BABAR 25th Anniversary Celebration

CKM BABAR achievements

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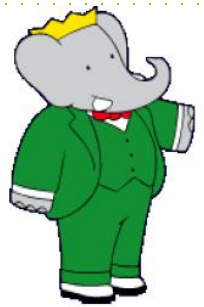
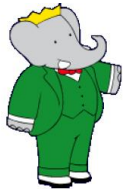


My story with BABAR

- Initial « Coup de foudre » for CP violation in B decays in 1987
  - May 1988 : My first BABAR talk : a presentation of the potential of future B factories during LAL Orsay bi-annual retreat
- 1988-1992 : Flirting around
  - PSI: a project of a symmetric machine was already well advanced(Ralf Eichler et al.) , toug dscussions to asymmetrize it
  - CERN in the ISR tunnel
  - DESY in the PETRA ring (« not enough ambitious for DESY »)
- 1993-1999 « The period of true passion
- October 1999 : Separation but we stay in good terms
  - Contribution to pipi/Kpi ratio measurement in 2000, BABAR computing financial crisis
- 2004-2005 : Happy return to home !
- 2007-2012 Leaving the « old lady » for a younger one ! (oh)
  - « The SuperB adventure »
- 2013-2018 : Now installed by yet another one (LHCb) but having an intermittent affair with BABAR (finish the update of my 2005 analysis)
- As often in real life, passion changes into tenderness after some 30 years!! But all such souvenirs stay for ever!



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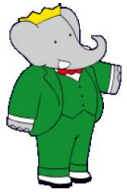
Many ways to define « achievements »

- New discoveries
- Improvment in physics knowledge
- Performances compared to initial predictions
- Performances compared to other experiments
- Publications and citations
- Prizes and awards
- Number of PhDs trained
- Tools and methods developped towards the goal

- I will cover only a few of these in rather arbitray manner. Apologies for the topics not covered or if the talk contents is not what was expected!



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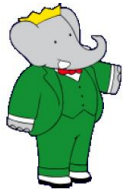
2008 Nobel prize !!

« CP violation in the B system is well described by the CKM mechanism »

Mister « K »

Mister « M »



2010 Dirac Prize, 2011 Franklin prize
Mister « C » Nicola Cabibbo

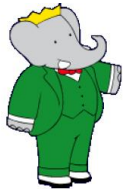
Panofsky Prizes

2005

Pier Oddone

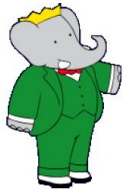
2016

Jonathan Dorfan and David Hitlin



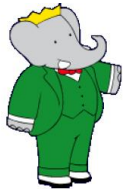
Grandiose initial goal

- CP violation in B decays will pave the way to new physics because
  - SM can not explain the baryon asymmetry in the universe
  - Many many ways for NP to change the predicted SM CP asymmetries in B decays
  - CP violation in B is a totally virgin field
- The hopes were very high but unfortunately, the « duck is still alive »

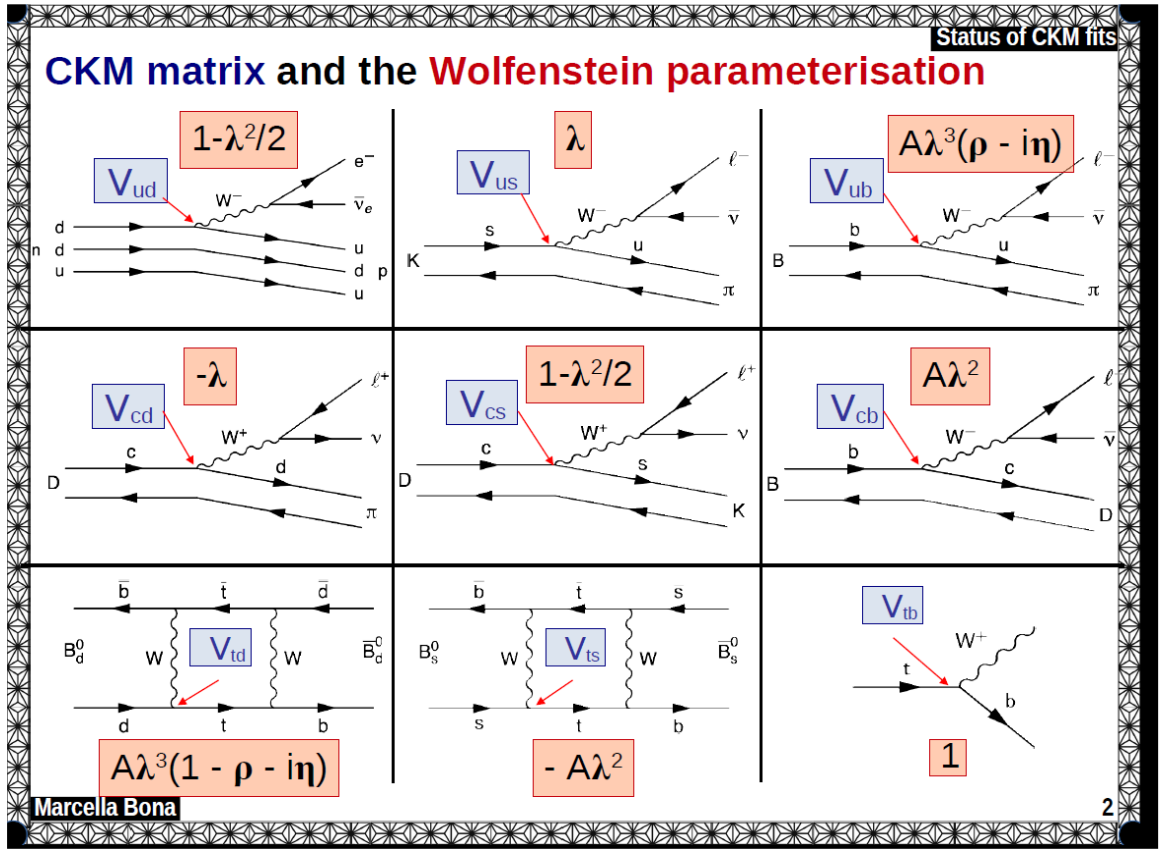


CKM physics constitued the core of the B factories program

- **BABAR physics book** (1998) :
  - 482 pages about CKM out of 815 physics related pages: 59%
- **Slightly less in the Physics of the B factories** (2015):
  - 236 pages out of 614 physics related pages ie 38 %
- Conclusions :
  - The physics program of the B factories proved to be much richer than originally anticipated
  - The common knowledge of CKM physics increased a lot in the HEP community over time

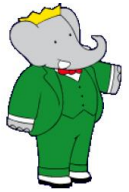


The Cabibbo-Kobayashi-Maskawa matrix is a 3x3 unitary matrix relating the quarks' flavor and mass eigen-states.



In the SM, the only source of CP violation is due to the imaginary part η

The unitary nature of the matrix allows to draw relationship between its parameters in a form of triangles



Each coefficient gives the amplitude for a quark to decay into another, through charge W emission or box diagrams

CKM matrix and Unitarity Triangle

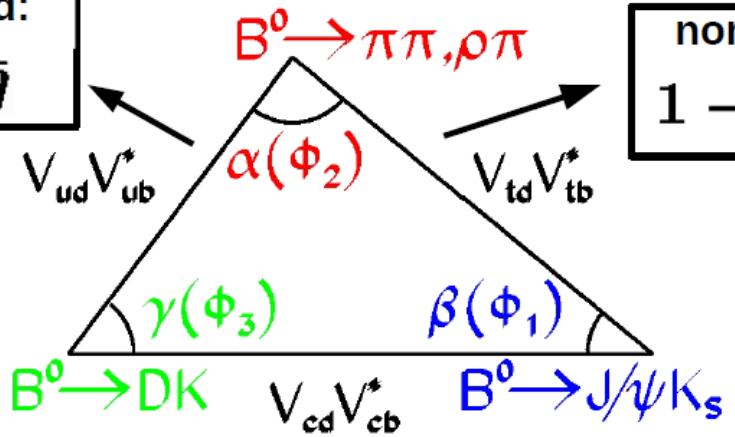
$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$

many observables functions of ρ and η: overconstraining

$$\alpha = \pi - \beta - \gamma$$

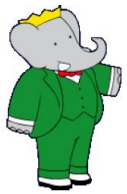
normalized: $\bar{\rho} + i\bar{\eta}$

normalized: $1 - \bar{\rho} - i\bar{\eta}$



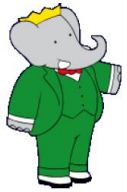
$$\gamma = atan\left(\frac{\bar{\eta}}{\bar{\rho}}\right)$$

$$\beta = atan\left(\frac{\bar{\eta}}{(1-\bar{\rho})}\right)$$



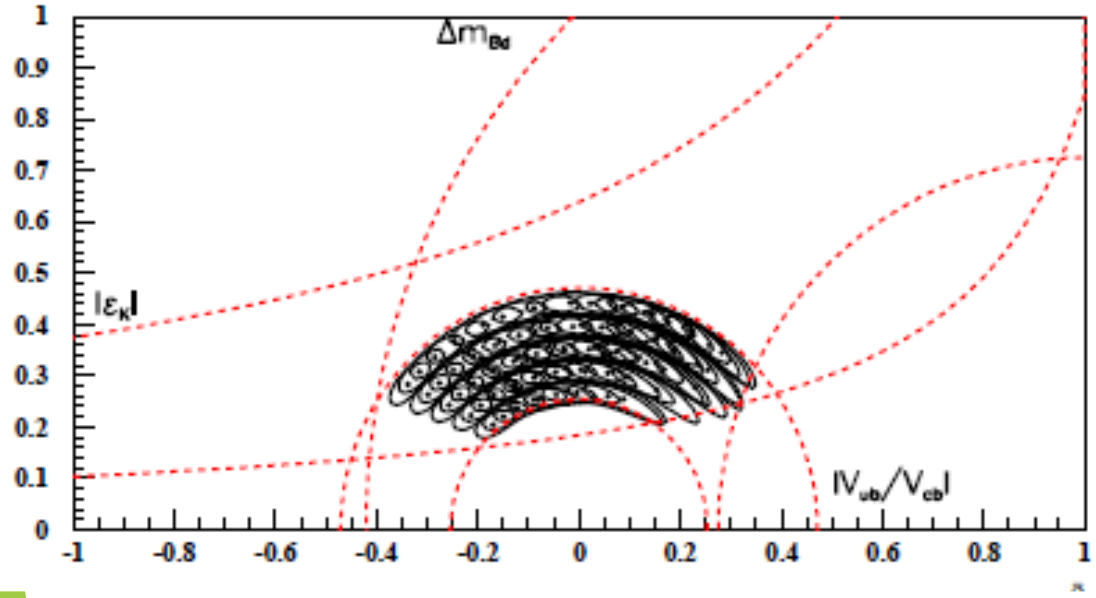
New Physics and CKM triangle

- In presence of new physics, the 3x3 CKM matrix can deviate from unitarity!!!
  - A simple case can be that the true matrix is 4x4
- The goal is then to OVERCONSTRAIN this triangle by measuring all sides and all angles, to find any deviation from SM prediction and any inconsistencies
- Angles are measured by CP violating quantities
- Sides are measured by characteristic B decay processes, or ratio of such processes.

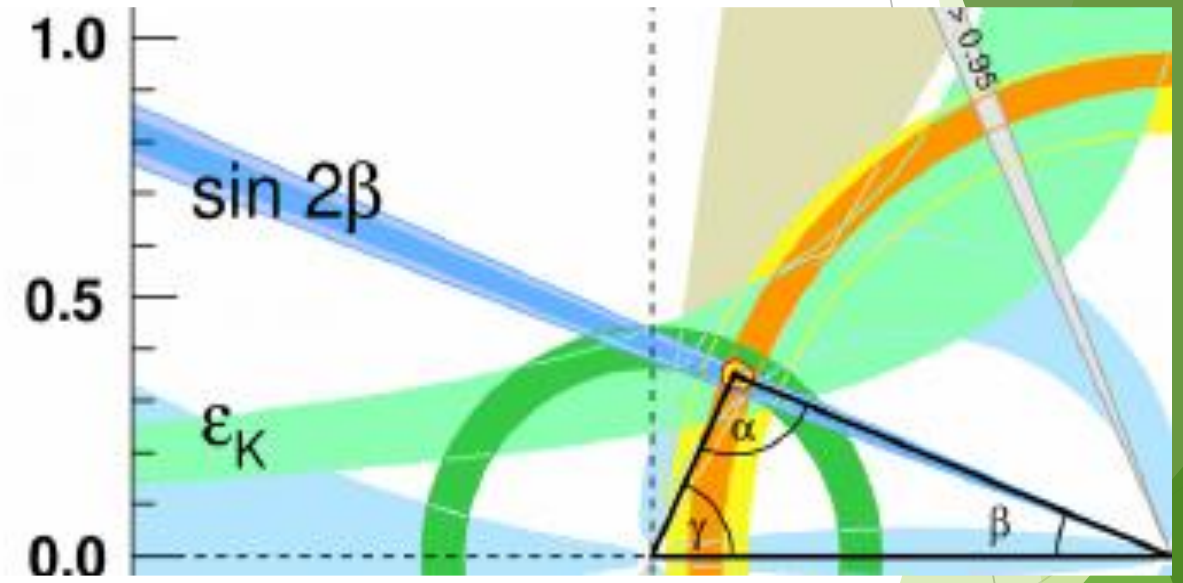


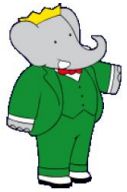
BABAR CKM achievements in a nutshell

BABAR Physics book , CKM knowledge in1998



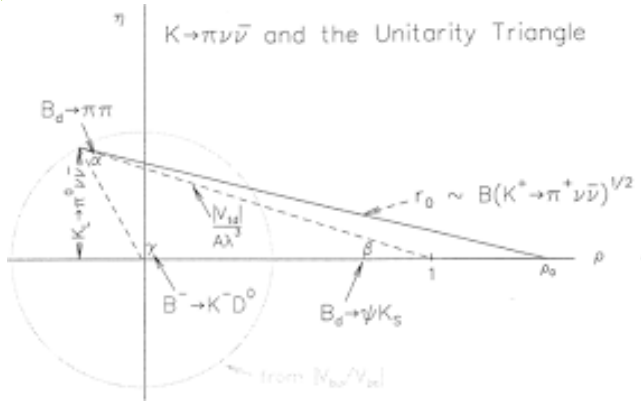
Physics of the B factories, CKM knowledge in 2015

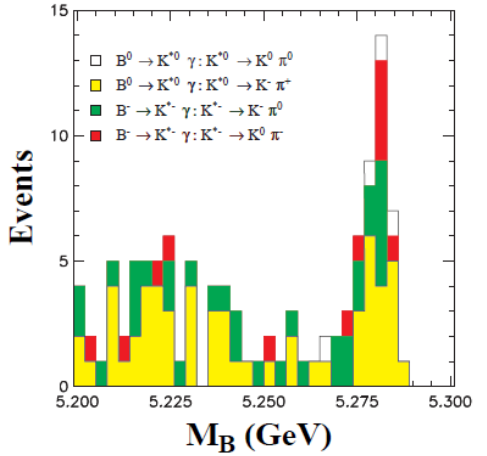


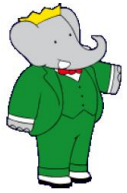


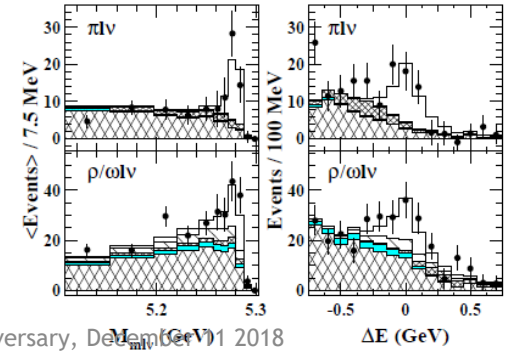
ICHEP 1996 (L. Gibbons)

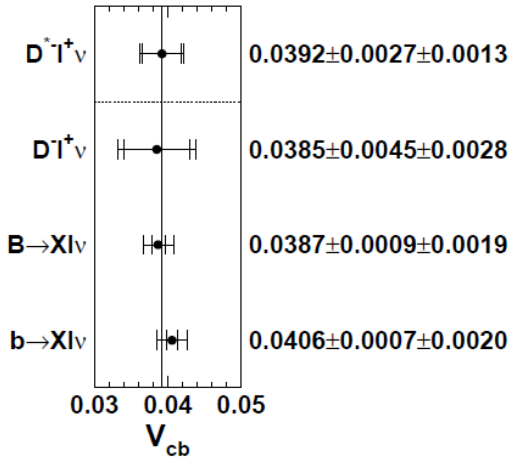
- Vcb OK
- Vub just starting LEP+ CLEO+Argus
- Vtd from K* gamma
- Unitarity triangle not drawn very often, elongated
- Problem with Fb and Bb constants

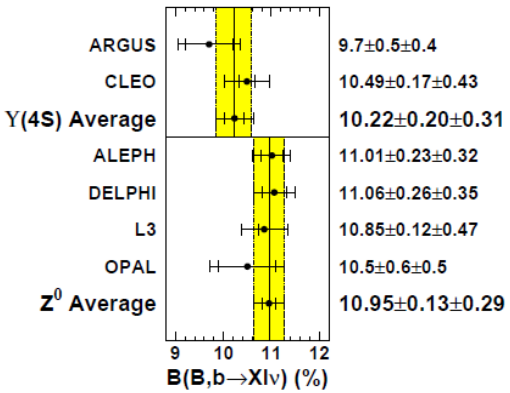






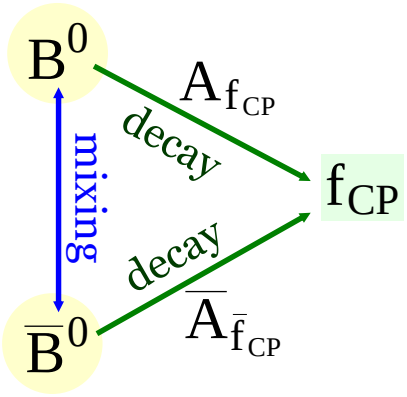






CP from Interference of Mixing and Decay

CP violation results from interference between decays with and without mixing



$$\lambda_{f_{CP}} = \underbrace{\frac{q}{p}}_{\text{mixing}} \cdot \underbrace{\frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}}}_{\text{decay}}$$

$$= |\lambda_{f_{CP}}| e^{-2i\varphi_{CP}}$$

Time-dependent CP asymmetry:

$$a_{f_{CP}}(t) = \frac{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) - \Gamma(B^0_{phys}(t) \to f_{CP})}{\Gamma(\bar{B}^0_{phys}(t) \to f_{CP}) + \Gamma(B^0_{phys}(t) \to f_{CP})}$$

$$= C_{f_{CP}} \cos(\Delta m_d t) + S_{f_{CP}} \sin(\Delta m_d t)$$

$$C_{f_{CP}} = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2}$$

$$S_{f_{CP}} = \frac{-2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}$$

$B \to J/\psi K_{S,L}$: dominated by single decay amplitude

$$\lambda_{J/\psi K_S} \equiv \frac{q}{p}\frac{\bar{A}_{J/\psi K_S}}{A_{J/\psi K_S}} = -\underbrace{\frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}}_{B^0-\bar{B}^0 \text{ mixing}} \underbrace{\frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{cs}}}_{\text{decay}} \underbrace{\frac{V_{cs} V_{cd}^*}{V_{cs}^* V_{cd}}}_{K^0-\bar{K}^0 \text{ mixing}}$$

$$S_{J/\psi K^0_{S,L}} = -\eta_{J/\psi K^0_{S,L}} \sin 2\beta$$

$$C_{J/\psi K^0_{S,L}} = 0$$

$\Rightarrow$ Theoretically clean way (~1%) to measure $\sin 2\beta$

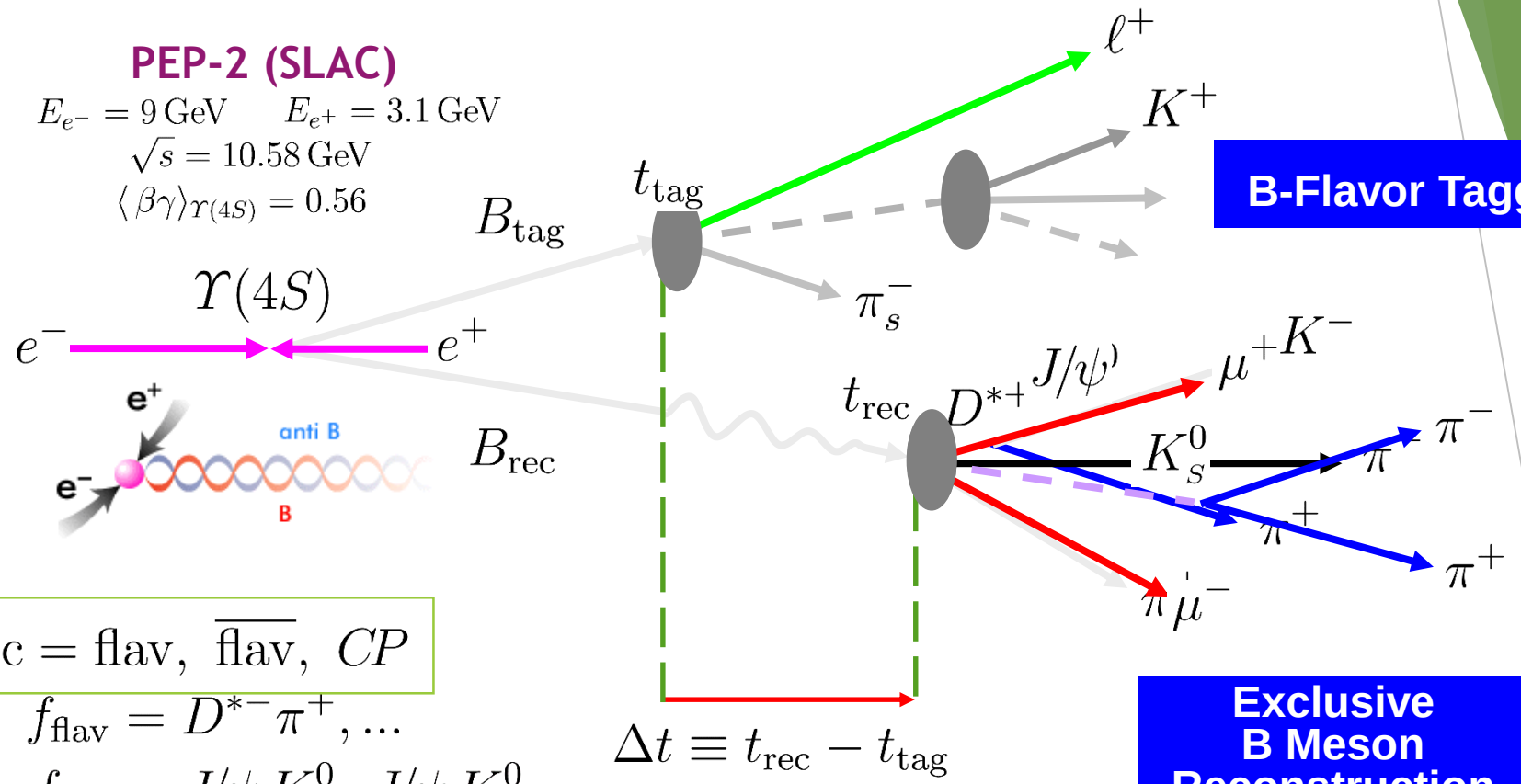
Ingredients of the Measurements

PEP-2 (SLAC)

$E_{e^-} = 9\,\text{GeV}$ $E_{e^+} = 3.1\,\text{GeV}$

$\sqrt{s} = 10.58\,\text{GeV}$

$\langle \beta\gamma \rangle_{\Upsilon(4S)} = 0.56$



B-Flavor Tagging

$$\text{rec} = \text{flav},\ \overline{\text{flav}},\ CP$$

$$f_{\text{flav}} = D^{*-}\pi^+, \ldots$$

$$f_{CP} = J/\psi\, K_S^0,\ J/\psi\, K_L^0, \ldots$$

$$\text{tag} = B^0,\ \overline{B}^0$$

$$f_{B^0} = X\ell^+\nu,\ XK^+,\ X\pi_s^-, \ldots$$

$$\Delta t \equiv t_{\text{rec}} - t_{\text{tag}}$$

Exclusive B Meson Reconstruction

Vertexing & Time Difference Determination

$$\Delta t \approx \Delta z / c \langle \beta\gamma \rangle_{\Upsilon(4S)}$$

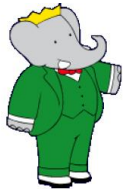
$$\langle \Delta z \rangle_{B\bar{B}} \approx 260\,\mu\text{m}$$

f_{flav}: determine Δt resolution, mistag rates w, (Δm_d, τ_B, ...)

f_{CP}: measure CP asymmetries

History of the sin2β measurement

- May 26 , 1999 First Collisions in BABAR
- July 31, 2000 Osaka, first measurement of sin2β presented in Osaka at ICHEP2000 ! sin2β=0.12±0.37±0.09
- In February 21, the first publication (in the same journal as BELLE) sin2β=0.12±0.37±0.09
- July 6 2001: sin2β=0.59±0.14(stat)±0.05(syst) (32 fb^{-1}) Phys.Rev.Lett.87:091801,2001
  - **This result establishes CP violation in the B system at 4.1 σ level (1159 citations)**
- **Belle follows (July 23) with 29 fb^{-1} ;** Phys.Rev.Lett.87(9):091802 (1160 citations)
- $\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$.



BABAR-PUB-01/01
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hep-ex/0102030

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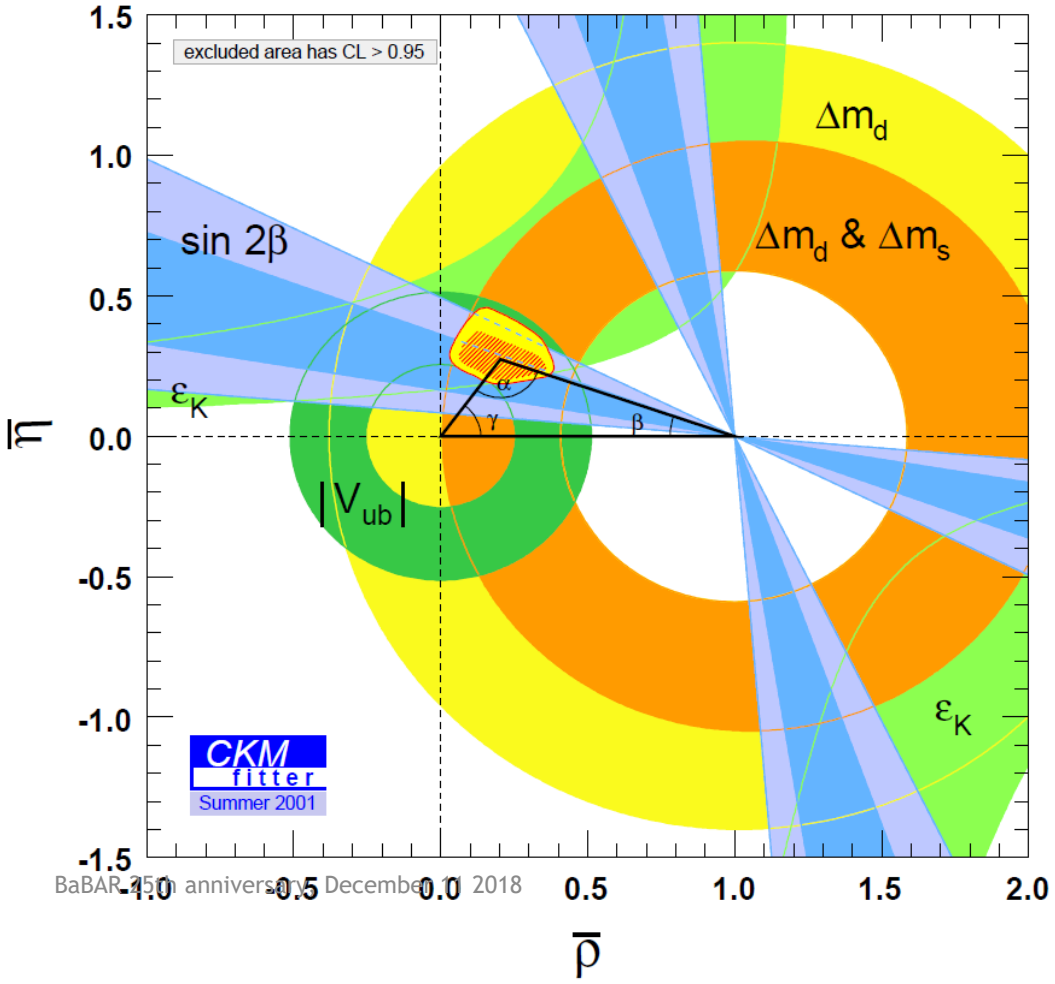
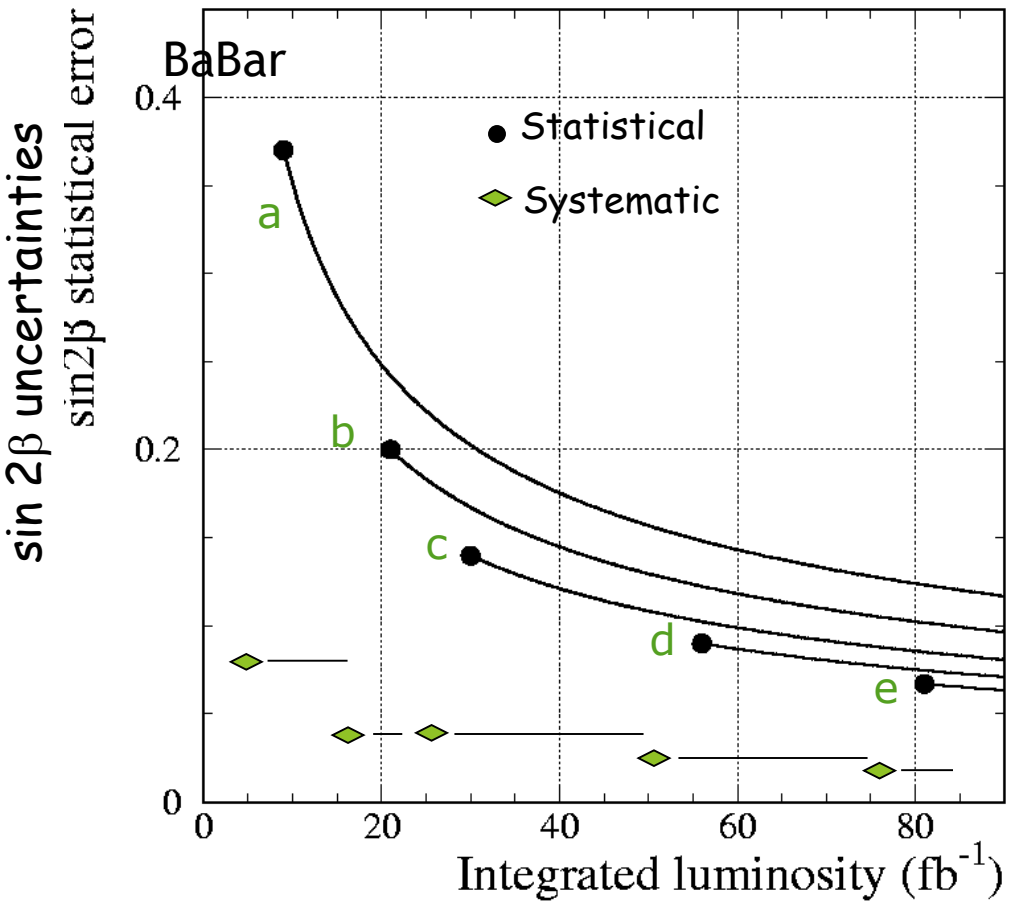
Unitarity triangle in 2001



Extrapolation: Some History…



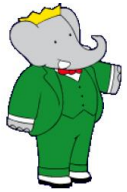
a) "Osaka 2000" measurement. (hep-ex/0008048).
   - Only J/ψ K_S and ψ(2s) K_S.

b) 1st Paper (PRL **86** (2001) 2515).
   - Added J/ψ K_L.
   - Simultaneous sin2β and mixing fit.

c) 2nd Paper (PRL **87** (2001) 091801).
   - Added J/ψ K^{*0} and χ_c K_S.
   - Better vertexing.
   - Better SVT alignment and higher K_S efficiency for new data.

d) Winter 2002 (hep-ex/0203007).
   - Improved event selection.
   - Reprocessed 1st 20 fb^{-1}.

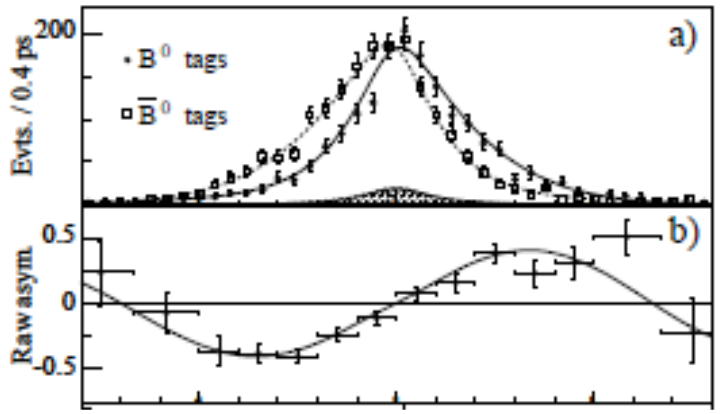
e) 3rd Paper (PRL **89** (2002) 201802)
   - Improved flavor tagging.
   - One more CP mode: $\eta_c K_S$.

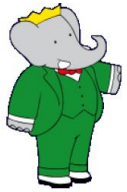


So far seem to do better than extrapolations predict

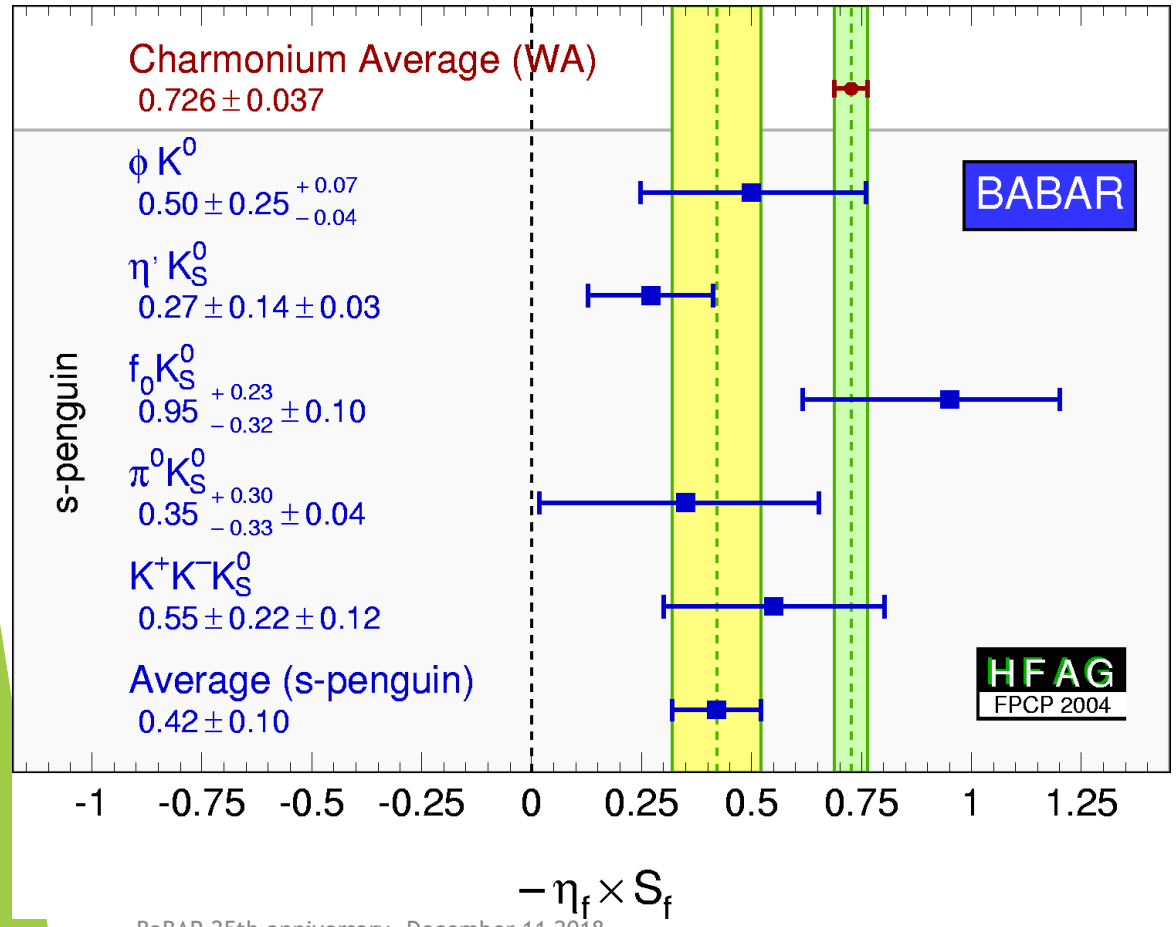
2004 a important year for CP physics

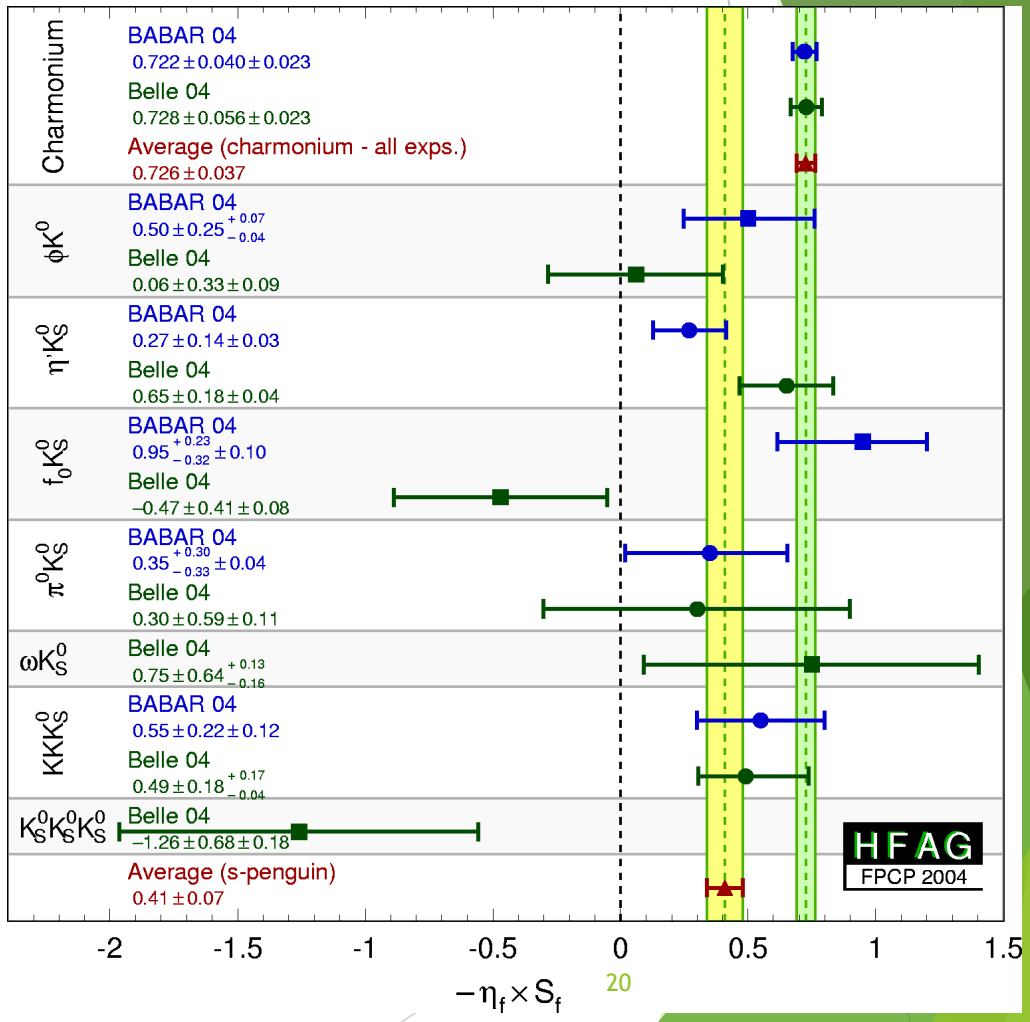
- Publication of the first REALLY high statistics sin2β paper based on 223 fb^{-1} (the summer 2001 publication was 32 fb^{-1} !)





The sin2β saga in b➔s transitions

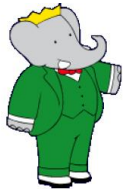


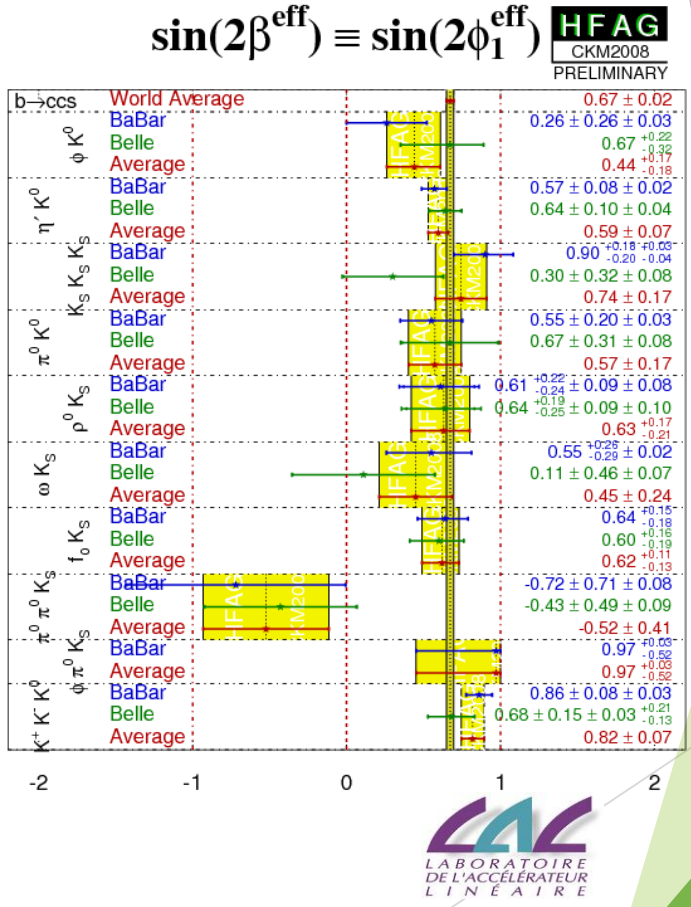


4 years of hope and fears…..

- Summer 2004: 3.8 σ between sin2b (b->c) and sin2b (b->s)
- Summer 2005: 2.8 σ
- Summer 2006: 2.6 σ
- Summer 2007: 2.2 σ
- Summer 2008: 0.7 σ

- SM is tough to beat….
- The 5 σ criterium is there for a reason!
- Will history repeat itself with Lepton Non Universality ?
  Similar pattern of several « semi-strong » indications apparently all going in the same direction





BABAR performances versus predicted and versus other experiments

- General assumption (called Schneider's theorem in LHCb):
  - Initial predictions always rather optimistic (simplified simulations, no backgrounds, several guestimates,etc)
  - Experimentalists's creativity always allows to overperform
  - As a result the initial predictions are very good!

Also quite true here !!

	Predicted(30 fb^{-1}) (Untagged)	BABAR Achieved (424 fb^{-1})	Ratio per fb^{-1}	BELLE Achieved(770 fb^{-1})	Ratio per fb^{-1}
#$J/\psi K^{\circ}(\pi^+\pi^-)$	660	6750	0,96	13040	0,94
Tagging	0,3	0,331	1,1	0,301	1,10
$\Delta(\sin 2\beta)$	0,12	0,036	0,89	0,029	1,09
#$J/\psi K_L$	650	5813	0,84	15937	0,66
$\Delta(\sin 2\beta)$	0,09	0,028	0,85	0,023	1,11

A very elegant and important measurement performed by BABAR: T violation

SYMMETRIES IN THE LAWS OF PHYSICS

- In Quantum Mechanics, there is an operator U_{CP} implementing the CP-symmetry acting on the states of the physical system, such that

$$U_C\ Q\ U_C^+ = -Q,\ U_P\ \vec{r}\ U_P^+ = -\vec{r},\ U_P\ \vec{p}\ U_P^+ = -\vec{p},\ U_P\ \vec{s}\ U_P^+ = \vec{s}$$

The operator U_{CP} is an observable with Conservation Laws: $K_L \rightarrow \pi\,\pi$

- The operator U_T implementing T-symmetry is such that

$$U_T\ \vec{r}\ U_T^+ = \vec{r},\ U_T\ \vec{p}\ U_T^+ = -\vec{p},\ U_T \vec{s} U_T^+ = -\vec{s}$$

By considering the commutator $[r_j, p_k] = i\hbar\delta_{jk} I$ **the operator U_T must be**

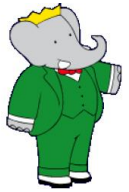
ANTI-UNITARY: UNITARY- for conserving probabilities, ANTI- for complex conjugation

ANTIUNITARITY introduces many intriguing subtleties:

$$S_{i\to f} \xrightarrow{T} S_{U_T f \to U_T i}$$

T - Violation means Asymmetry under Interchange in $\rightleftarrows$ out states

- **Similarly for ANTIUNITARY CPT which needs not only in $\leftrightarrows$ out, but also $\mathrm{i,f} \to \bar{\mathrm{f}}, \bar{\mathrm{i}}$, in transitions.**



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WHAT IS T-TRANSFORMATION EXPERIMENTALLY ?

The problem is in the preparation and filtering of the appropriate initial and final meson states for a T-test

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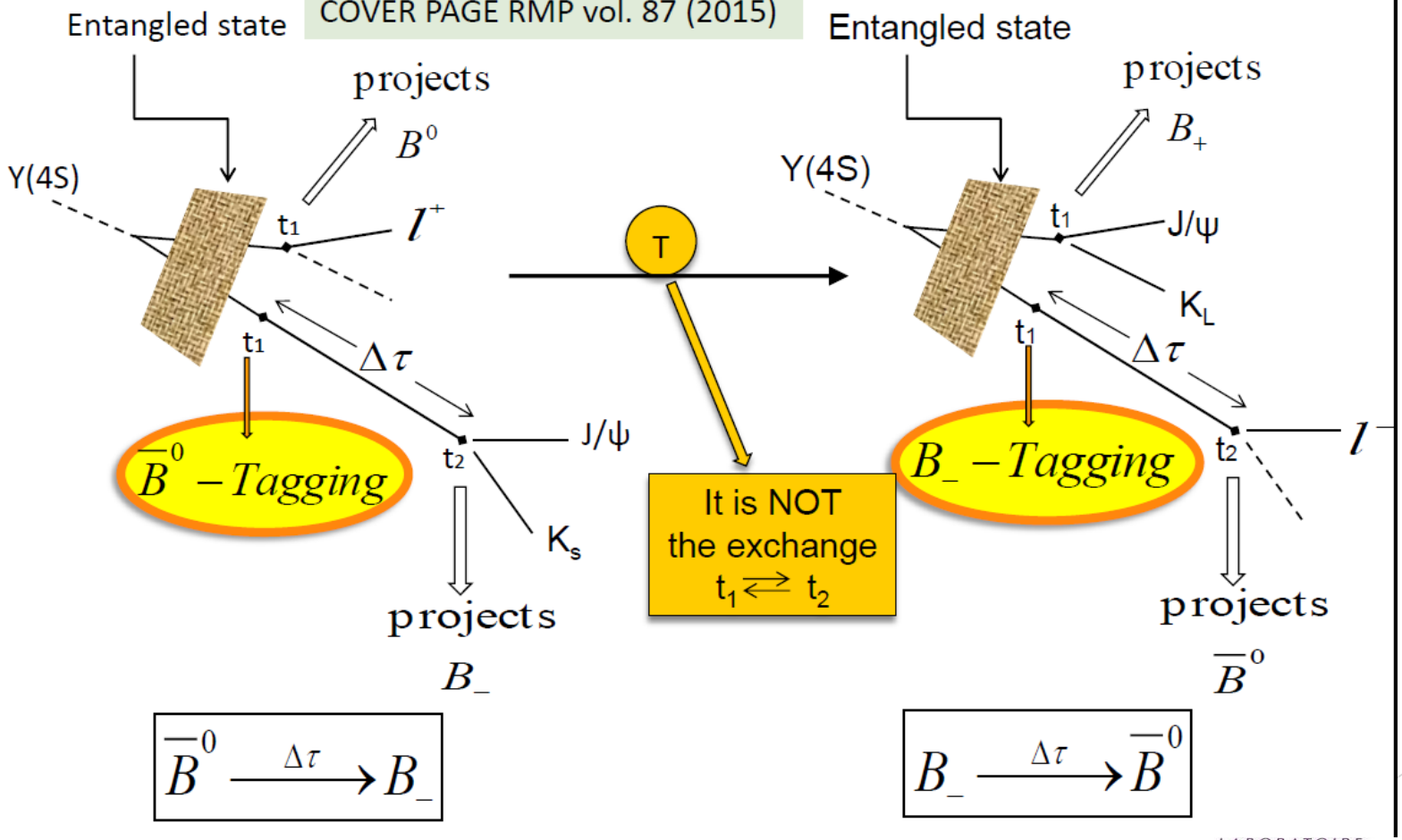

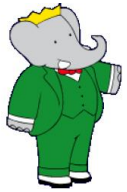

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GENUINE T, CP, CPT ASYMMETRIES

J.B., F. Botella, M. Nebot, JHEP 1606 (2016) 100

- 3 different Observables ΔC_h, ΔC_c, ΔS_c for each symmetry

9 Asymmetry parameters with different information content

Using BABAR data PRL 2012, we obtain

$$\Delta S_c^T = -0.687 \pm 0.020\,; \quad \Delta S_c^{CP} = -0.680 \pm 0.021$$

Impressive separate evidence of TRV, CPV

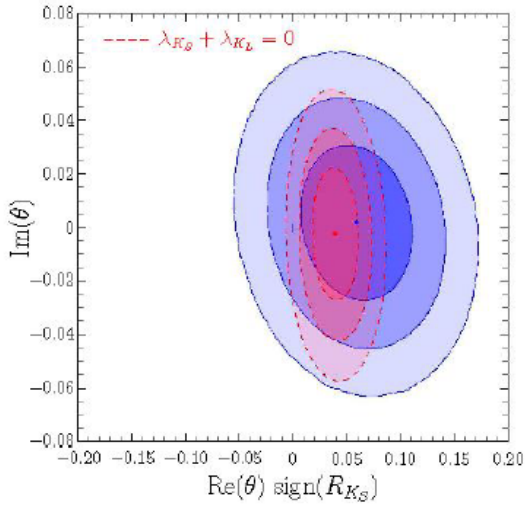
- "Intriguing" 2σ - effect for CPTV

$$\Delta C_c^{CPT} = -\Delta C_h^{CPT} = (2.7 \pm 1.5) \cdot 10^{-2}$$

interpreted in the evolution Hamiltonian

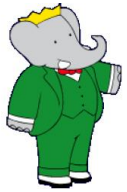
it should be seen in $\Delta C_c^{CP} = (5.0 \pm 1.5) \cdot 10^{-2}$

at LHCb: **Unorthodox CPV term!**



- Analysis assuming perfect ENTANGLEMENT

The two Time-Ordered Decays **f, g** satisfy



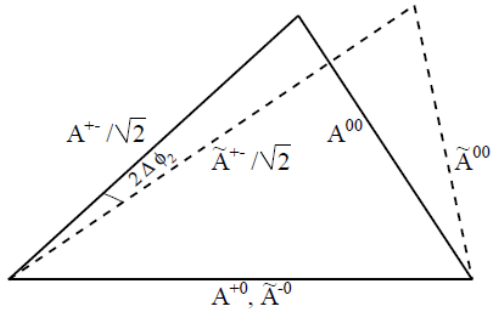
$C_h(f,g) = C_h(g,f)$; $C_c(f,g) = C_c(g,f)$; $S_c(f,g) = -S_c(g,f)$

sin2α measurements

- This angle is measured by the same method with b->u transitions
- The initial favorite mode B ➔ $\pi\pi$, supplemented by more complex decays

$\pi\pi\pi^\circ$, and $\pi\pi\pi\pi$ decays.

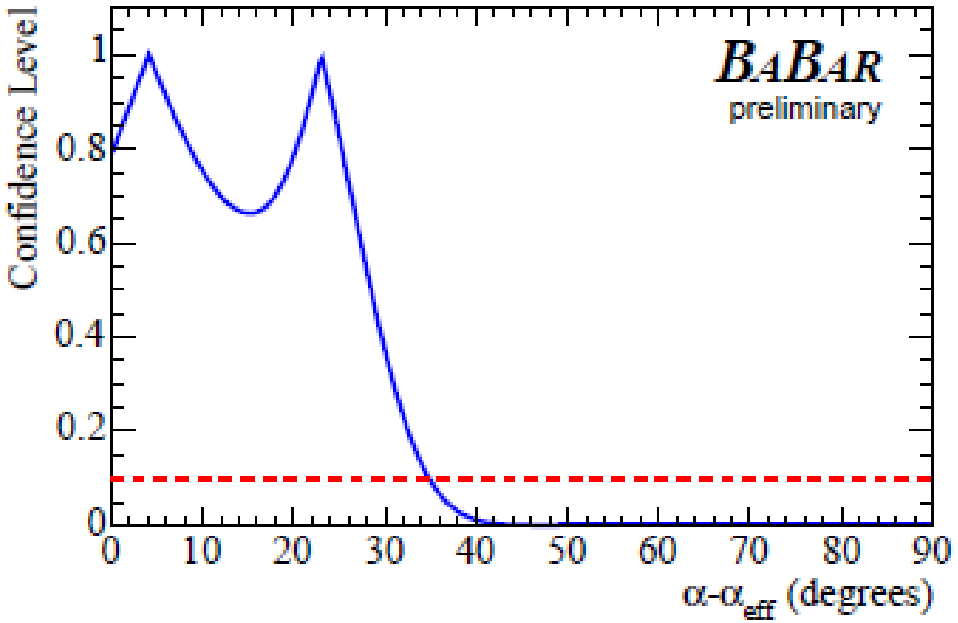
- It was known since the beginning that PENGUIN POLLUTION could make the measured angle differ from true α.
- Several delicate constructions were proposed to control this pollution based on measurements of the related channels (eg B ➔$\pi^\circ\pi^\circ$)
- The amount of this pollution depends of the modes and of the ratios of branching fractions.
- Babar mesured the channel B->$\rho\rho$ in 2004, showing that two-body channels was not the best.



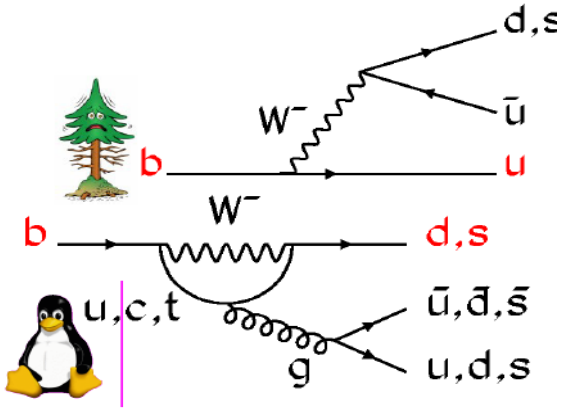
Influence of the value BR(B →π°π°) on α - α_{eff}

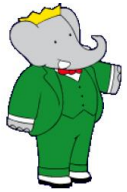
$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.17 \pm 0.32 \pm 0.10) \times 10^{-6} \ , \ C_{\pi^0\pi^0} = -0.12 \pm 0.56 \pm 0.06 \ ,$$

arXiv:hep-ex/0408081

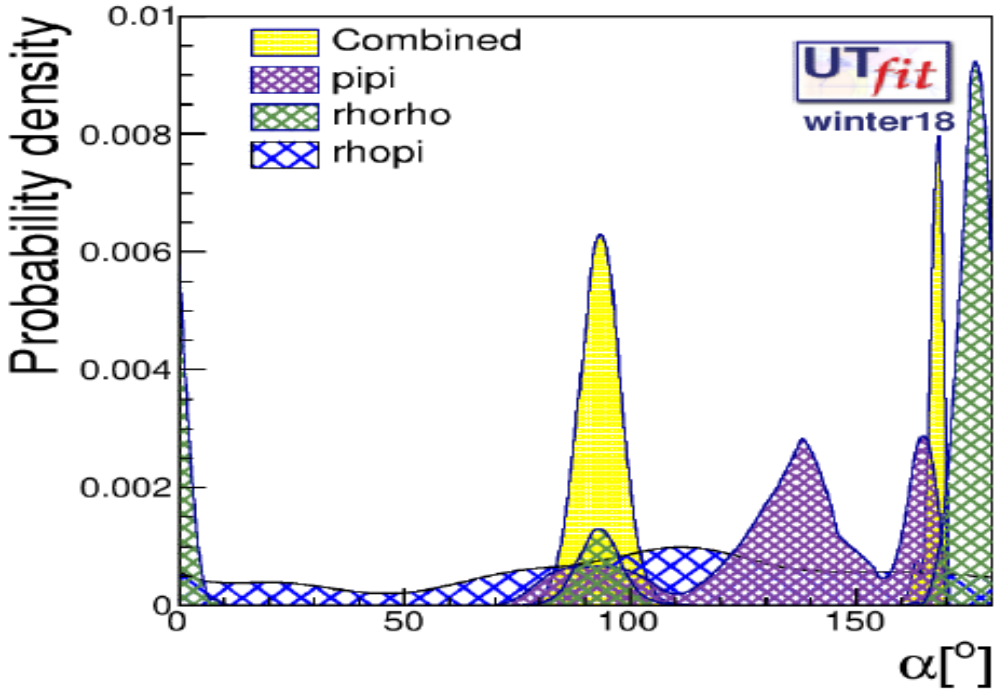


A precise determination of α with the ππ mode is doomed





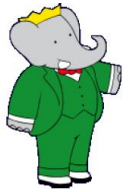
The ρρ channel is the best



p-value

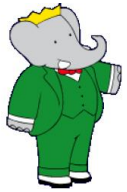
combined SM: (93.3 ± 5.6)°

UTfit prediction: (90.1 ± 2.2)°



BABAR $\sin 2\alpha_{eff}$ performances versus predicted and versus other experiments

	Predicted (30 fb1)(Untagged)	BABAR Achieved (424 fb-1)	Ratio per fb-1	BELLE Achieved(770 fb-1)	Ratio per fb-1
$\#\pi^+\pi^-$	380	1394	0,35	2964	0,86
#Kp	470	5410	1,09	9205	1,07
$\Delta(\sin 2\alpha)$	0,29	0,1	0,77	0,08	1,08



Observation of direct CPV violation. The Kπ puzzle

- In 2004, direct CPV violation was observed by BABAR. The branching fraction BR($B^0 \to K^-\pi^+$) is different from BR($\bar{B}^0 \to K^+\pi^-$) , and BR($B^+ \to K^+\pi^0$) is different from BR($B^- \to K^-\pi^0$)
  - By far, the simplest way to distinguish matter from antimatter. Very handy before shaking hands with an alien!!!
- But the two asymmetries do not agree with other as they should under usual isopin symmetry

	$B^0 \to K^+\pi^-$	$B^+ \to K^+\pi^0$	$B^+ \to K^0\pi^+$	$B^0 \to K^0\pi^0$
Belle	$-0.094 \pm 0.018 \pm 0.008$	$+0.07 \pm 0.03 \pm 0.01$	$+0.03 \pm 0.03 \pm 0.01$	$+0.14 \pm 0.13 \pm 0.06$
BABAR	$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$+0.030 \pm 0.039 \pm 0.010$	$-0.029 \pm 0.039 \pm 0.010$	$-0.13 \pm 0.13 \pm 0.03$
CDF	$-0.086 \pm 0.023 \pm 0.009$	–	–	–
CLEO	$-0.04 \pm 0.16 \pm 0.02$	$-0.29 \pm 0.23 \pm 0.02$	$+0.18 \pm 0.24 \pm 0.02$	–
Average	-0.098 ± 0.012	$+0.050 \pm 0.025$	$+0.009 \pm 0.025$	-0.01 ± 0.10

Table 3: Summary of $\mathcal{A}_{CP}$ measurements by Belle, BABAR, CLEO and CDF.

Observation of direction CP violation in Kπ decays

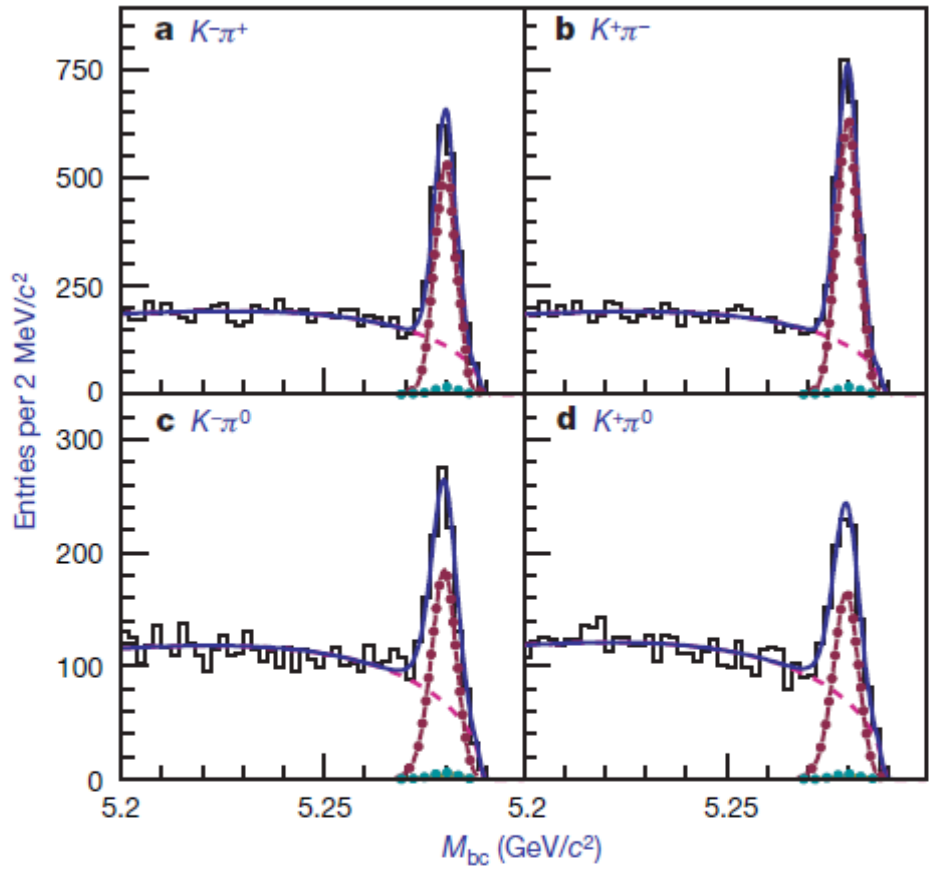
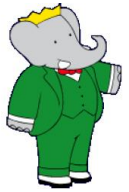


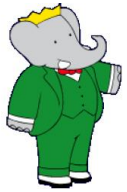
Figure 17.4.5. The direct *CP* violation in $B \to K^{\mp}\pi^{\pm}$ (top) and $B^{\pm} \to K^{\pm}\pi^0$ (bottom) can be seen in the difference between the heights of signal distributions (red/points) in the left and right plots (Lin, 2008).

The future lies in the check of well designed sum rules relating all these parameters: Another nice challenge for LHCb and BELLE-II!

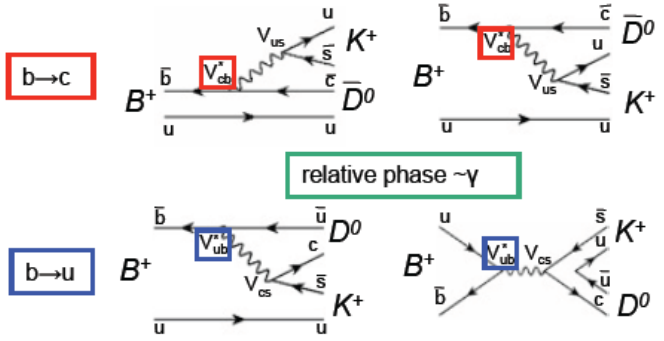


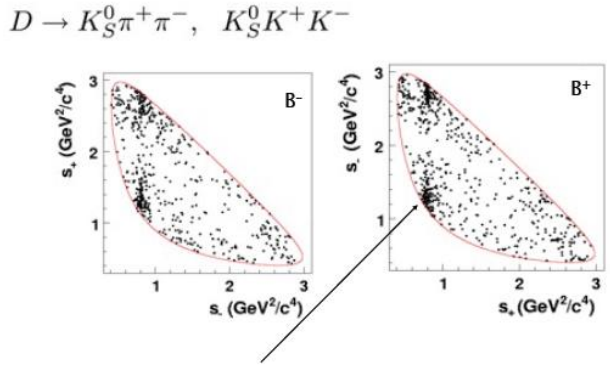
γ measurements

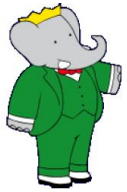
- There are several methods used to measure γ and all of them have been successfully pionereed at BABAR such as B->DK, Dalitz analysis of B->D(K0pipi) K
- However it is fair to say that the precisions that was reached by BABAR and BELLE were not sufficient to constraint the unitarity triangle.
- LHCb and BELLE-II will reach the necessary precision to put this constraint into action
- This will be quite interesting since γ is in principle very largely immune to new physics, so comparing between γ and 180°-α-β will be quite meaningful

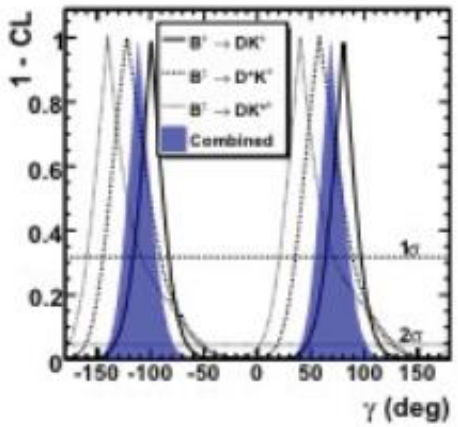


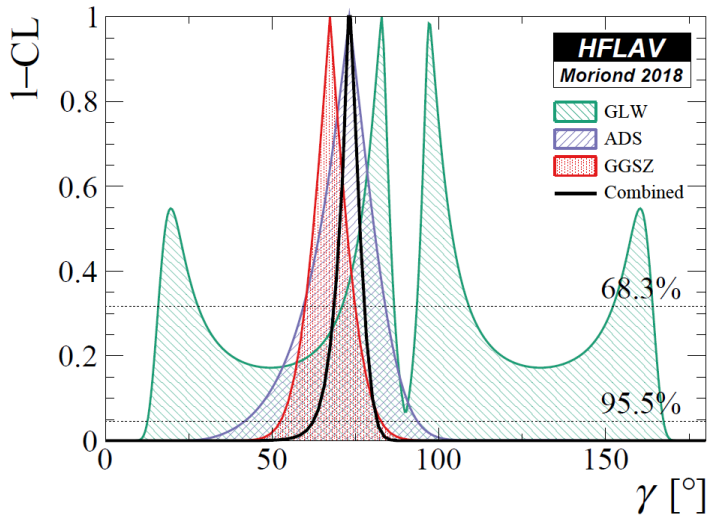
An illustration of BABAR measurements (CKM 2012) and present average (HFAG2018)











A recent measurement using BABAR+BELLE regarding CP violation

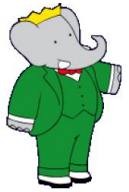
Overview of Combined *BABAR*+Belle Measurements

1. $B^0 \to D^{(*)}_{CP} h^0$ with two-body D meson decays to *CP* eigenstates:
   - Time-dependent *CP* violation measurement of $\sin(2\beta)$
   - Theoretically clean mode, could provide new $\sin(2\beta)$ SM reference

   Result: - First observation of *CP* violation in this mode
   - Published in PRL [PRL **115**, 121604 (2015)]

2. $B^0 \to D^{(*)} h^0$ with the three-body D meson $D \to K^0_S \pi^+ \pi^-$ decay:
   - Time-dependent Dalitz plot analysis to measure $\cos(2\beta)$
   - Make full use of the joint approach by applying common assumptions and the same model simultaneously to the *BABAR* and Belle data sets

   Result: - Most precise measurement of $\cos(2\beta)$
   - First evidence for $\cos(2\beta) > 0$
   - Exclusion of multifold solutions of the Unitarity Triangle
   - Joint PRL and PRD publications have been submitted
   [arXiv:1804.06152, arXiv:1804.06153]



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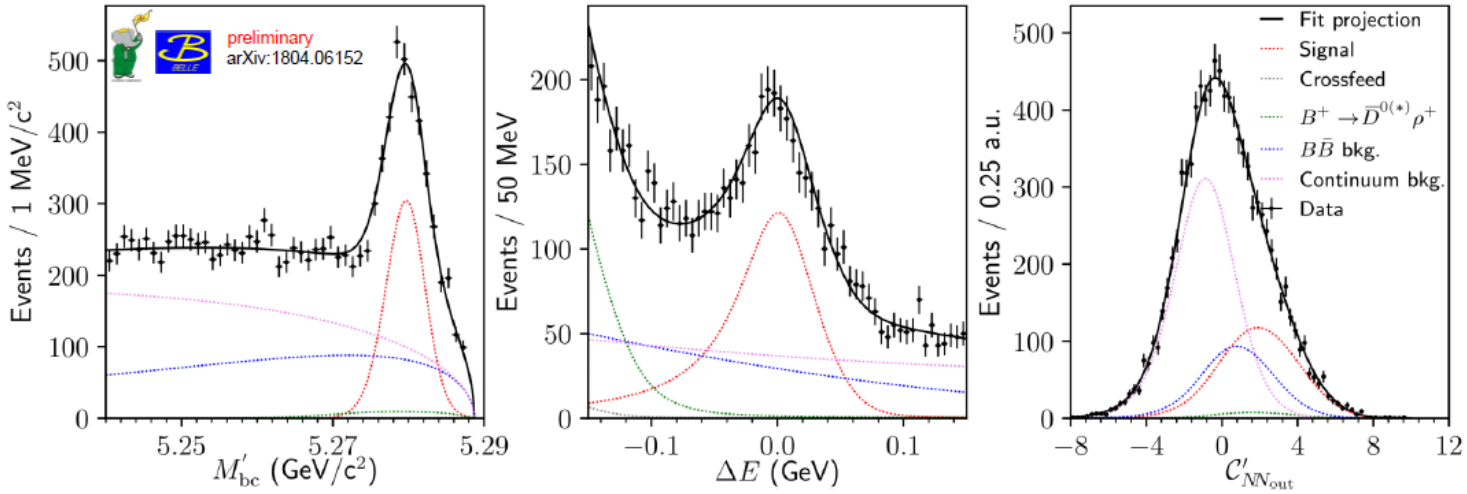
2. Combined *BABAR*+Belle Analysis: cos(2β) from $B^0 \to D^{(*)}h^0$

- Reconstruct $B^0 \to D^{(*)}h^0$ with h^0 in $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma, \pi^+\pi^-\pi^0$ and $\omega \to \pi^+\pi^-\pi^0$

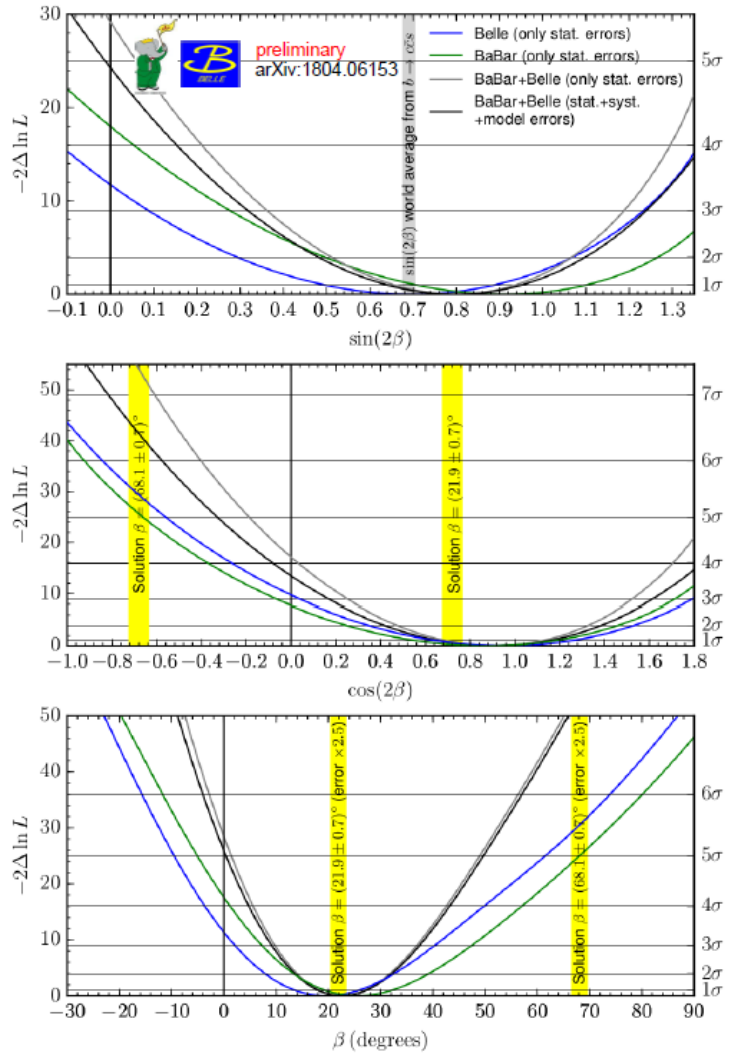
  $D \to K^0_S\pi^+\pi^-$ and $D^{*0} \to D\pi^0$.

- In total, 5 B^0 decay modes are reconstructed.
- $e^+e^- \to q\bar{q}$ $(q \in \{u, d, s, c\})$ continuum background is identified by neural networks.
- Extract signal by 3D fit of beam-constr. mass M'_{bc}, energy-difference ΔE and NN'_{out}.



BABAR: 1129 ± 48 signal events
Belle: 1567 ± 56 signal events

2. Combined *BABAR*+Belle Analysis: cos(2β) from $B^0 \to D^{(*)}h^0$



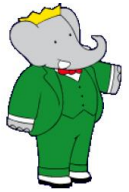
- Single most precise measurement of $\cos(2\beta)$
- First evidence for $\cos(2\beta) > 0$ (3.7σ)
- Direct exclusion of the 2nd solution

  $$\pi/2 - \beta = (68.1 \pm 0.7)^\circ$$

  of the CKM Unitarity Triangle (7.3σ)

  → Reduction of the trigonometric ambiguity of the CKM Unitarity Triangle
- Exclusion of $\beta = 0^\circ$ (5.1σ)

  → Observation of CP violation in $B^0 \to D^{(*)}h^0$ decays
- Joint PRL (arXiv:1804.06152) and PRD (arXiv:1804.06153) papers have been submitted.



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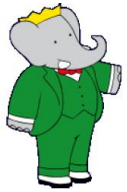
V_{ub} and V_{cb}

- These CKM parametrs are measured with b➔c and b➔u semileptonic decays: Dlν or πlν
- These have large branching fractions and are easy to identify at first sight. However progress has been slow in this area for several reasons:
  - For V_{cb} , hadronic uncertainties and extrapolation uncertainties to the full phase space
  - For $V_{ub,}$ same plus visibility in a even more limited region of phase space because of V_{cb} related events.
- Both measurements systematically dominated since 2001
- Difficult to separate BABAR/BELLE/theory progress over the years

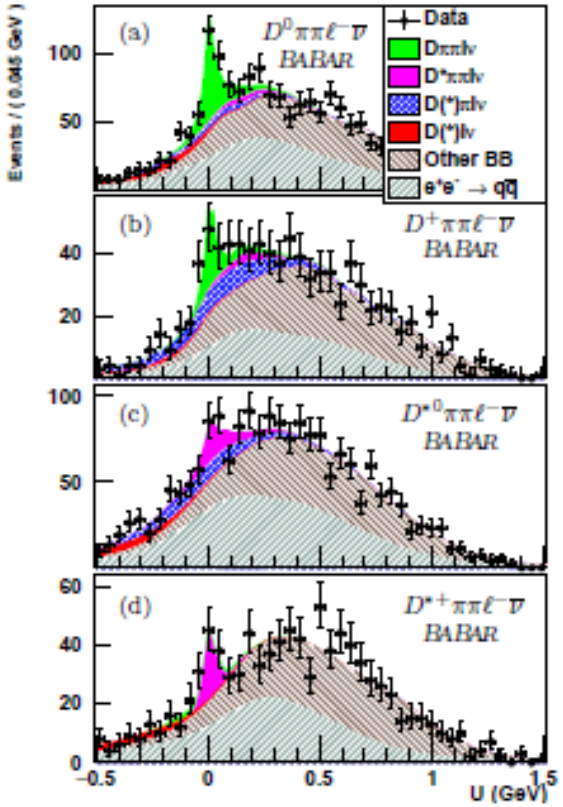


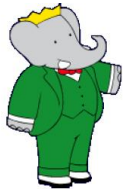
Semileptonic decays with extra pions

- One BABAR significant contribution was the observation of modes with one or two extra pions [Phys.Rev.Lett. 116 041801 (2016)]

These high multiplicity modes are important to

- Close the gap between inclusive and exclusive BRs
- Quantify the D** feed-down for $D^*\tau\nu$ measurements





Vub/Vcb present status

Status of CKM fits

V_{cb} and V_{ub} from semileptonic B decays

UTfit

$|V_{cb}|$ *(excl)* = $(38.9 \pm 0.6)\ 10^{-3}$

$|V_{cb}|$ *(incl)* = $(42.19 \pm 0.78)\ 10^{-3}$

~3.3σ discrepancy

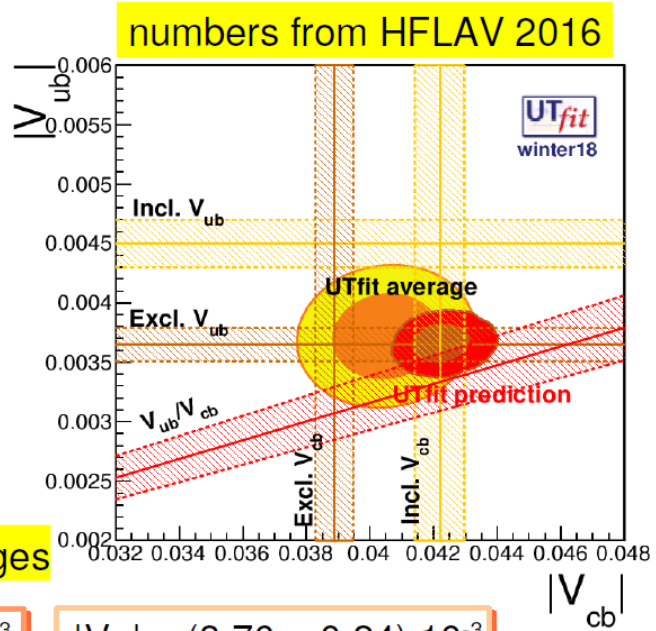
$|V_{ub}|$ *(excl)* = $(3.65 \pm 0.14)\ 10^{-3}$

$|V_{ub}|$ *(incl)* = $(4.50 \pm 0.20)\ 10^{-3}$

~3.4σ discrepancy

$|V_{ub} / V_{cb}|$ *(LHCb)* = $(7.9 \pm 0.6)\ 10^{-2}$

numbers from HFLAV 2016



2D D'Agostini skeptical averages

$|V_{cb}| = (42.14 \pm 0.97)\ 10^{-3}$

uncertainty ~ 2.4%

$|V_{ub}| = (3.76 \pm 0.24)\ 10^{-3}$

uncertainty ~ 6.4%

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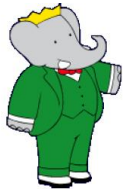


Status of CKM fits

V_{cb} and V_{ub}

CKM fitter

new average — Belle B → D* lν combined (tagged and untagged), BGL
Belle and Babar B → Dlν combined, BGL:

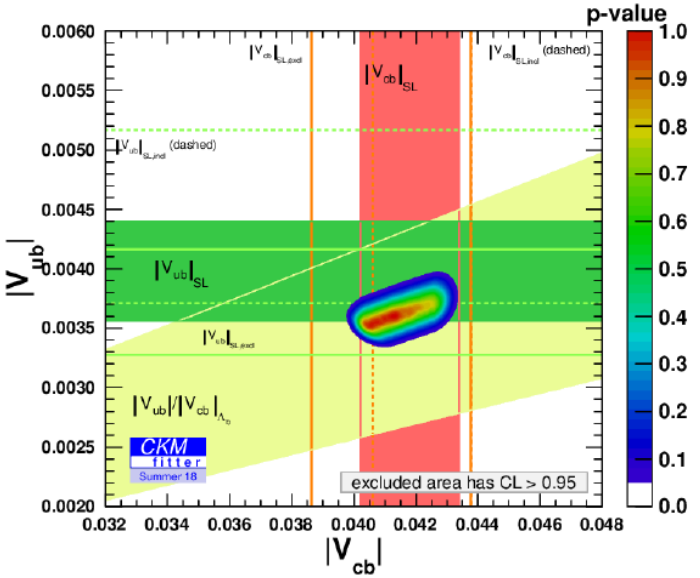
$|V_{cb}|$ *(excl)* = $(41.2 \pm 0.6(\text{exp}) \pm 0.9(\text{LQCD}) \pm 0.2(\text{EM})) \times 10^{-3}$

$|V_{cb}|$ *(incl)* = $(42.2 \pm 0.4 \pm 0.6) \times 10^{-3}$

no discrepancy!

$|V_{ub}|$ *(excl)* = $(3.72 \pm 0.09 \pm 0.22) \times 10^{-3}$

$|V_{ub}|$ *(incl)* = $(4.44 \pm 0.17 \pm 0.31) \times 10^{-3}$



update for Summer 2018

$|V_{cb}| = (41.8 \pm 0.4 \pm 0.6) \times 10^{-3}$

$|V_{ub}| = (3.98 \pm 0.08 \pm 0.22) \times 10^{-3}$

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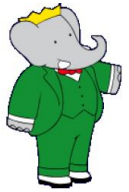
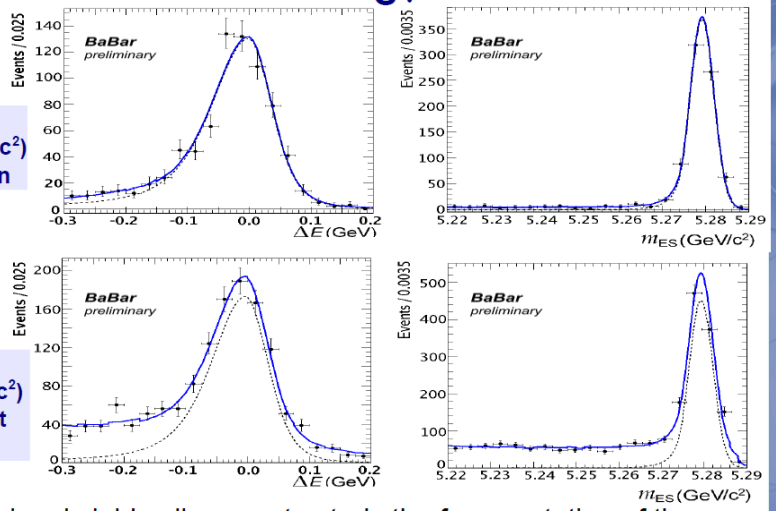


V_{td}/V_{ts} measurement by BABAR

Fit to data for $B \to X_s \gamma$

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

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



– Large signal yields allows us to study the fragmentation of the non-resonant $b \to s\gamma$ decays, and adjust our simulation accordingly.

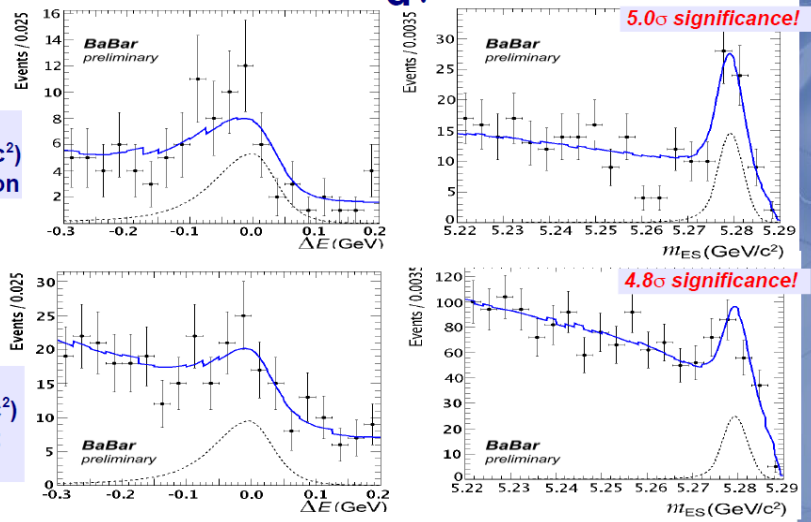
Fit to data for $B \to X_d \gamma$

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

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

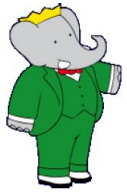
5.0σ significance!

4.8σ significance!

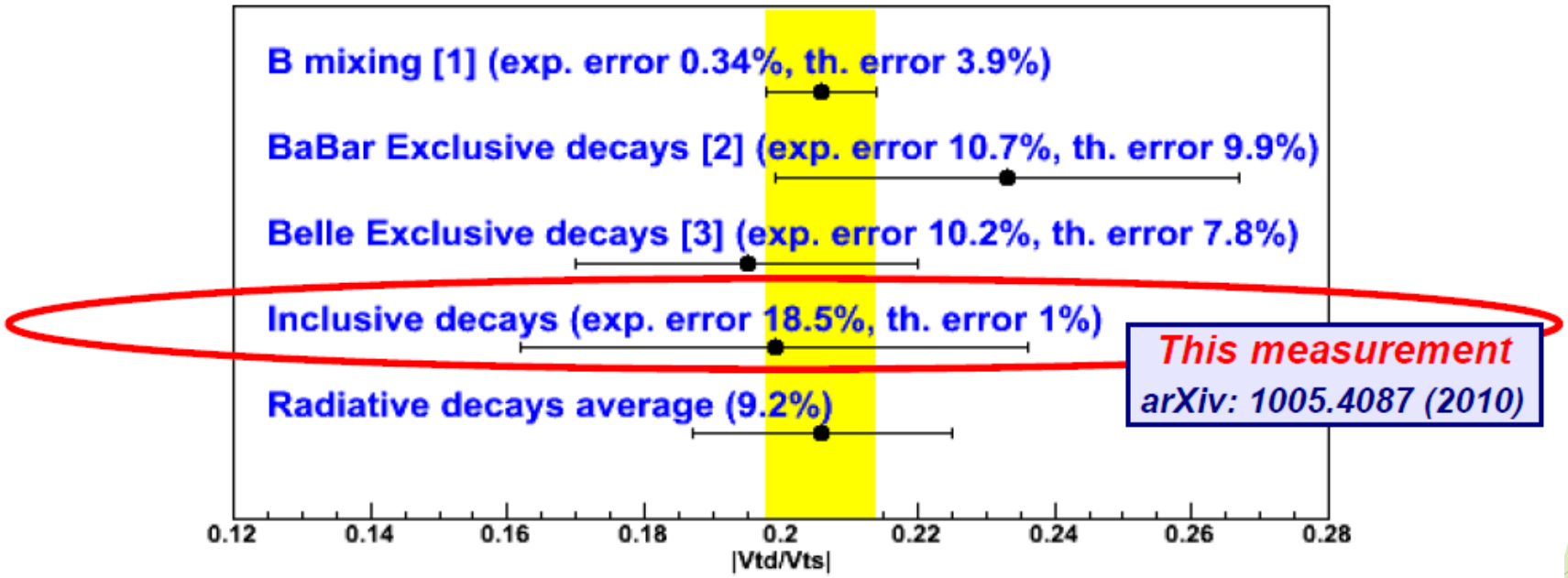


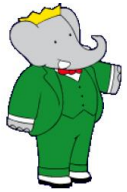
– (Jagged lines artefact of combination of several binned histogram PDFs.)

– **First significant observation of $b \to d\gamma$ in non-resonant modes!**

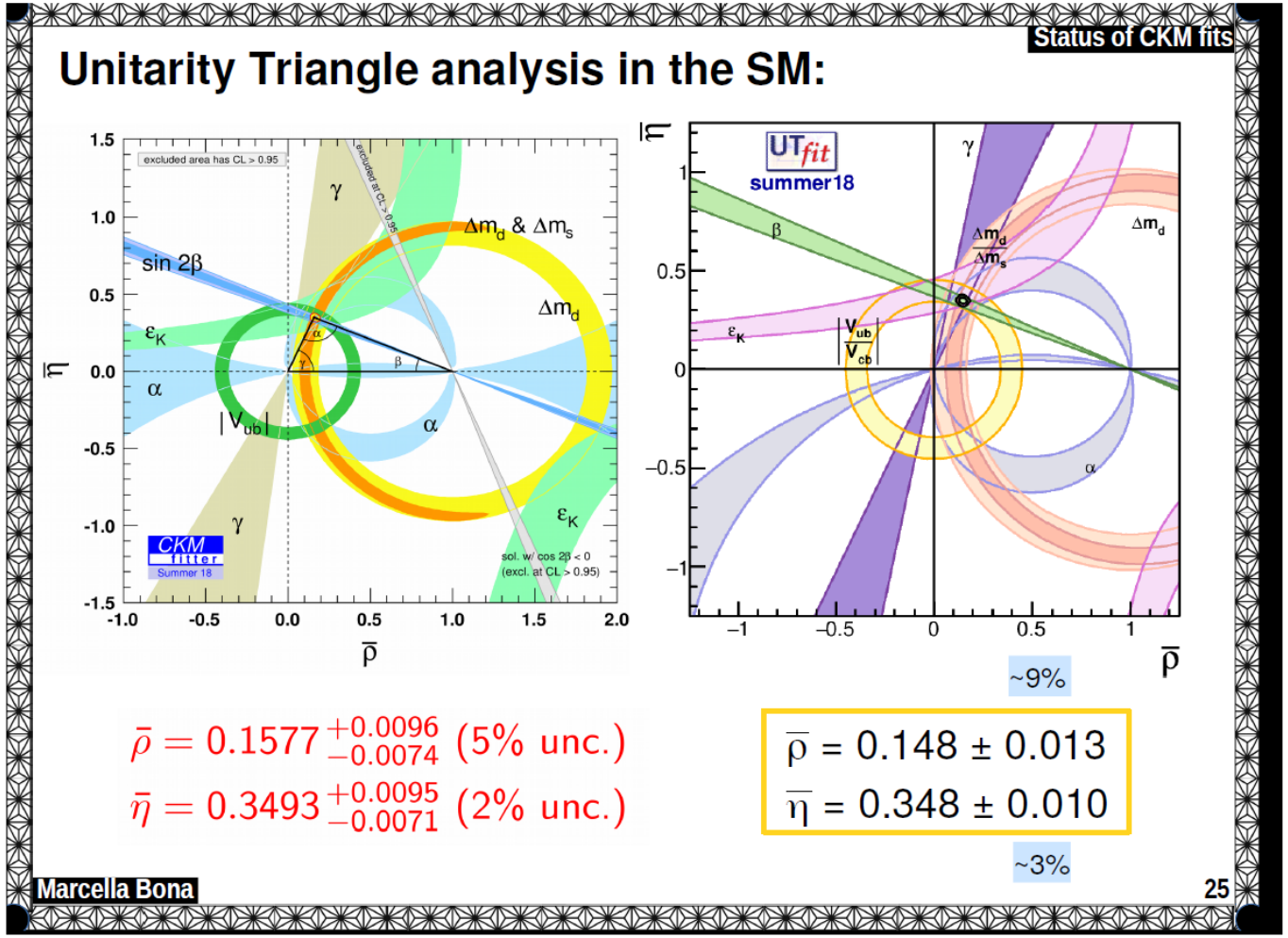


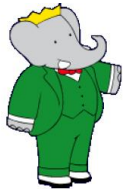
Good agreement with Bs mixing
errors still larger , a good challenge for BELLE-II





CKM triangle in 2018 and beyond





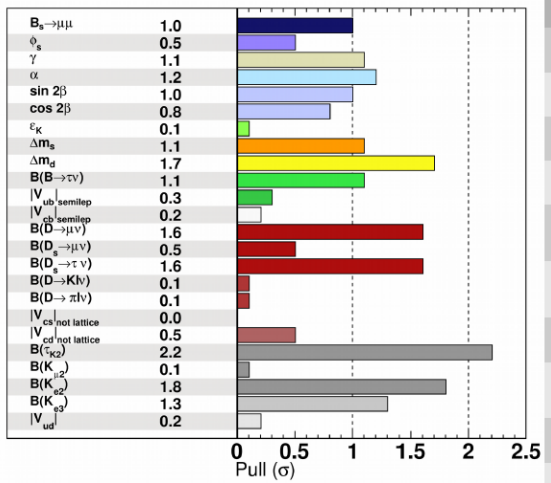
Status of CKM fits

Compatibility of the constraints

obtained excluding
the given constraint
from the fit

CKM fitter

UTfit



Observables	Measurements	Prediction	Pull (#σ)
sin2β	0.689 ± 0.018	0.738 ± 0.033	~ 1.2
γ	70.0 ± 4.2	65.8 ± 2.2	~ 1
α	93.3 ± 5.6	90.1 ± 2.2	< 1
$\lvert V_{ub}\rvert \cdot 10^3$	3.72 ± 0.23	3.66 ± 0.11	< 1
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	4.50 ± 0.20	-	~ 3.8
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	3.65 ± 0.14	-	< 1
$\lvert V_{cb}\rvert \cdot 10^3$	40.5 ± 1.1	42.4 ± 0.7	~ 1.4
BR($B \to \tau\nu$) [10^{-4}]	1.09 ± 0.24	0.81 ± 0.05	~ 1.2
$A_{SL}^d \cdot 10^3$	-2.1 ± 1.7	-0.292 ± 0.026	~ 1
$A_{SL}^s \cdot 10^3$	-0.6 ± 2.8	0.013 ± 0.001	< 1

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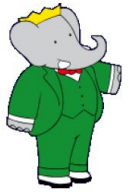

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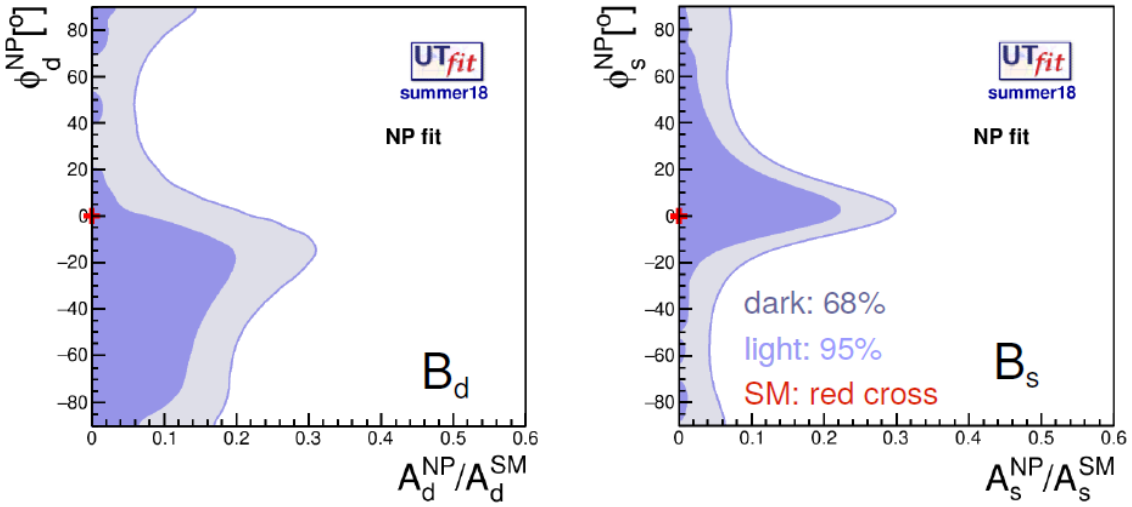
Still room for new physics !!!

Status of CKM fits

NP parameter results

$$A_q = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP} - \phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$



The ratio of NP/SM amplitudes is:

< 18% @68% prob. (30% @95%) in B_d mixing

< 20% @68% prob. (30% @95%) in B_s mixing

see also Lunghi & Soni, Buras et al., Ligeti et al.

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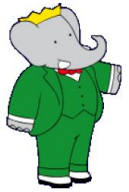
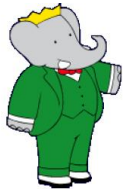


World famous BABAR tools

- Cornelius (tagging package)
- sPlot (optimum background subtraction)
- RooFit (very advanced fiiting package)
- EvtGEN (all knowledge about B decays in an event Generator)
- CKMfitter/ UTfit Frequentist and bayesan overall CKM fitters
- First world-wide Grid ever deployed) (albeit not yet automated)
- Blind analysis



Conclusions

- BABAR achievements in CKM physics were just fantastic !
- They were due to
  - the complete dedication of the PEP-II and BABAR collaborations
  - the great level of creativity of these teams
  - the strong competition with our BELLE colleagues
  - The intimate relationship with many theorists
  - The good coordination and strong support of funding agencies and of our labs
  - The extraordinary world-wide efforts of our computing centers
  - And the extremely friendly atmosphere of the BABAR collaboration!

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Talk outline

- Disclaimer
- CKM panorama before BABAR, ie ICHEP 1998

https://arxiv.org/abs/hep-ex/9903063

- CKM tools invented by BABAR: the tagging group, sweights
- Physics of teh B factories https://arxiv.org/ftp/arxiv/papers/1406/1406.6311.pdf
- S plots 440 citations https://arxiv.org/abs/physics/0402083

- BABAR results regarding CKM
  - Sin2 beta

    https://arxiv.org/abs/0705.2998 2007
  - Sin 2 alpha

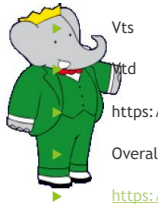
    https://arxiv.org/abs/0906.2082 2009
  - Angle gamma

    https://arxiv.org/abs/1301.3283 2013
  - Vcb

    http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-11606.pdf 2006

    http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-11606.pdf 2010
  - Vub

    https://arxiv.org/abs/1611.05624
  - Vts
  - Vtd
  - https://pos.sissa.it/120/226/pdf
  - Overall
  - https://www.sciencedirect.com/science/article/abs/pii/S0375947409003704



- Direct CP violaton in Kp modes
- BABAR/BELLE comparison
- HFAC HFLAV