

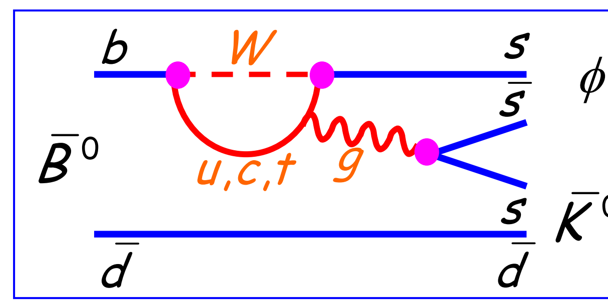
Now: looking for New Physics as correction to CKM

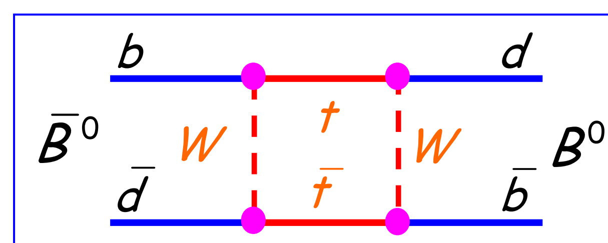
Paradigm change!

CPV in Penguin Modes

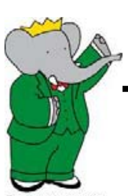


CPV in $B^0 \to \phi K_S^0, \eta' K_S^0, \ldots$



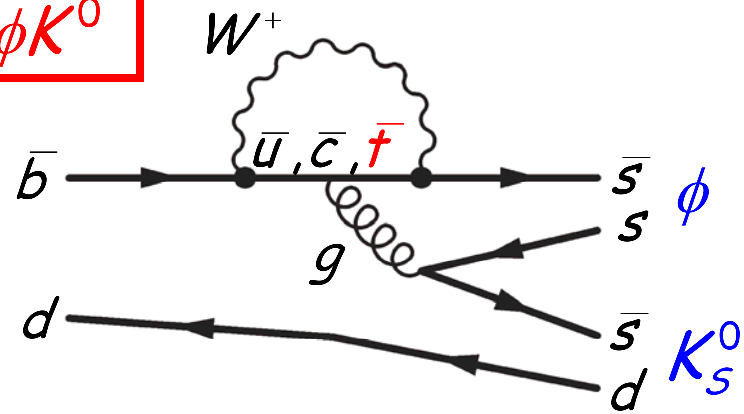


Interference of suppressed
$b \to s$ Penguin decay with mixing



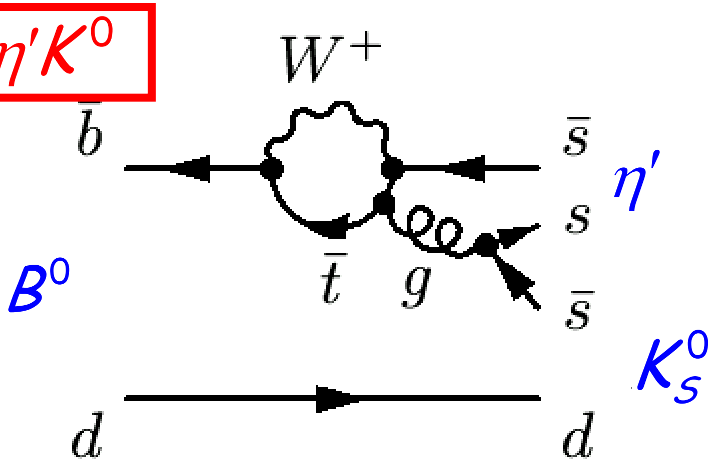
Potential New Physics contributions

$B^0 \to \phi K^0$

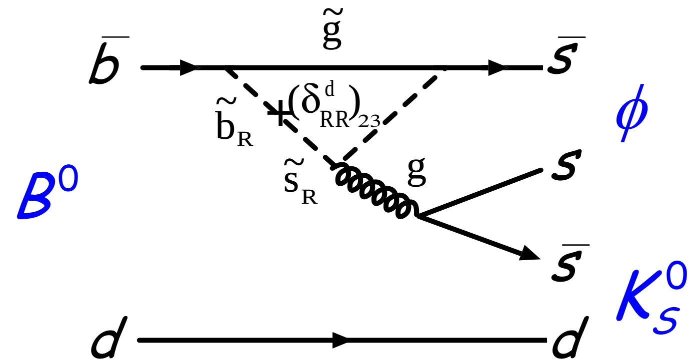


"Internal Penguin"

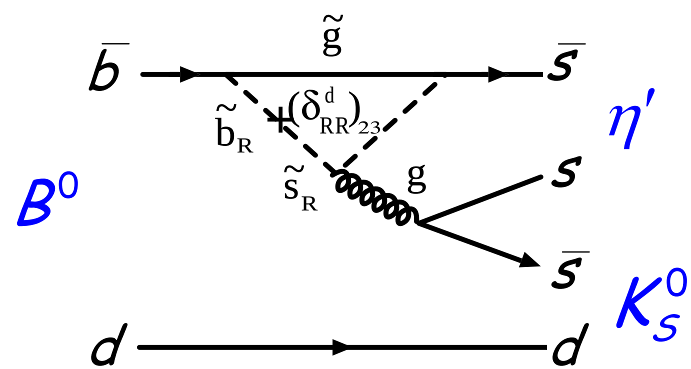
$B^0 \to \eta' K^0$



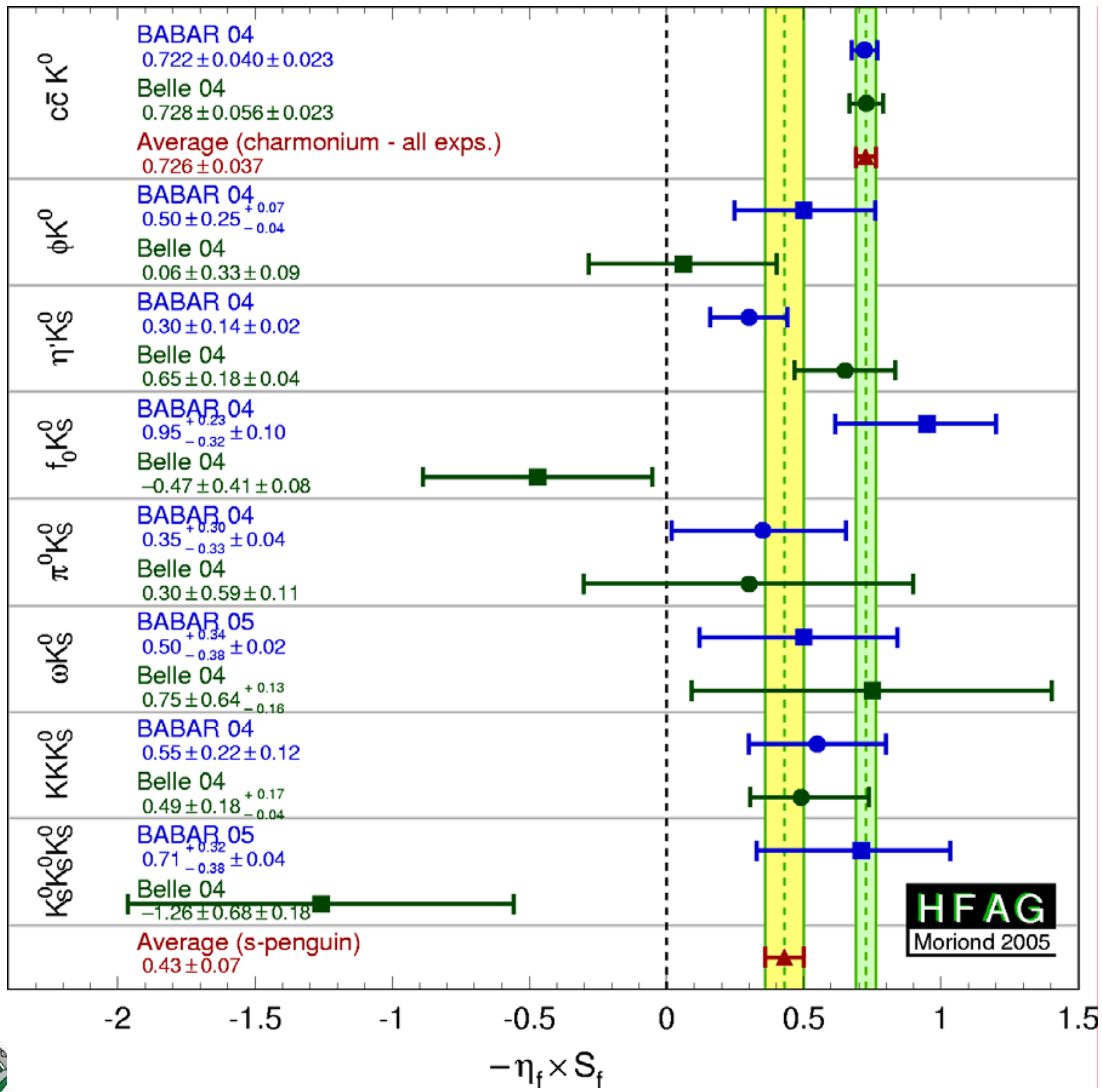
New physics in loops?



SUSY contribution with new phases



CPV in charmonium & s-penguin modes



Charmonium

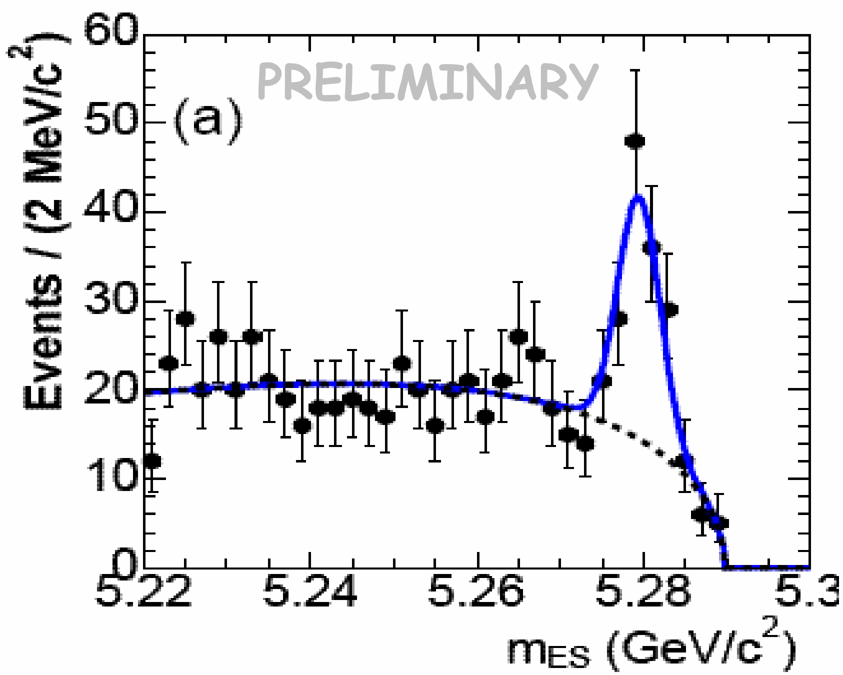
s-Penguins

Good consistency between B Factory experiments

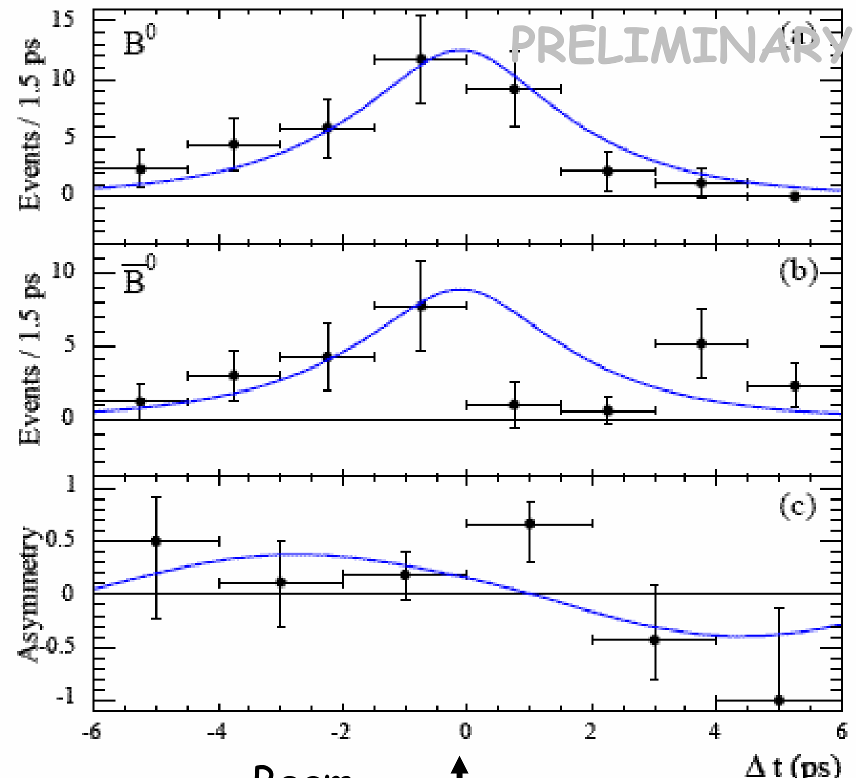
3.7σ between *CP* violation in s-penguin vs sin2β (cc)

No sign of Direct *CP*

New three-body mode: $B \to K_S K_S K_S$



88±10 signal events

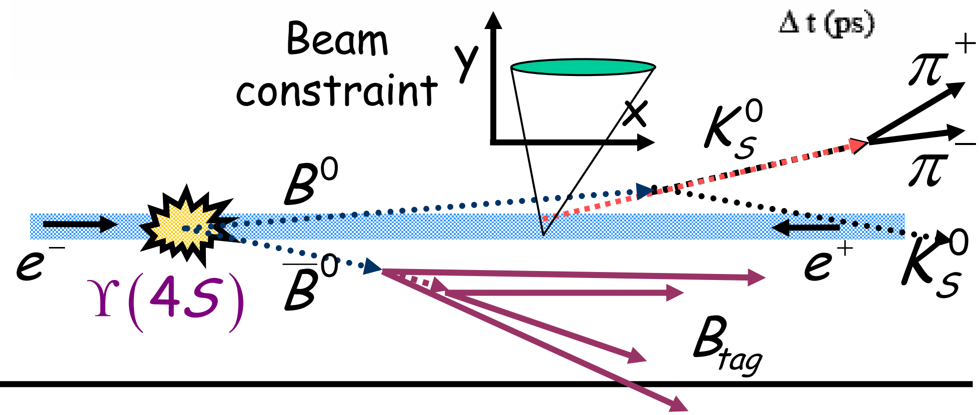


BABAR PUB-04/052

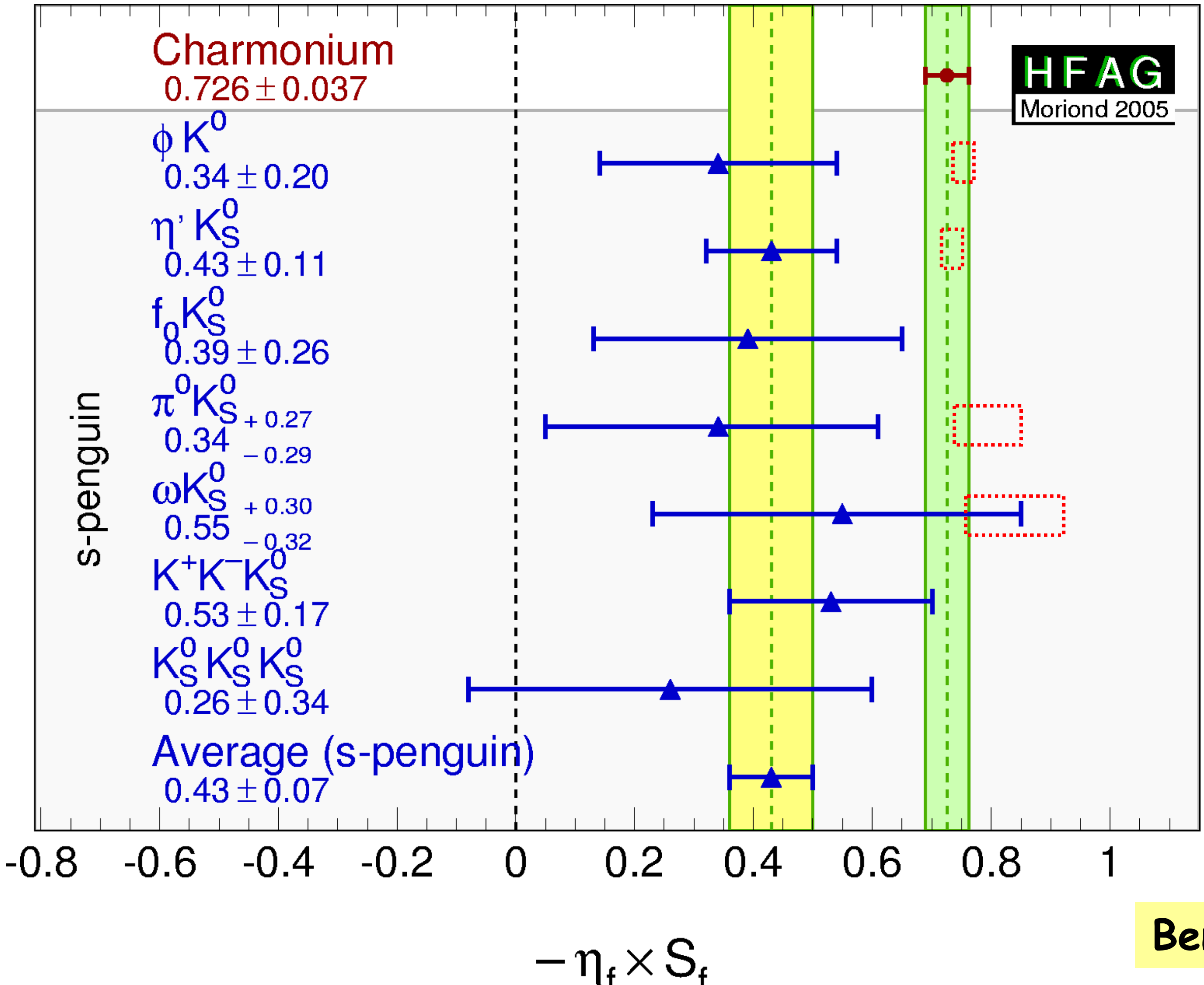
Aspen05

$$-\eta_{CP} \cdot S_{3K_S} = +0.71\,^{+0.38}_{-0.32} \pm 0.04$$

$$C_{3K_S} = -0.34\,^{+0.28}_{-0.25} \pm 0.05$$



How good are Standard Model predictions?



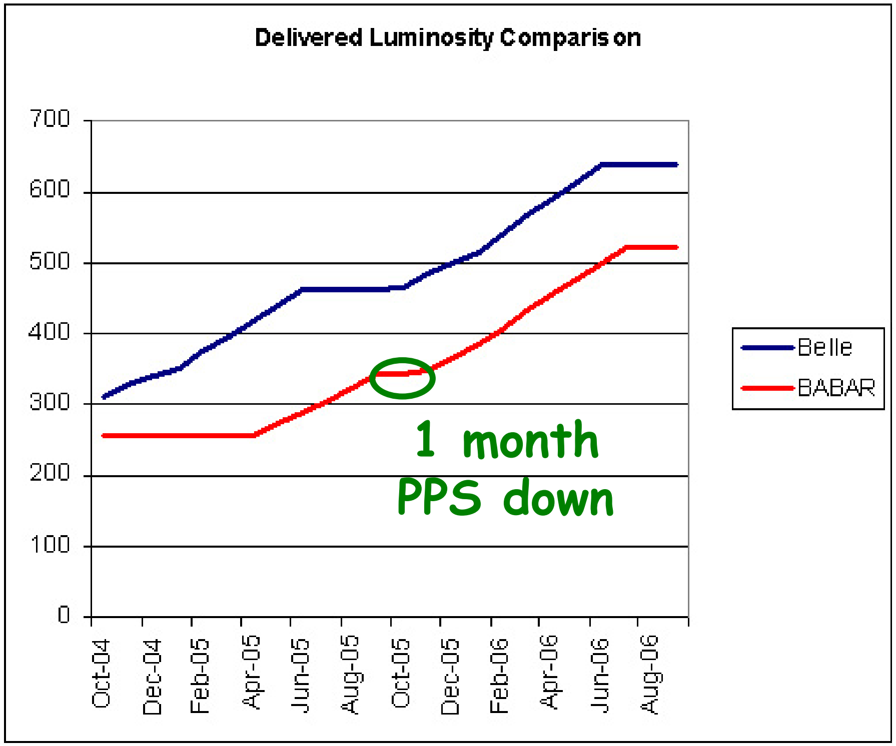
Present SM uncertainty "3 sigma"

Beneke, CKM05

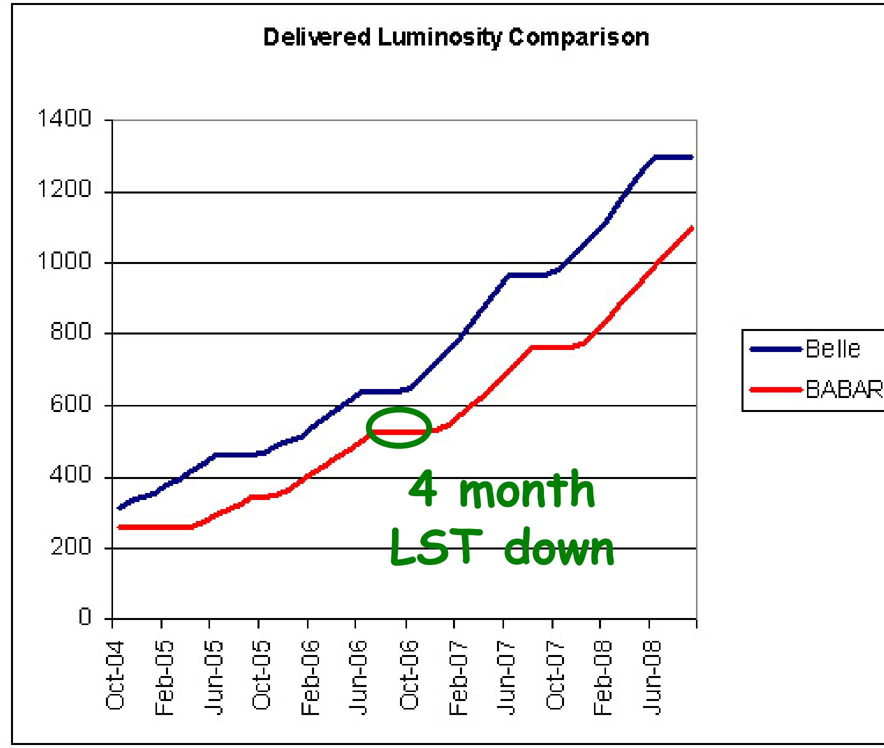
PEP-II/BABAR run plan for 2005-2008

- ***Run 5: Apr 2005 to July 31, 2006***
  - Down for month of October for PPS certification, Linac & PEP-II safety issues, DCH readout phase 2, LST preparations
  - Run through holidays in Dec 2005
- ***LST installation down: Aug 1 to Nov 30, 2006***
  - Installation of remaining 4 barrel sextants of the IFR
  - Installation of PEP-II vacuum upgrades and rf-station
  - LCLS construction and installation
- ***Run 6: Dec 1, 2006 to Aug 31, 2007***
  - Down for Sep-Nov 2007 for LCLS construction & installation
  - Run through holidays in Dec 2006
- ***Run 7: Dec 1, 2007 to Sep 30, 2008***
  - Run through holidays in Dec 2007

Projections of data sample growth

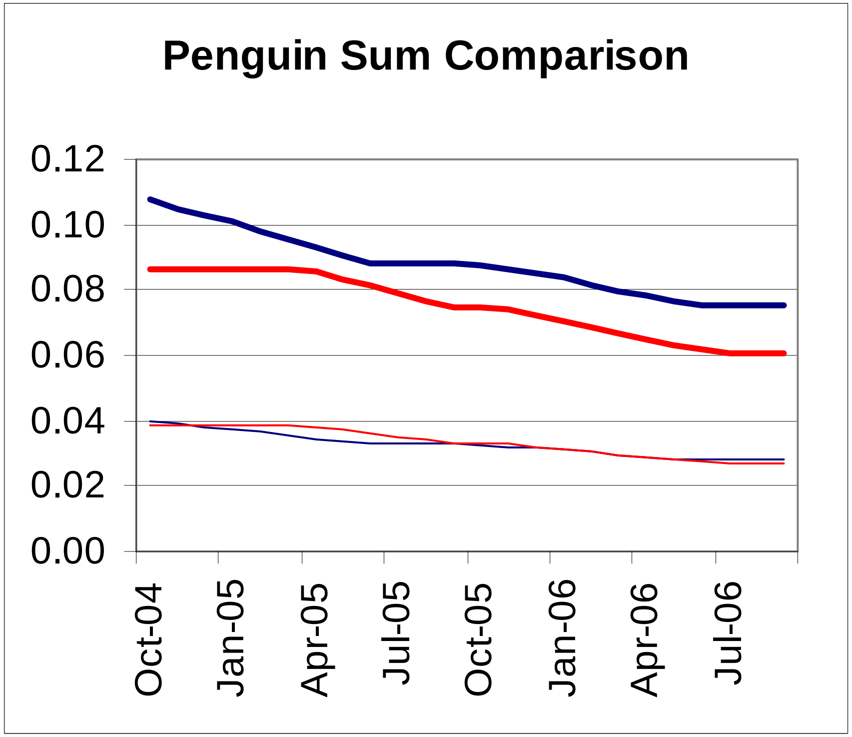


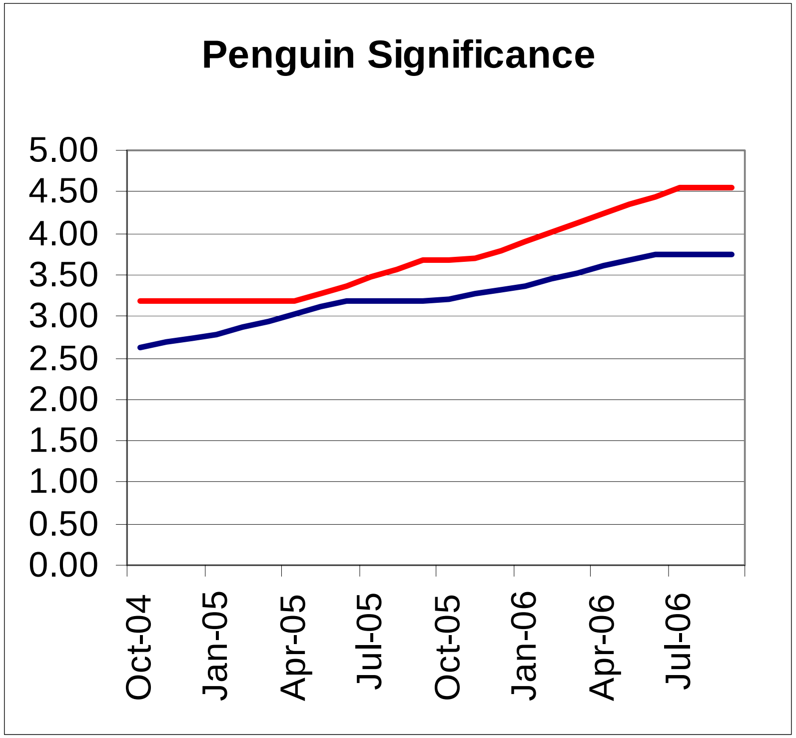
Double data by summer 2006



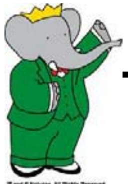
Double again by Sep 2008

Snapshot I: Summer 2006

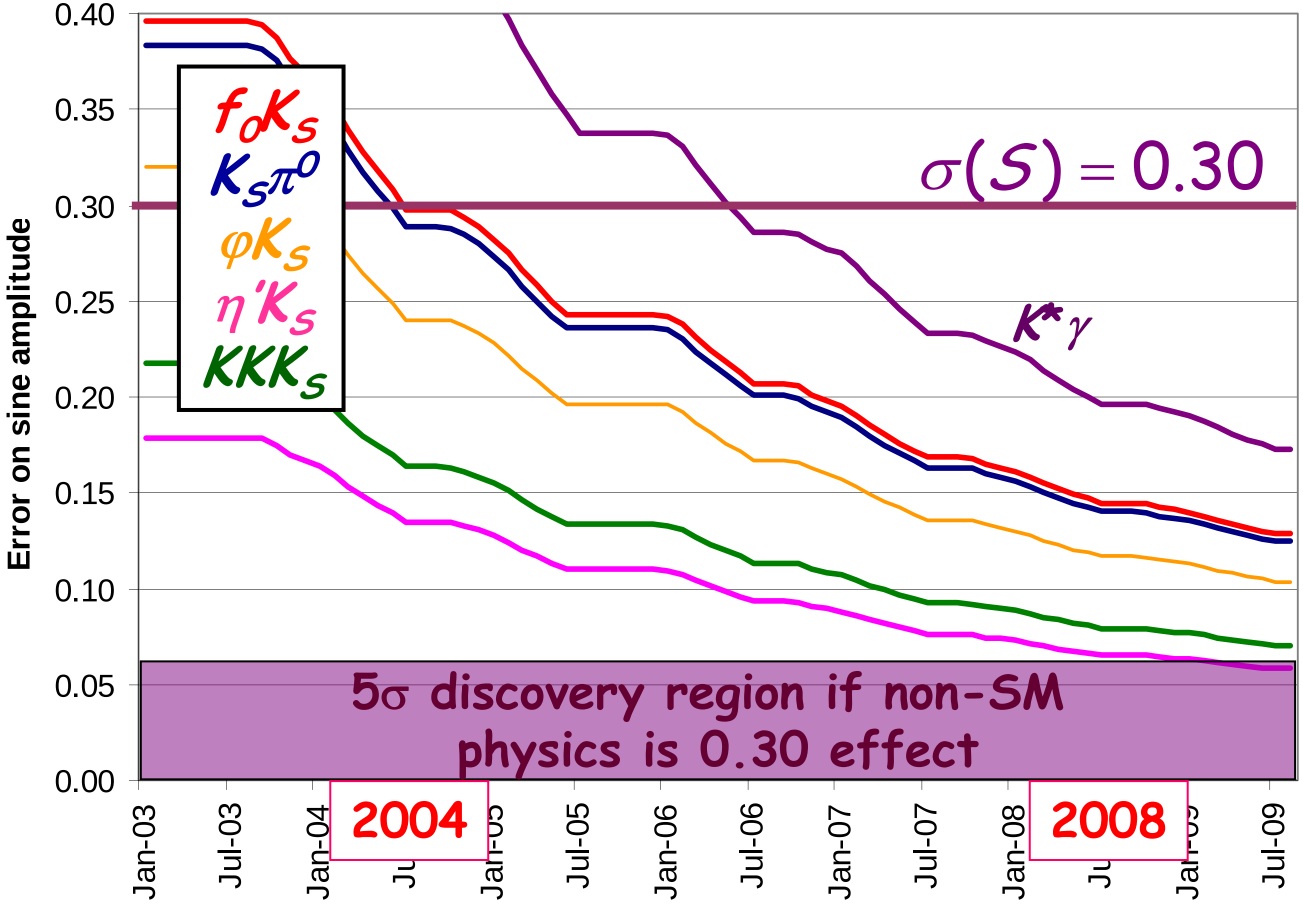




Sum of all modes reaches ~5 sigma level



Snapshot II: Summer 2008

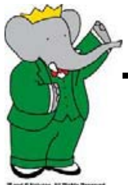


Luminosity expectations:

2004=240 fb^{-1}
2008=1.1 ab^{-1}

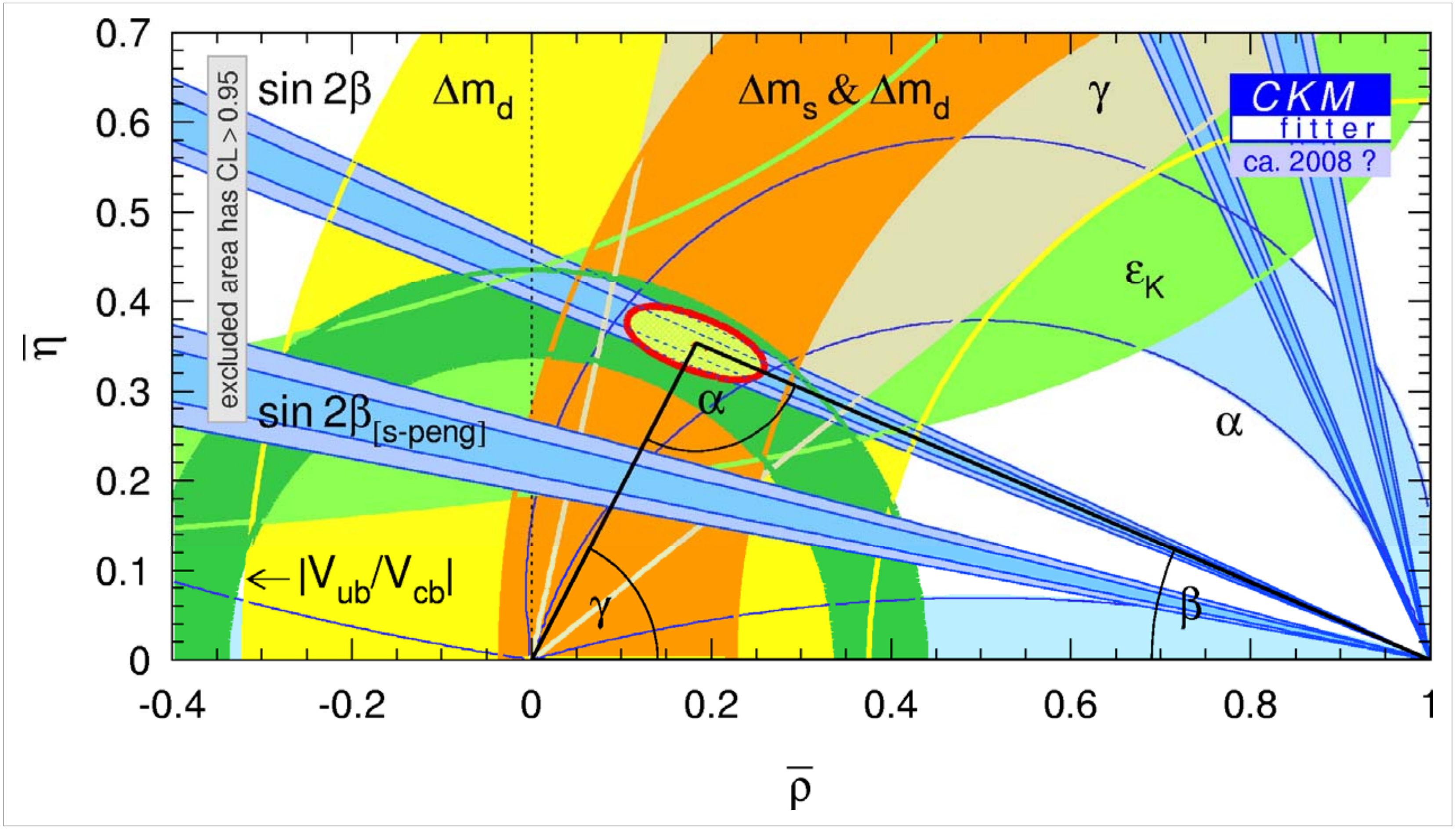
Golden modes reach 5 sigma level

Projections are statistical errors only;
but systematic errors at few percent level



Global CKM fit: 2008

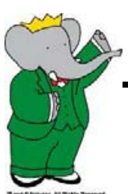
95% contours



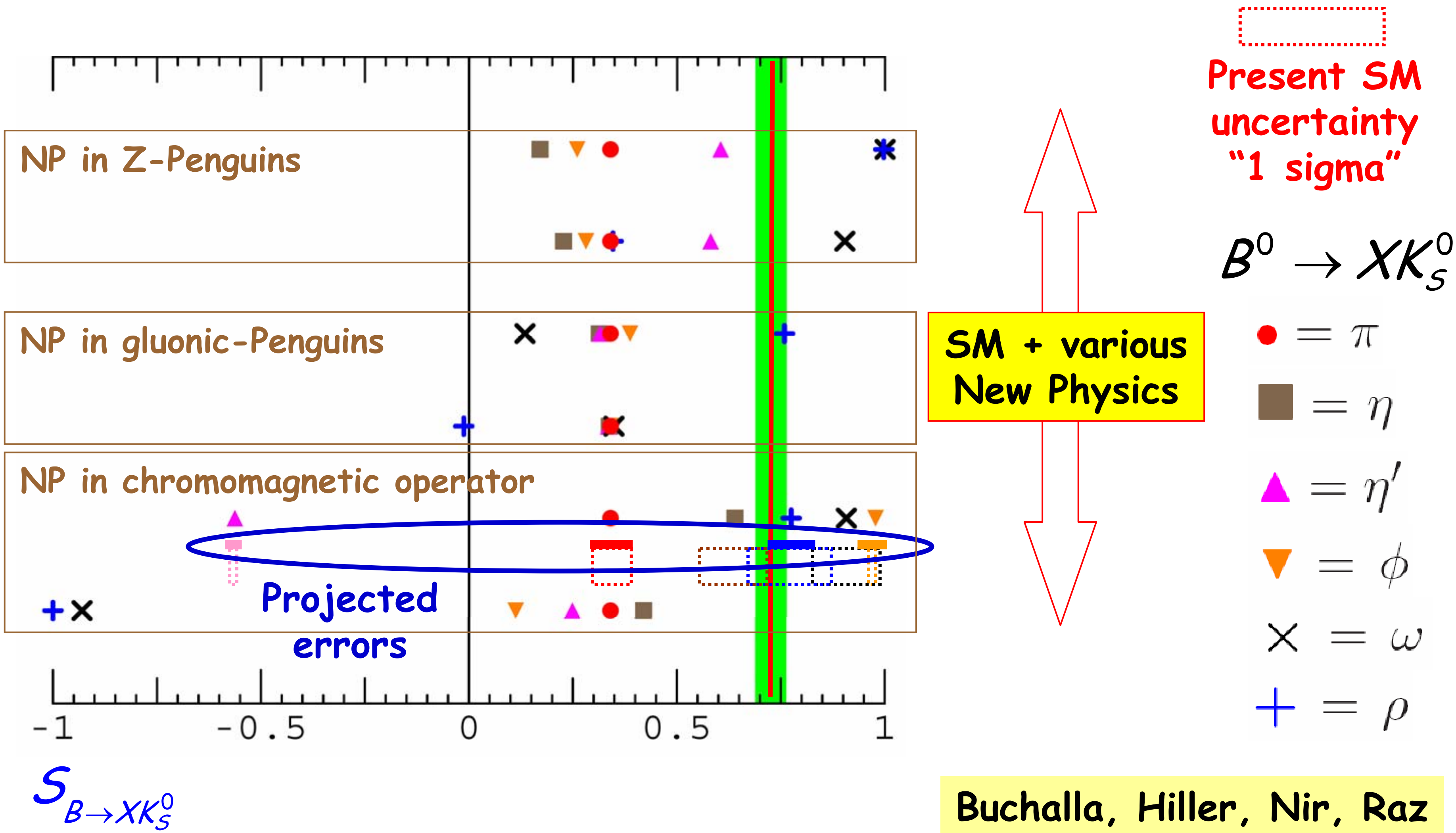
$\sigma(V_{ub}) = 7\%$

$\sigma(\Delta m_s) = 5\%$

$\sigma(\sin 2\beta) = 0.019 \quad \sigma(\alpha) = 6^{\circ} \quad \sigma(\gamma) = 10^{\circ}$

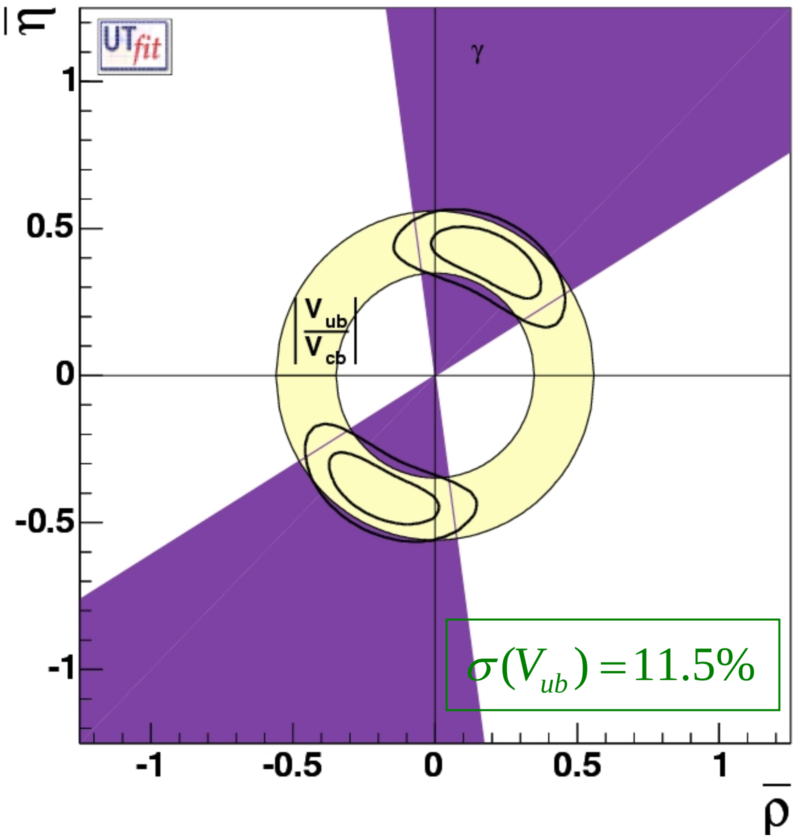


Snapshot III: Fall 2010?

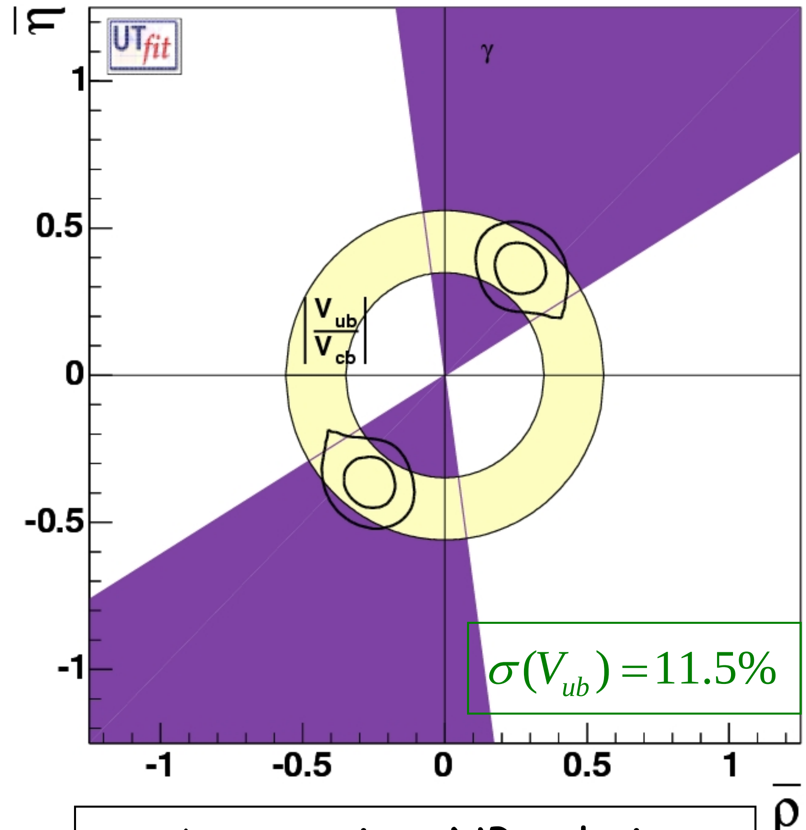


Buchalla, Hiller, Nir, Raz
hep-ph/0503151

UT constraints with ~no NP assumptions



Assumption: no NP in trees
[almost any NP model]

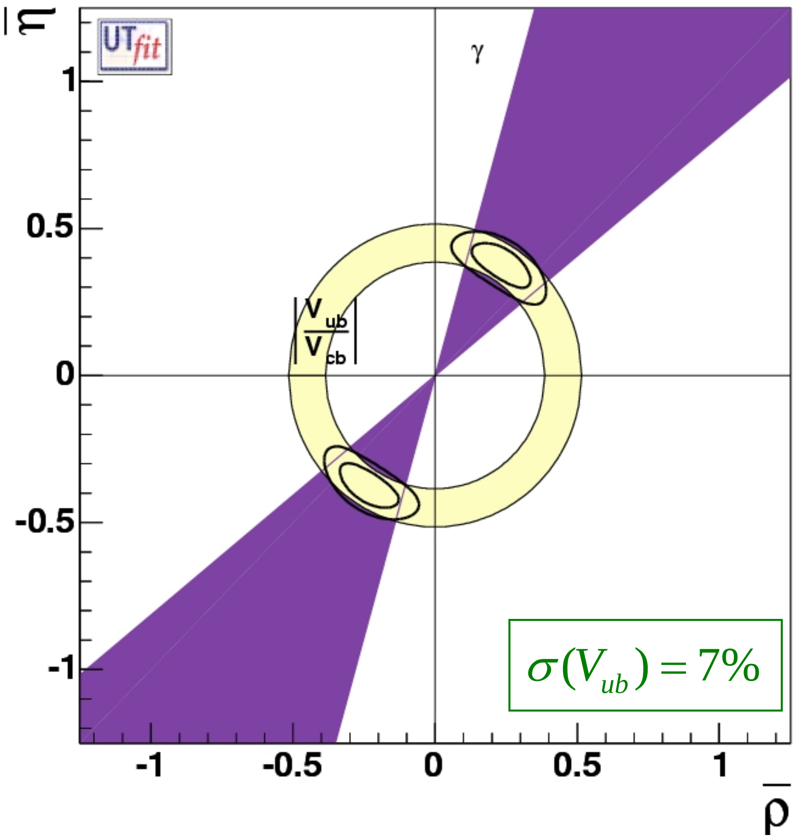


Assumption: NP only in
$|\Delta F|=2$ and $b \to s$
[not too strong]

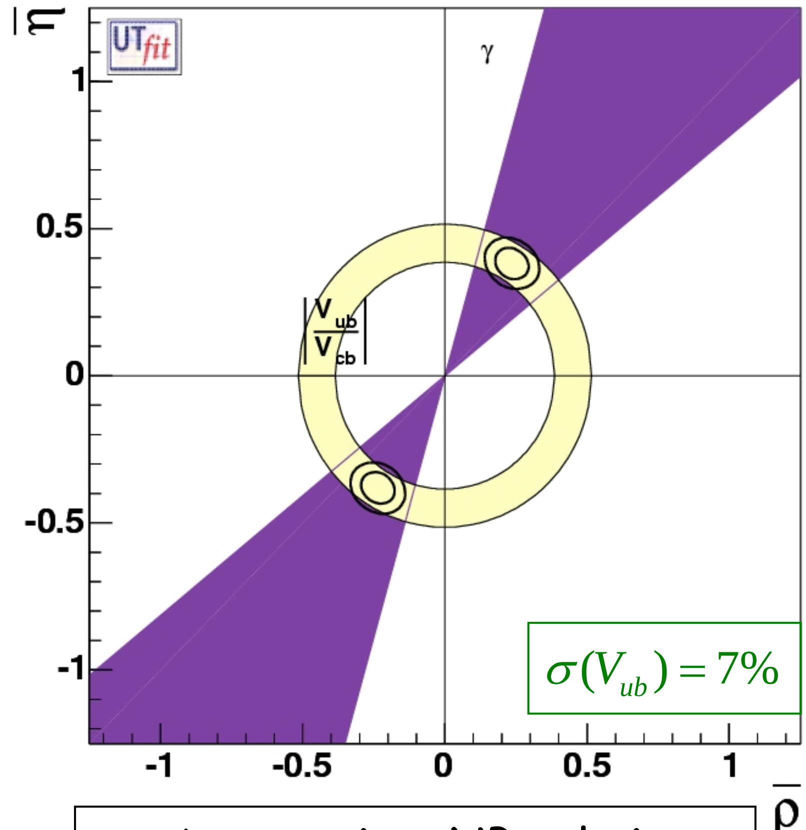
68% contours

UT constraints in 2008

68% contours



Assumption: no NP in trees
[almost any NP model]



Assumption: NP only in
|ΔF|=2 and b→s
[not too strong]

Significant constraint on all New Physics models in LHC era

Summary: Physics reach of BABAR

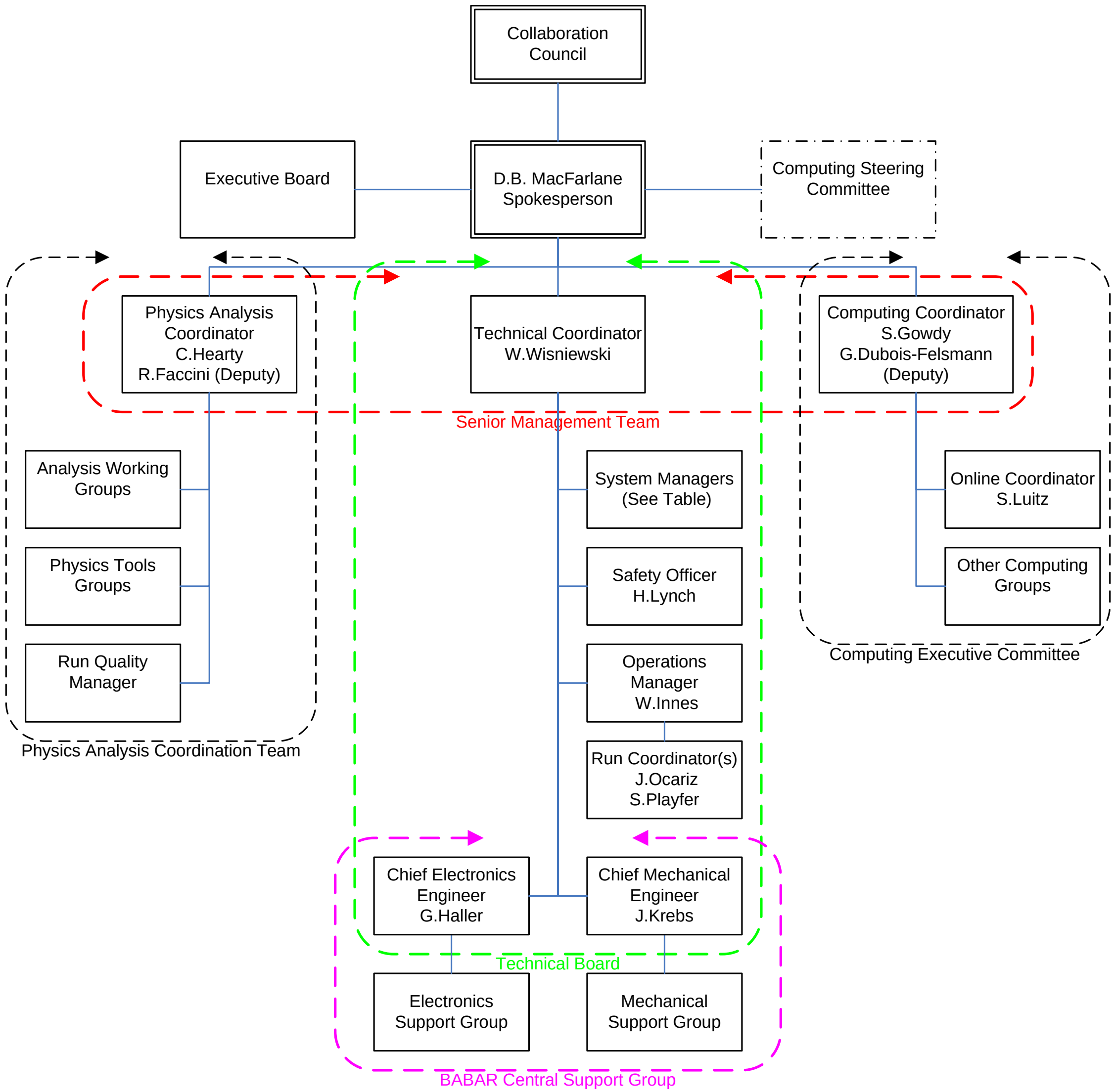
- ***Goal for 2005-2006: double current data set***
  - Delay in Run 5 can be overcome by summer 2006 with extended running period, with substantial reduction in errors on CP violation asymmetries in rare decay modes
  - Error on average of Penguin modes should reach 0.06
- ***Goal for 2007-2008: double again to ~1 ab^{-1}***
  - Individual Penguin modes with errors in range 0.06-0.12
  - Suite of fundamental Standard Model measurements with substantially improved levels of precision

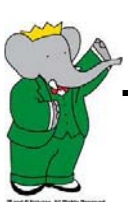
  - **Sensitivity to New Physics through rare decays, *CP* violation, & large data sample with a significant discovery potential**
  - **Full program of flavor physics/CP violation measurements provide fundamental constraints on future New Physics discoveries**

- ***Beyond 2008 might offer exciting opportunities if New Physics has been seen by B Factories & LHC***

Backup Slides

BABAR line organization

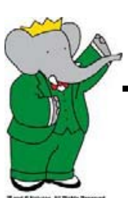




BABAR training matrix

Category	Training Requirement	Recommended Supervisor	Documentation Requirements
a. Short-term visitor	None. Category (b) or higher recommended for BABAR users.	None	None
b. Office worker	EOESH, GERT, ES&H 239	Member of BABAR Management team or SLAC Group Leader	Office JHAM, Office Building AHA
c. Shift-taker	(b) above plus Shift Training	Run Coordinator	(b) above plus Shifter JHAM, IR-2 AHA
d. System worker	(b) above plus BABAR Orientation, job specific training	System Manager	(b),(c) above plus System JHAM(s)
e. R&D worker	(b) above plus job specific training	R&D Manager	(b) above plus job specific JHAM, job site AHA

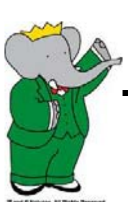
http://www.slac.stanford.edu/BFROOT/www/Organization/Spokesperson/safety/safety_checklist.htm



BABAR work categories

Short-term visitor	*Attends no more than one collaboration meeting per year or equivalent*
Office worker	*Only works in the ROB or one of the other office areas but not IR-2 or other laboratory space*
Shift-taker	*Stands shifts on BABAR in IR-2*
System worker	*Does maintenance work on a detector system in IR-2 or in a system laboratory space*
R&D worker	*Does development or testing work in a lab setting or temporary system space*

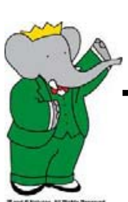
EOESH, GERT, 239



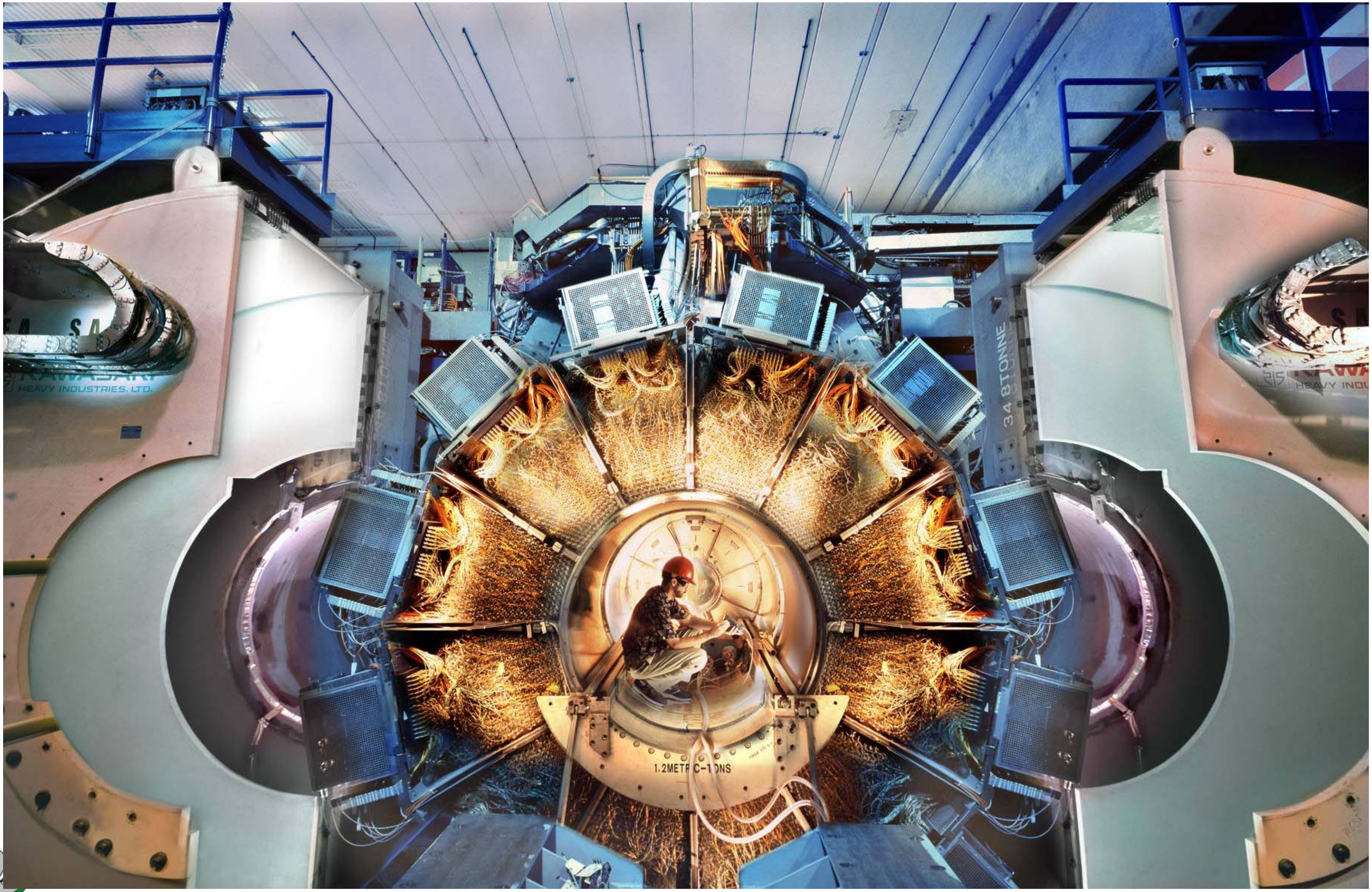
Operational & physics manpower

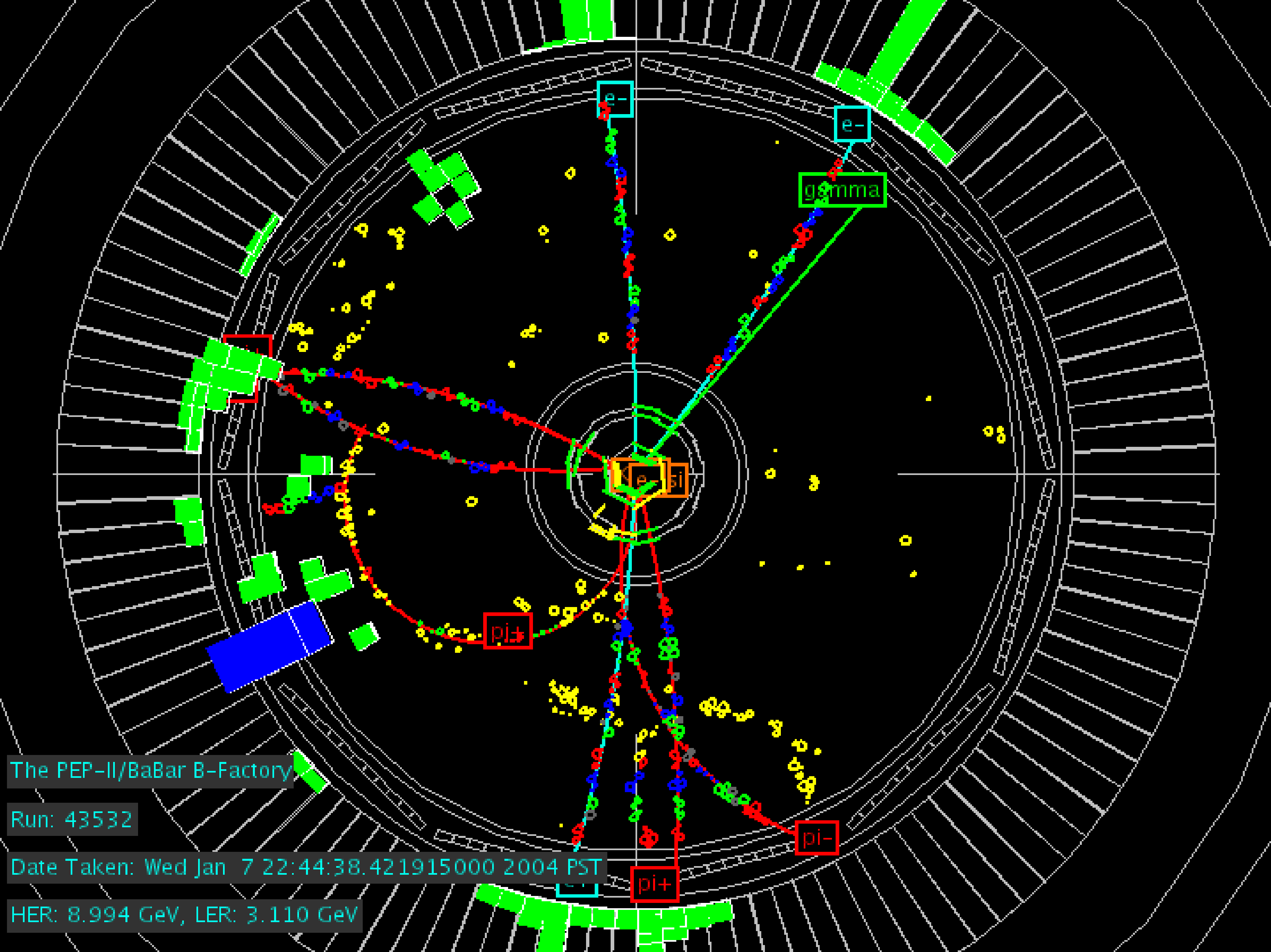
Community	CY2004	CY2005	CY2006	CY2007	CY2008	Physics
US University	63.0	60.0	56.0	52.0	52.0	
students/posdocs	15.2	14.5	13.5	12.5	12.5	68.0
faculty/staff	32.5	31.0	28.9	26.8	26.8	33.8
	47.7	45.4	42.4	39.4	39.4	101.8
SLAC	33.0	32.0	30.0	26.0	26.0	
students/postdocs	16.0	15.5	14.5	12.6	12.6	20.0
faculty/staff	17.0	16.5	15.5	13.4	13.4	20.5
	33.0	32.0	30.0	26.0	26.0	40.5
non-US	65.0	63.0	62.0	60.0	60.0	
students/postdocs	31.5	30.5	30.0	29.0	29.0	123.0
faculty/staff	33.5	32.5	32.0	31.0	31.0	63.5
	65.0	63.0	62.0	60.0	60.0	186.5
Total	161.0	155.0	148.0	138.0	138.0	
students/postdocs	62.6	60.4	58.0	54.2	54.2	211.0
faculty/staff	83.1	80.0	76.4	71.2	71.2	117.8
	145.7	140.4	134.4	125.4	125.4	328.8

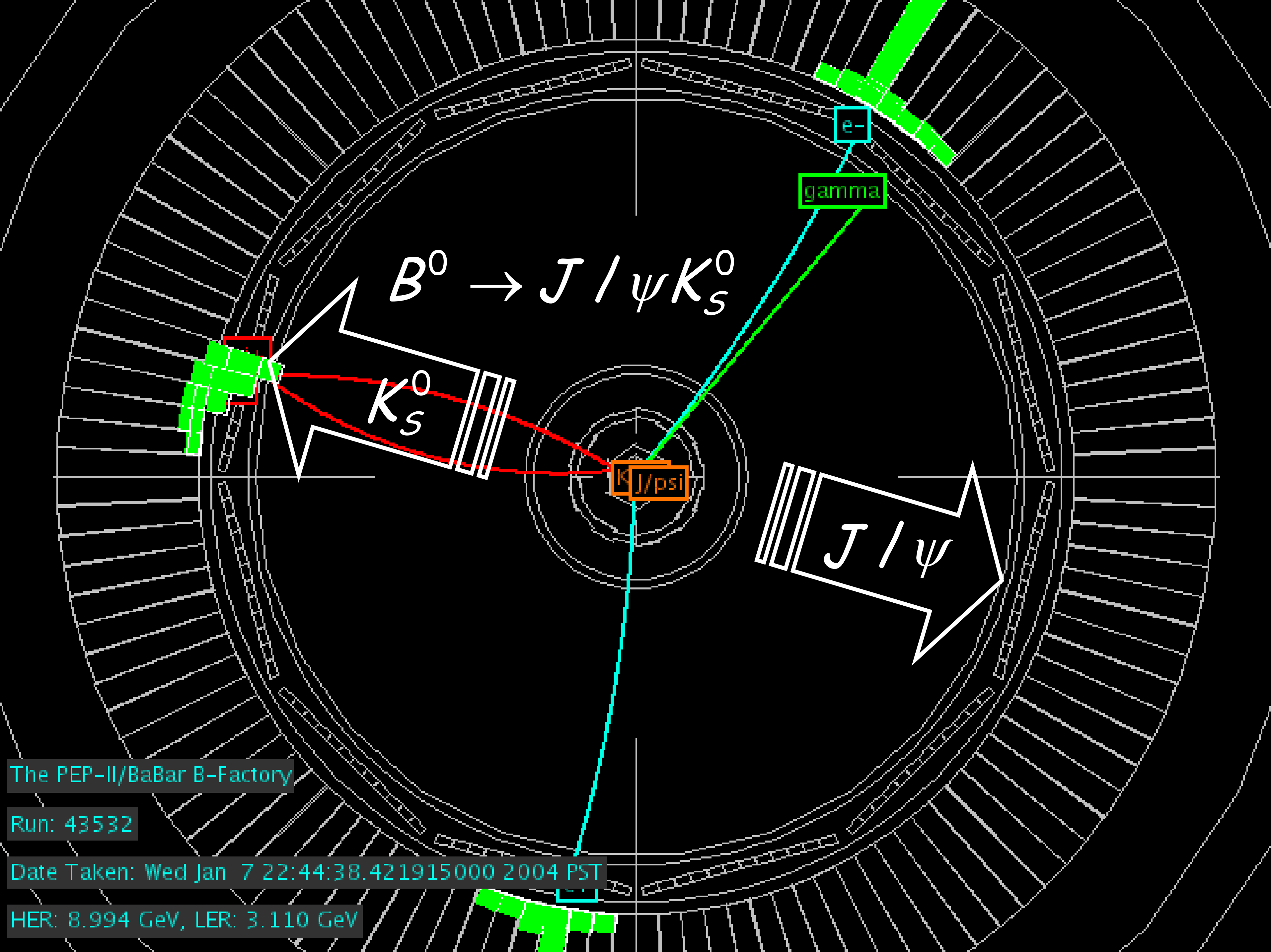
Detector operations, online & offline data processing, MC production



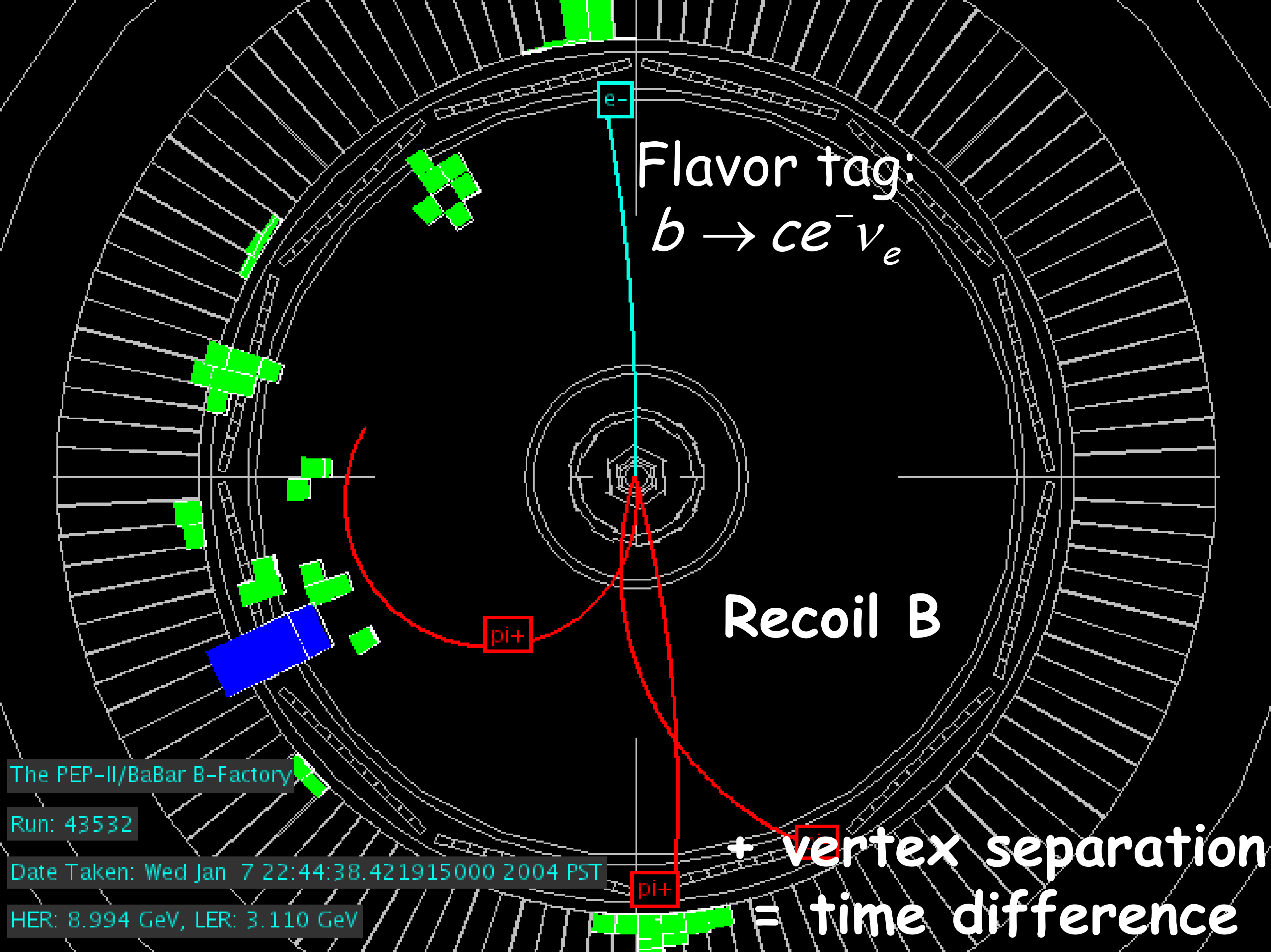
BABAR Detector

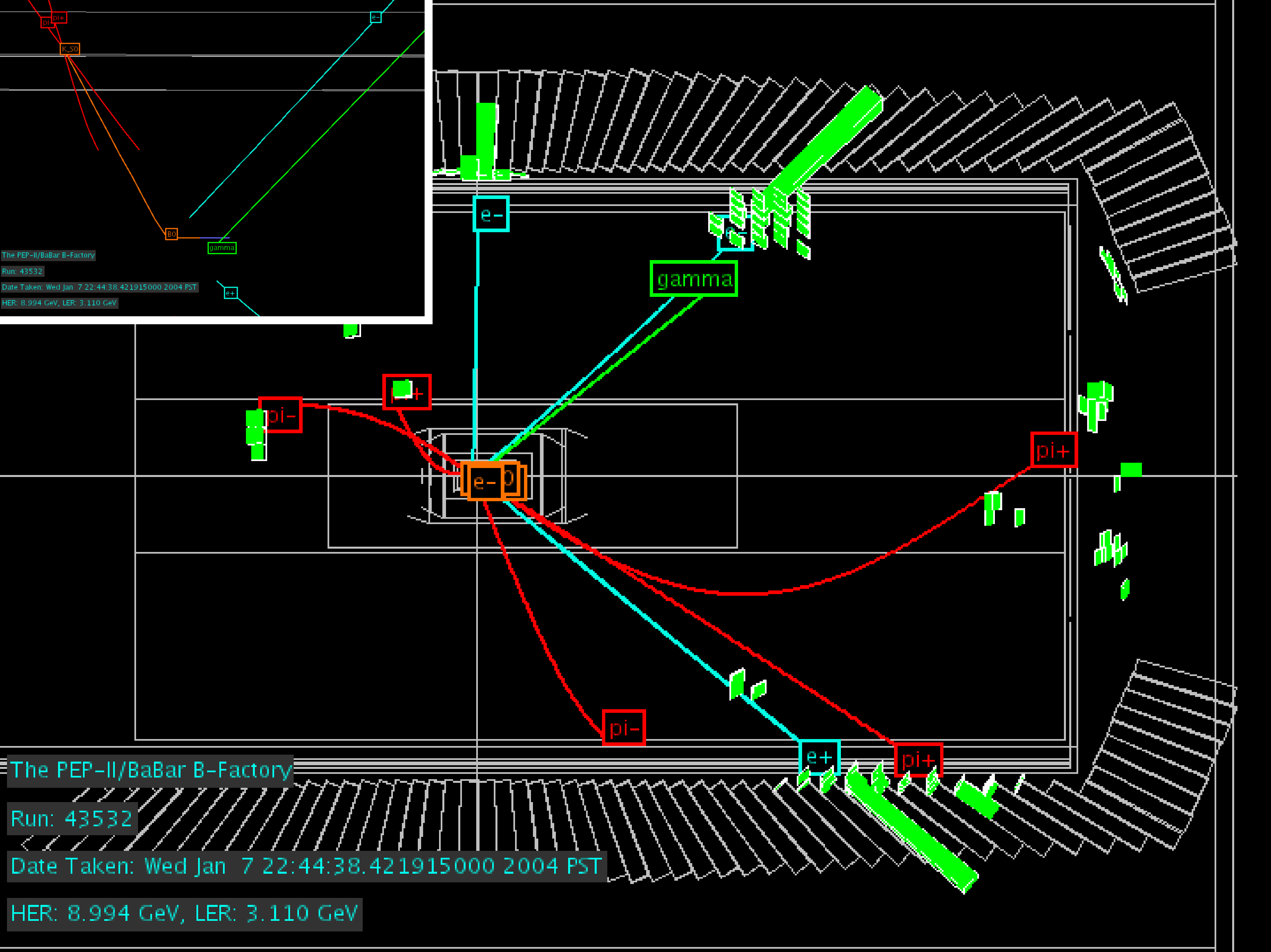



e-
e-
gamma
e-
pi+
pi-
pi+
The PEP-II/BaBar B-Factory
Run: 43532
Date Taken: Wed Jan 7 22:44:38.421915000 2004 PST
HER: 8.994 GeV, LER: 3.110 GeV



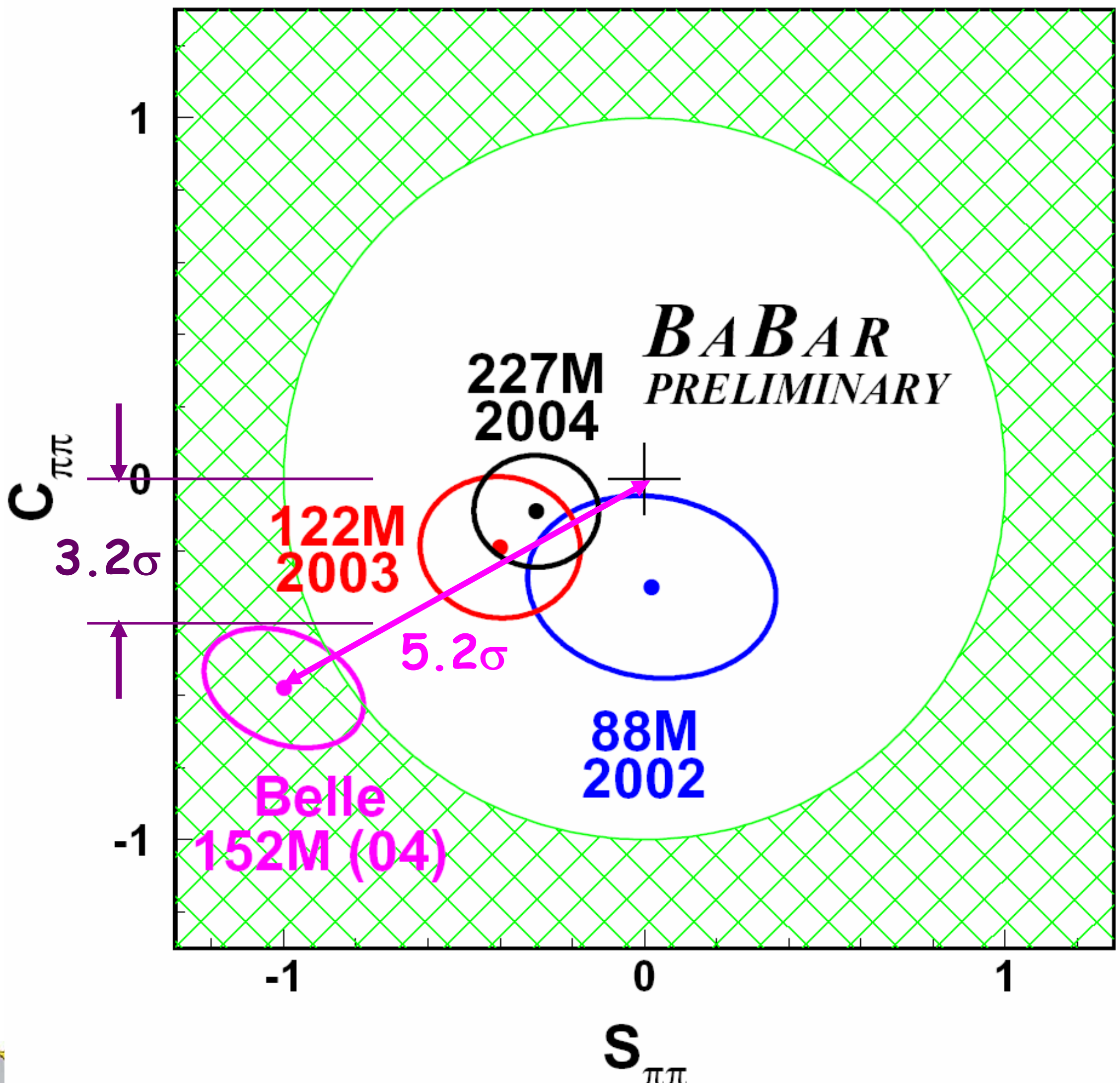
$B^0 \to J/\psi K_S^0$
e-
gamma
K_S^0
J/psi
J/ψ
The PEP-II/BaBar B-Factory
Run: 43532
Date Taken: Wed Jan 7 22:44:38.421915000 2004 PST
HER: 8.994 GeV, LER: 3.110 GeV


e-
Flavor tag:
$b \to c e^- \nu_e$
pi+
Recoil B
The PEP-II/BaBar B-Factory
Run: 43532
Date Taken: Wed Jan 7 22:44:38.421915000 2004 PST
HER: 8.994 GeV, LER: 3.110 GeV
pi+
+ vertex separation
= time difference



pi+
pi-
e-
K_S0
B0
gamma
The PEP-II/BaBar B-Factory
Run: 43532
Date Taken: Wed Jan 7 22:44:38.421915000 2004 PST
HER: 8.994 GeV, LER: 3.110 GeV
e+
e-
gamma
pi-
pi+
e-
pi+
pi-
e+
pi+
The PEP-II/BaBar B-Factory
Run: 43532
Date Taken: Wed Jan 7 22:44:38.421915000 2004 PST
HER: 8.994 GeV, LER: 3.110 GeV

Summer 2004 results for $B \rightarrow \pi\pi$

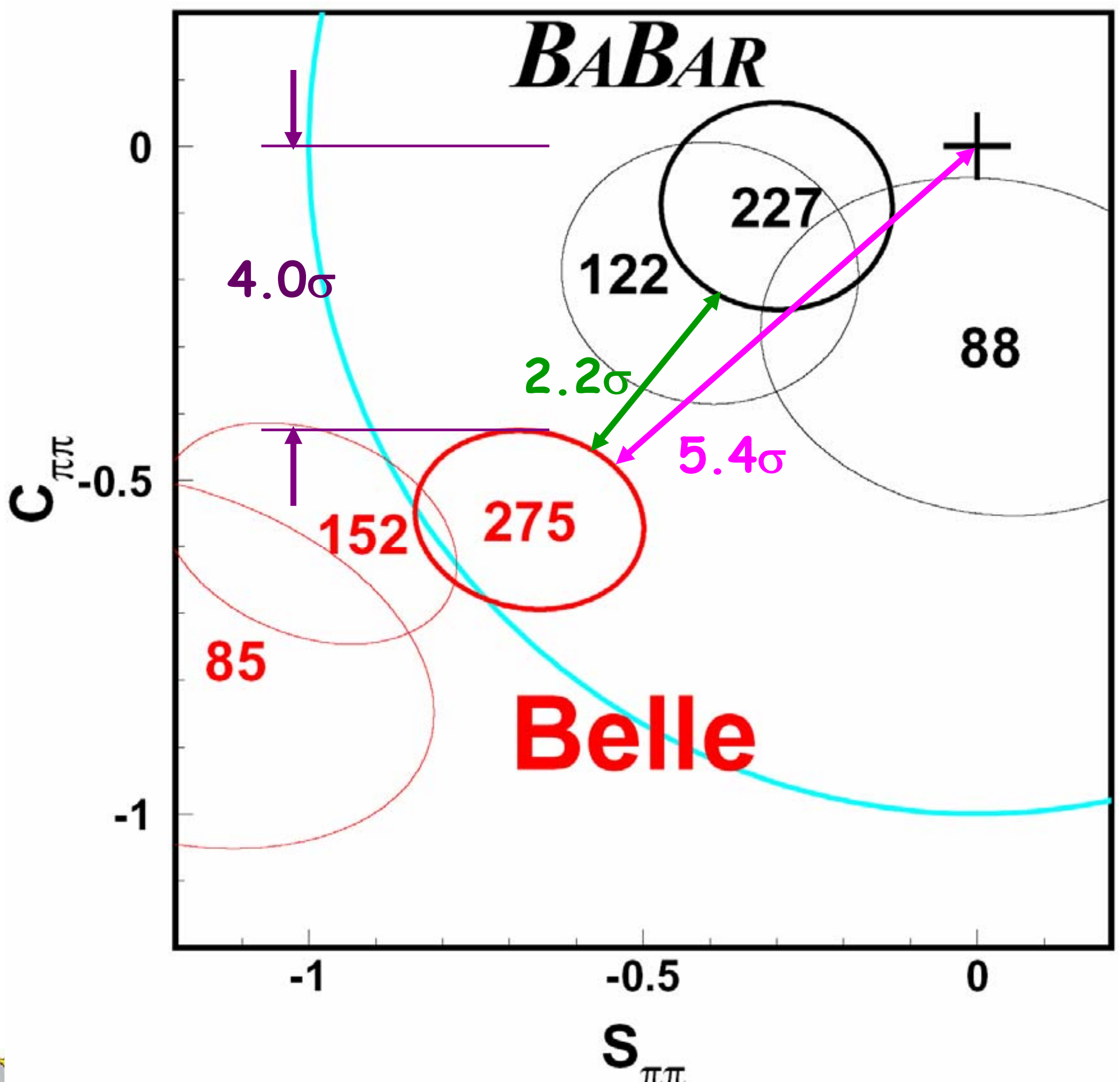


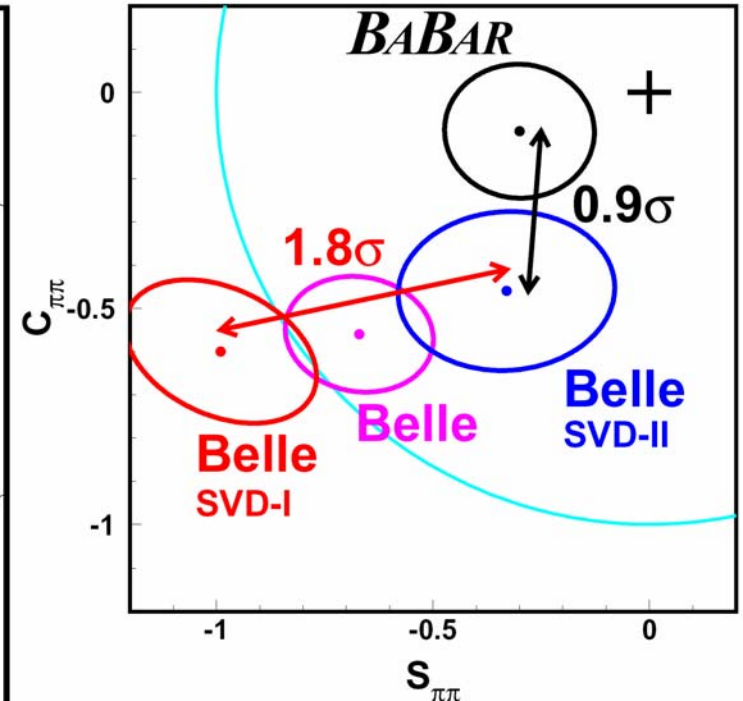
>3σ discrepancy between *BABAR* & Belle

Belle 3.2σ evidence for Direct *CP* violation not supported by *BABAR* measurements

Caution averaging!

Winter 2005 results for $B \to \pi\pi$



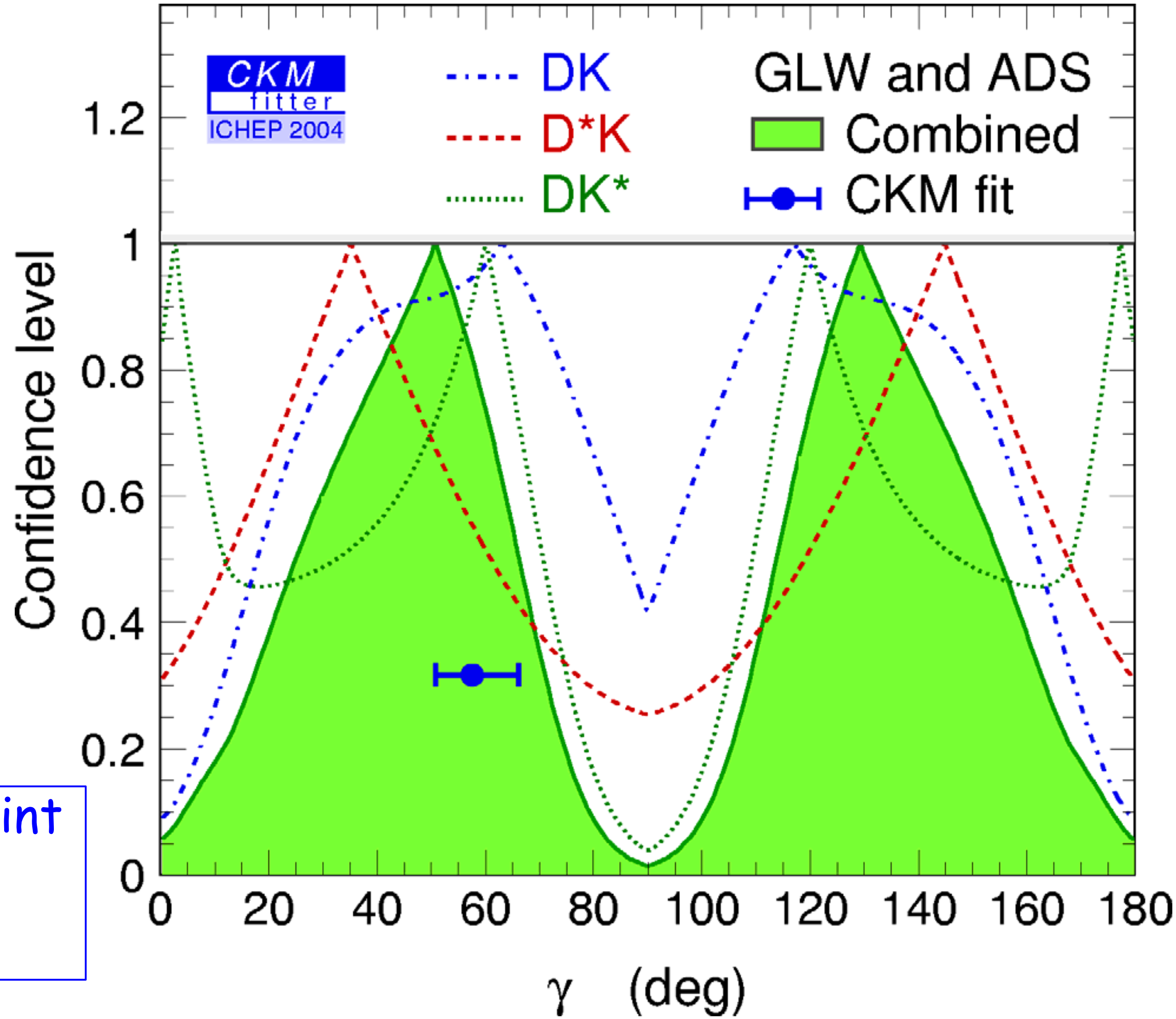


~2.2σ discrepancy between *BABAR* & Belle

Belle 4.0σ evidence for Direct *CP* violation not supported by *BABAR* measurements

Combined GLW and ADS constraint on γ

BABAR & Belle combined



From combined GLW and ADS fit:

$$\gamma = \left[51^{+20}_{-34}\right]^{\circ}$$

CKM indirect constraint fit: $\gamma = \left[58^{+8}_{-7}\right]^{\circ}$

Competition: Better physics performance

S	Belle				BABAR				Errors/Luminosity			
									Belle	BABAR		
Mode	S	stat err	lumi	Untag sample	S	stat err	lumi	Untag sample	st*sqrt(L)	st*sqrt(L)	Perf Ratio	Lumi Ratio
phiK0	0.060	0.330	253	175	0.500	0.250	205	212	5.249	3.579	1.466	2.150
etapK0	0.650	0.180	253	512	0.270	0.140	205	819	2.863	2.004	1.428	2.040
KKK0	0.490	0.180	253	399	0.550	0.170	205	452	2.863	2.434	1.176	1.384
f0K0	-0.470	0.410	253	102	0.950	0.320	192	152	6.521	4.434	1.471	2.163
pi0K0	0.300	0.590	253	173	0.350	0.300	205	300	9.385	4.295	2.185	4.773
ccbarK0	0.728	0.056	140	5417	0.722	0.040	205	10320	0.663	0.573	1.157	1.339
pipi	-1.000	0.210	140	373	-0.300	0.170	205	467	2.485	2.434	1.021	1.042
rhopi S	-0.280	0.230	140	483	-0.100	0.140	192	1184	2.721	1.940	1.403	1.968
rhopi A+-	-0.020	0.160	140	483	-0.210	0.110	192	1184	1.893	1.524	1.242	1.543
rhopi A-+	-0.530	0.290	140	483	-0.470	0.140	192	1184	3.431	1.940	1.769	3.129
Averages											1.432	2.153

Typically better errors for BABAR despite larger Belle dataset

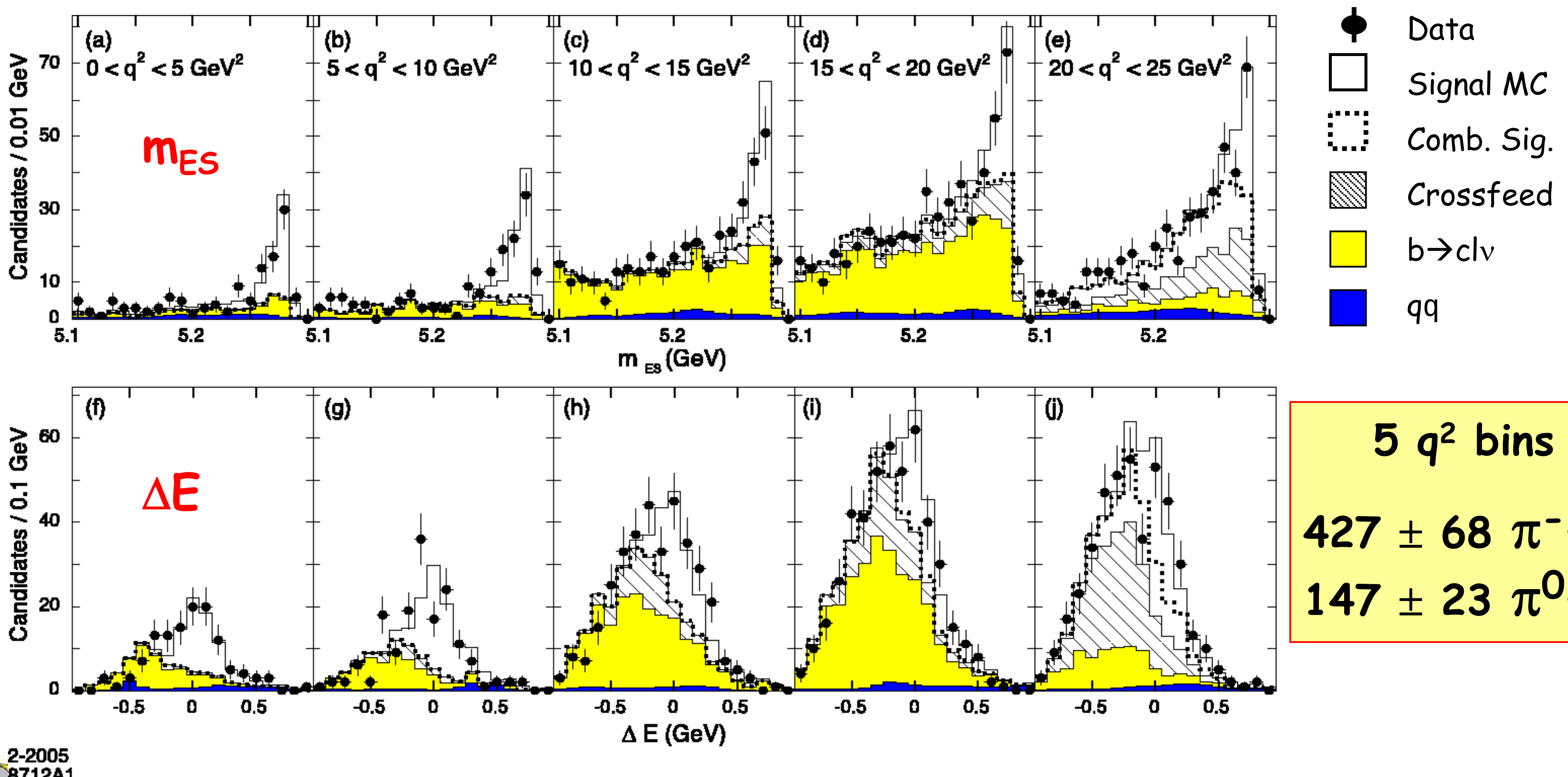
Normalized performance ratio

Bottom line: BABAR is getting the equivalent of a factor of 2 in luminosity through better analysis/detector performance

m_{ES} and ΔE fit for $B \to \pi \ell \nu$

$\Gamma(B^0 \to \pi^- \ell \nu) = 2\,\Gamma(B^+ \to \pi^0 \ell \nu)$

82 fb^{-1}



5 q^2 bins

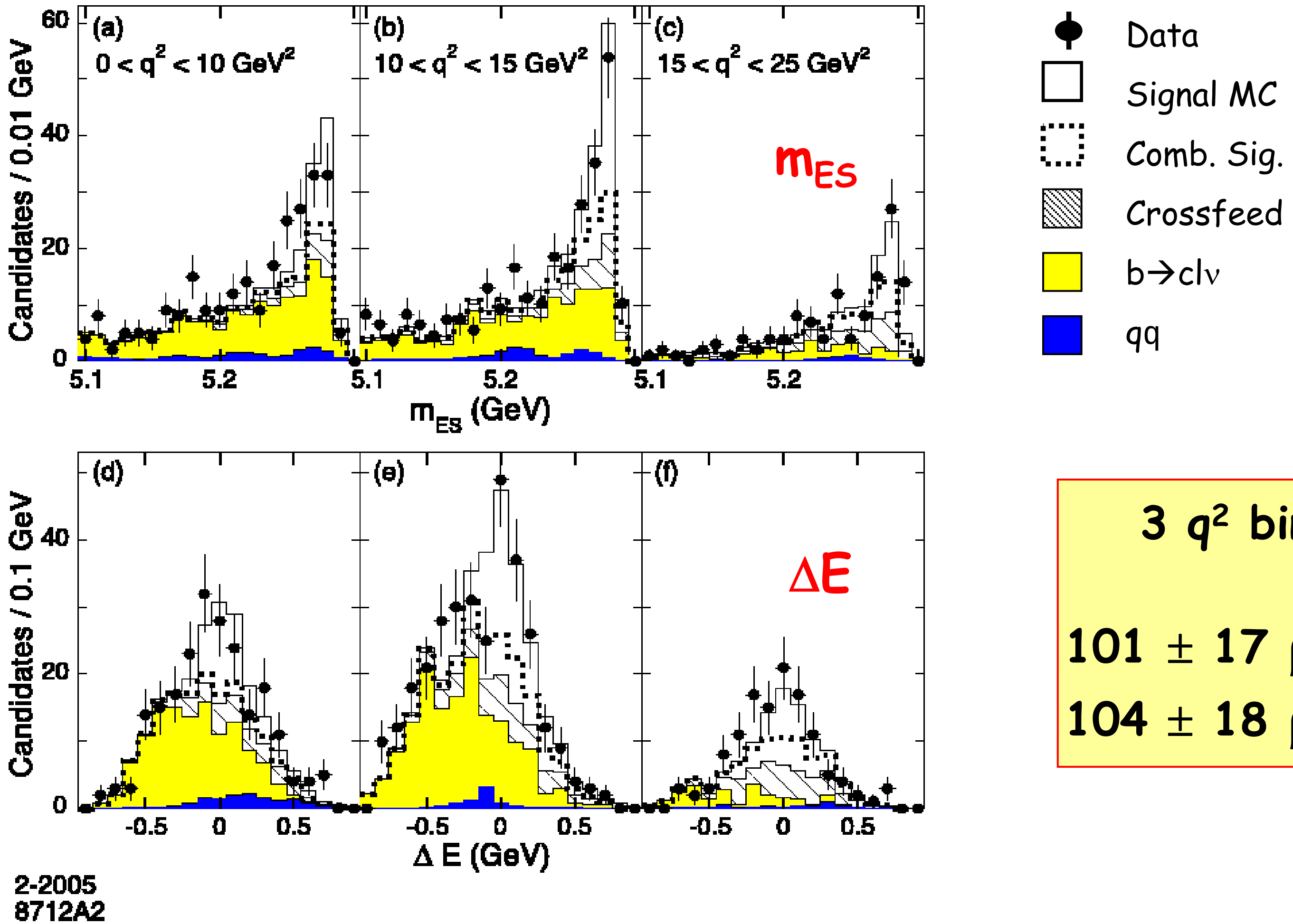
427 ± 68 $\pi^- \ell \nu$

147 ± 23 $\pi^0 \ell \nu$

m_{ES} and ΔE fit for $B \to \rho \ell \nu$

$\Gamma(B^0 \to \rho^- \ell \nu) = 2\,\Gamma(B^+ \to \rho^0 \ell \nu)$

82 fb^{-1}



3 q^2 bins

$101 \pm 17\ \rho^- \ell \nu$

$104 \pm 18\ \rho^0 \ell \nu$