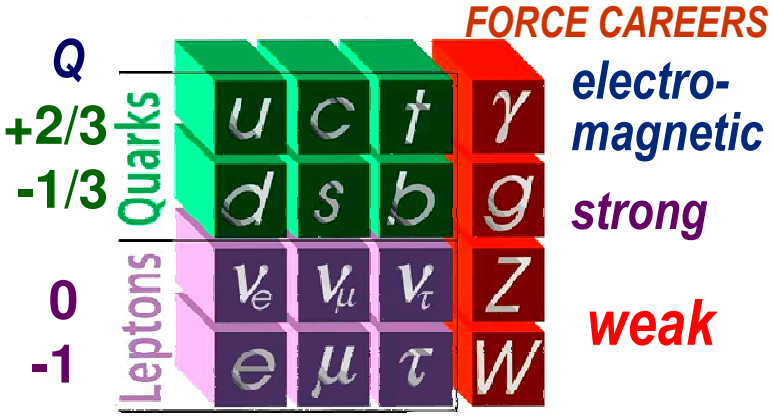
BEAUTY PHYSICS

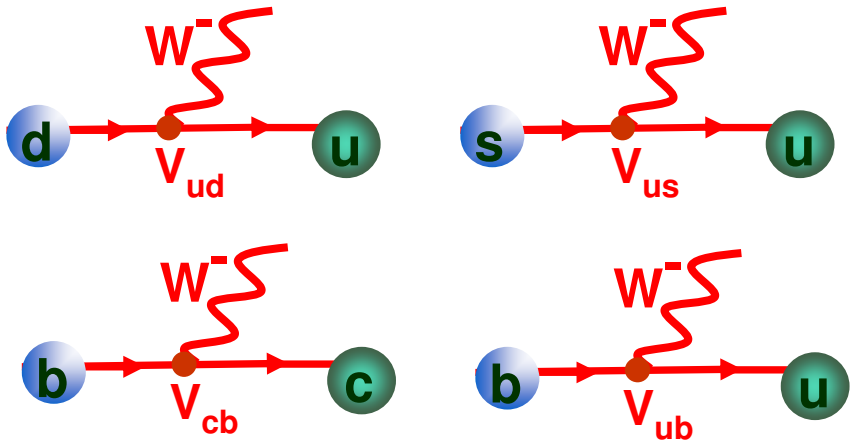
Outline:

- **introduction** (for non-experts);
- **selected results;**
- **beauty physics in the LHC era;**
- **beauty physics in Poland;**
- **summary.**

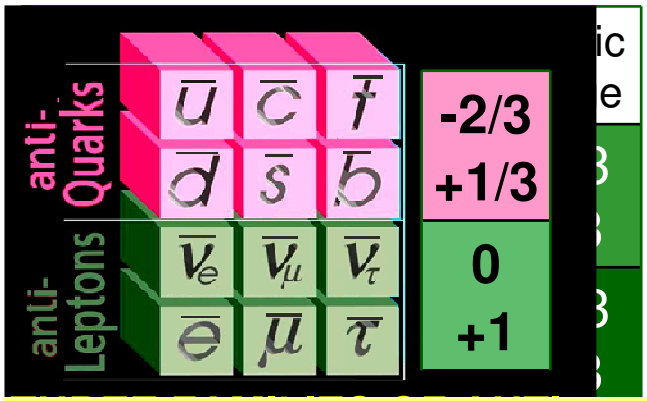
Symposium on Physics of Elementary Interactions in the LHC Era; April 21-22, 2008, Warsaw

FLAVOR IN THE STANDARD MODEL





THREE FAMILIES OF MATTER



$V_{ud} \approx 1 >> V_{us} \approx 0.2 >> V_{cb} \approx 0.04 >> V_{ub} \approx 0.004$

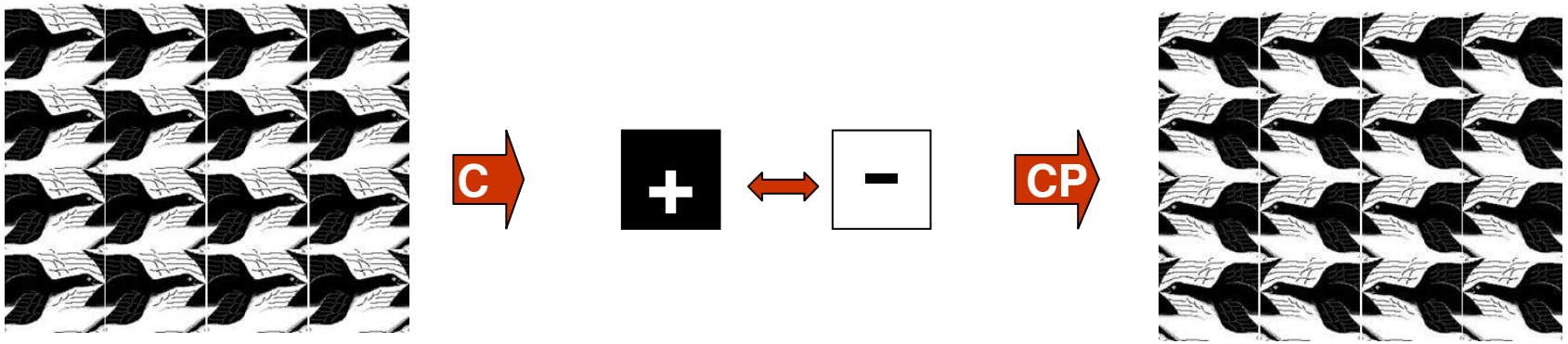
- What is flavor? Why three families?
- What determines the V_{ij} and the mass pattern?
- How antimatter disappeared in the Universe?

Long-term step-by-step experimental approach in flavor physics needed to address these grand questions.

BEAUTY IS A SPECIAL GIFT FROM NATURE

BEAUTY & CP VIOLATION (CPV)

- CP-transformation: charge conjugation (C) & mirror reflection (P)



- **CP-SYMMETRY:** physical processes in nature occur in precisely the same manner if all particles were converted to their antimatter opposites using the **CP** transformation.
- **1964: CP VIOLATION** discovered in K_L decays

  $N(K_L^0 \to \pi^- e^+ \nu_e) > N(K_L^0 \to \pi^+ e^- \bar{\nu}_e)$

  asymmetry: 0.2%÷0.3%

  H. Christenson, J. W. Cronin, V. L. Fitch, R. Turlay, Phys. Rev. Lett. **83**, 138 (1964)

  absolute difference between matter and antimatter!
- **1972: CPV** in the SM requires 3 quark families

  M. Kobayashi, T. Maskawa, Progr.Theor. Phys. **49**, 652 (1973)
- **1977: b** quark discovered at FNAL

LARGE CP-ASYMMETRIES EXPECTED IN THE BEAUTY SECTOR

BEAUTY FACTORIES

ENERGY FRONTIER

$hh \rightarrow \bar{b}b + X$

$\bar{b}/b \Rightarrow B^0 / \bar{B}^0, B^{\pm}, B_s, B_c, \Lambda_b, \ldots$

beauty-factory

LHC

$10^5 \div 10^6$ $\bar{b}b$/s; $\sigma(\bar{b}b)/\sigma_{inel} \sim 0.006$

ATLAS, CMS } general purpose experiments; beauty physics at the beginning of LHC operation ($L \sim 10^{33}/cm^2/s$)

LHCb – dedicated beauty physics exp. optimized @ $L = 2 \times 10^{32}/cm^2/s$

LUMINOSITY FRONTIER

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow \bar{B}B$

$\Gamma(\Upsilon(4S) \rightarrow \bar{B}B) > 96\%$; $B = B^0, B^+$

$\sigma(\bar{B}B)/\sigma_{tot} \sim 0.25$

B-factory

$L_{peak} \cong 2 \times 10^{35}/cm^2/s$
$\rightarrow 2 \times 10^9$ $\bar{B}B$/yr
$\rightarrow 2 \times 10^9$ $\tau^+\tau^-$/yr

SuperKEKB *(upgrading KEK)*
final target $\sim 8 \times 10^{35}/cm^2/s$
smooth transition: 50 ab^{-1}

SuperBelle *(upgrading Belle)*

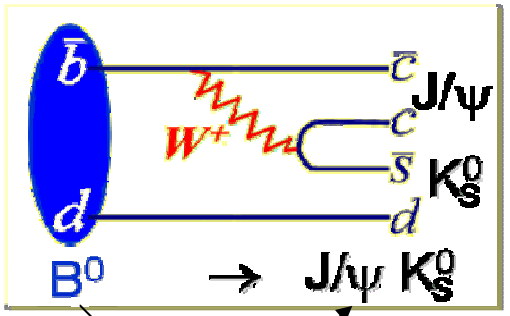
INFN Frascati

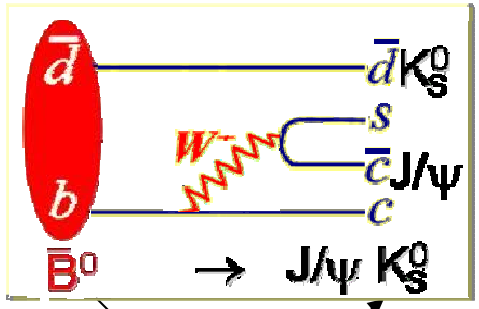
$L_{peak} > 10^{36}/cm^2/s$

HIGHLIGHTS & HOT TOPICS

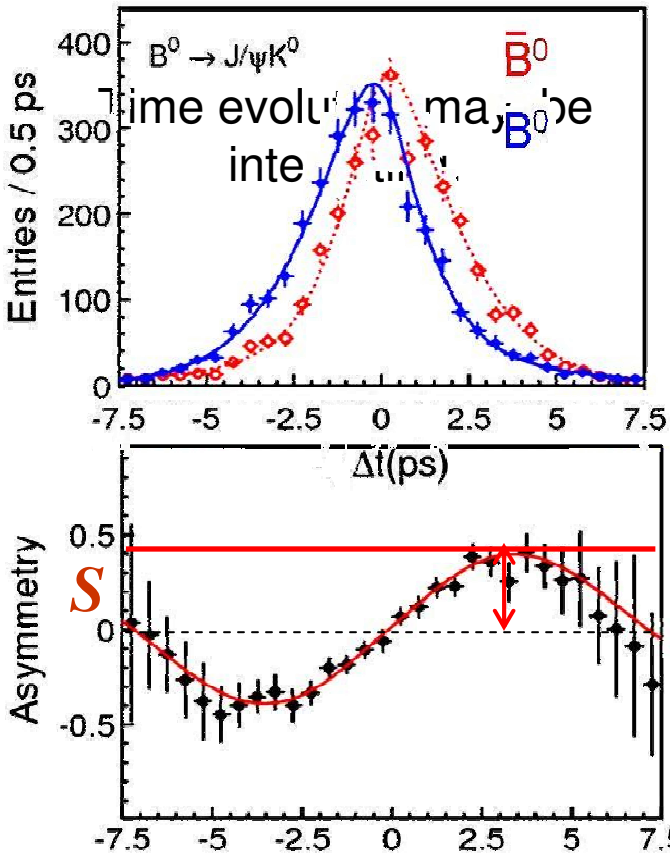
selected out of > 500 papers

OBSERVATION OF CP VIOLATION IN $B^0 \to J/\psi K^0$





dN/dΔt($B^0 \to J/\psi K^0$)



Asymmetry:

$A_{CP}(\Delta t) \propto dN/d\Delta t(\bar{B}^0 \to f) - dN/d\Delta t(B^0 \to f)$

$A_{CP}(\Delta t) = S \sin(\Delta m_d \Delta t)$

535 M $B\bar{B}$ pairs

$S_{J/\psi K} = 0.642 \pm 0.031\ (stat) \pm 0.017\ (syst)$

384 M $B\bar{B}$ pairs

$S_{J/\psi K} = 0.697 \pm 0.035\ (stat) \pm 0.016\ (syst)$

large CPV in B^0 system !

first seen by Belle & BaBar in 2001

The idea from I. Bigi, A. Carter and A. Sanda, 1981

BEAUTY, CPV & THE STANDARD MODEL

- V_{CKM}-Cabibbo-Kobayashi-Maskawa matrix

  contains information on the strength of flavor-changing weak decays

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

$V_{ub}=|V_{ub}|e^{-i\gamma}$

$V_{td}=|V_{td}|e^{-i\beta}$

unitarity condition:

Makoto Kobayashi receiving the EPS prize

Manchester, July 2007

- sides of the UNITARITY TRIANGLE (**UT**) can be determined from decay rates
- angles of **UT** can be extracted from CP-asymmetries

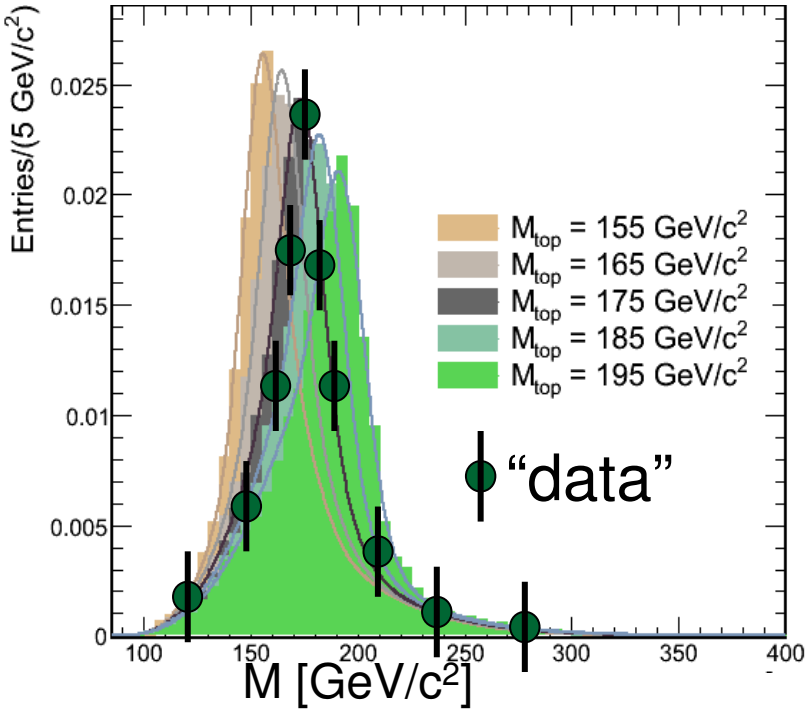
for $B^0 \to J/\psi K^0$: $S = \sin(2\beta)$

Kobayashi-Maskawa model of CPV is now a tested theory

VERIFICATION OF THE UNITARITY CONDITION
⇒ FUNDAMENTAL TEST OF THE SM

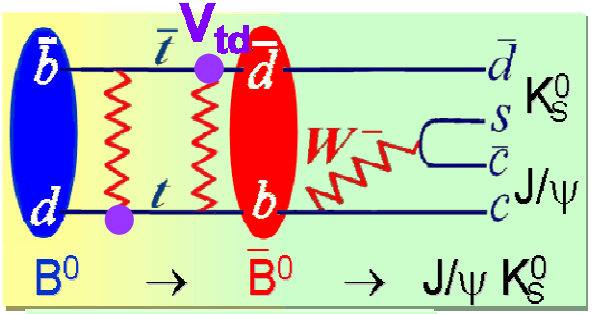
NEW PHYSICS SEARCHES

CURRENT B-FACTORIES STUDY TOP PHYSICS !



top mass at *energy frontier*:
CDF & D0 @ TEVATRON

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



$V_{td} = |V_{td}|\, e^{-i\beta}$

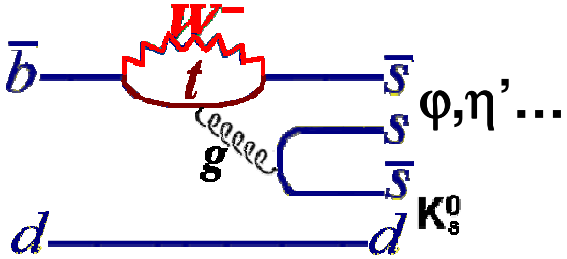
coupling (including CP-violating phase*)* at *luminosity frontier:* Belle, BaBar

another example:
B decays through
penguin loops

If new physics at O(1)TeV…
⇒ It is plausible to expect its effects in B decays.

NEW PHYSICS SEARCHES IN b→s TRANSITIONS

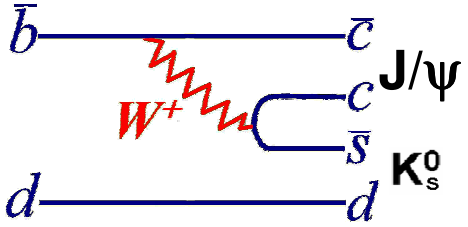
$B^0 \to \varphi K^0$, $B^0 \to \varphi\eta'$…



but decay rates… ~$10^{-5} \div 10^{-6}$

similar to

$B^0 \to J/\psi K^0$

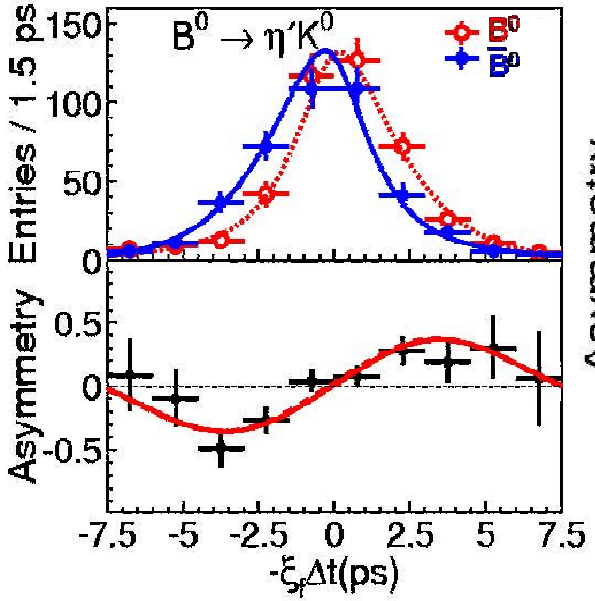


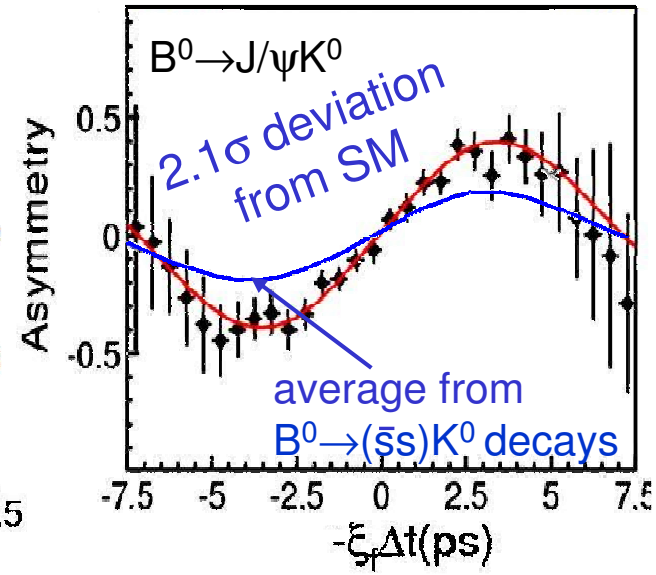
decay rate 8.7×10^{-4}

$A_{CP}(\Delta t)$ in $\bar{B}^0/B^0 \to (\bar{s}s)K^0$

STANDARD MODEL

$S_{(\bar{s}s)K^0} = S_{J/\psi K^0} = \sin(2\beta)$





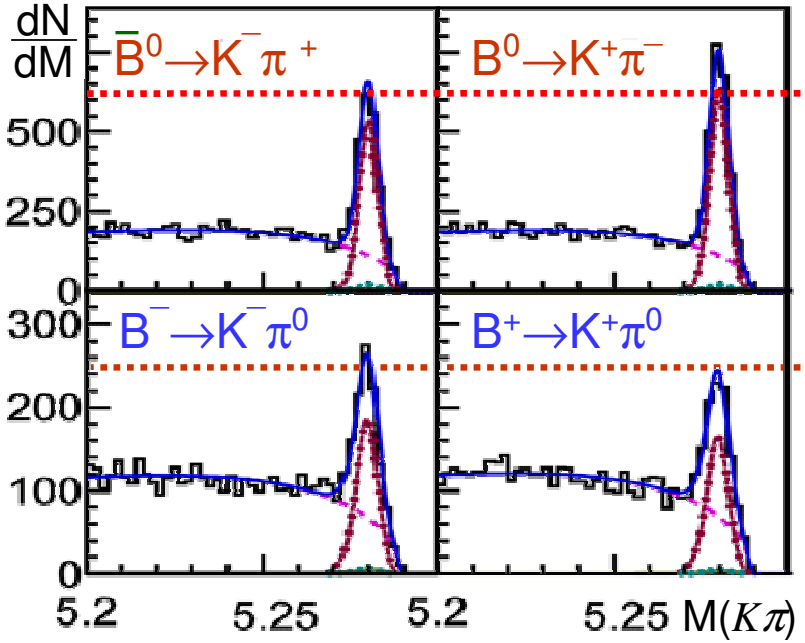
another puzzle:
polarization in $B \to \varphi K^*$

SM: $f_T/f_L \approx 0.1$

Exp: $f_T/f_L \approx 1$ $\quad f_T(f_L)$ – *fraction of transverse(longitudinal) polarization*

B→Kπ puzzle

Belle Collab., Nature, 452, 332 (20 March 2008)



asymmetry: $A_{CP} \propto N(\bar{B} \to \bar{f}) - N(B \to f)$

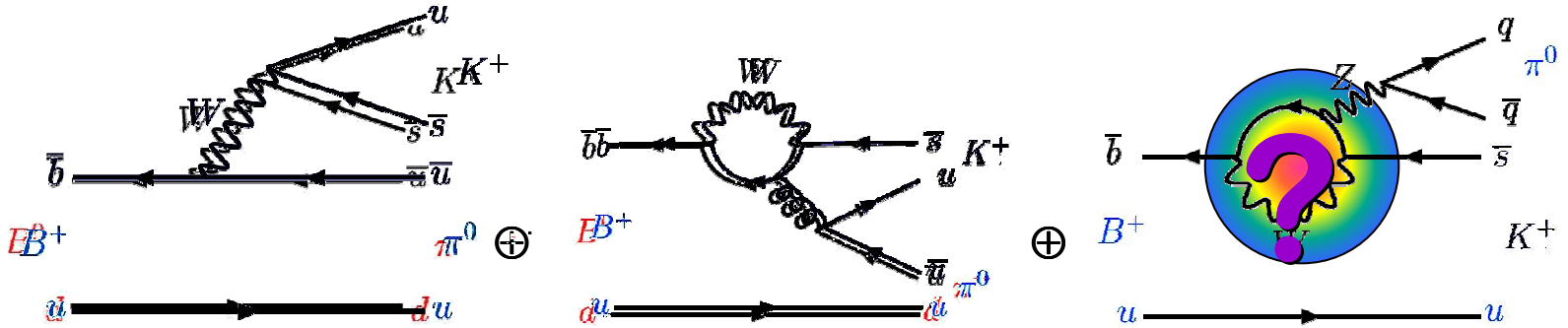
A_{CP}= **-0.094** ±0.018 (*stat*) ±0.008(*syst*)

A_{CP}= **+0.07** ±0.03 (*stat*) ±0.01(*syst*)

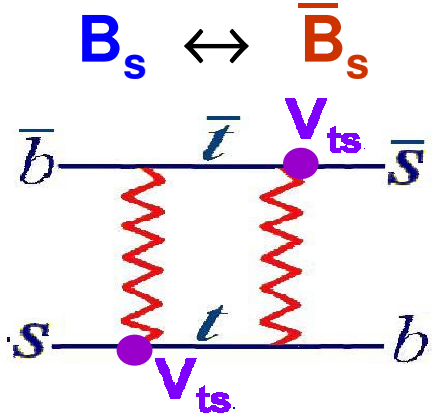
$$\Delta A \equiv A_{CP}(K^{\mp}\pi^0) - A_{CP}(K^{\mp}\pi^{\pm}) = 0.164 \pm 0.037$$

SM: $\Delta A \approx 0$

~4σ deviation from SM?



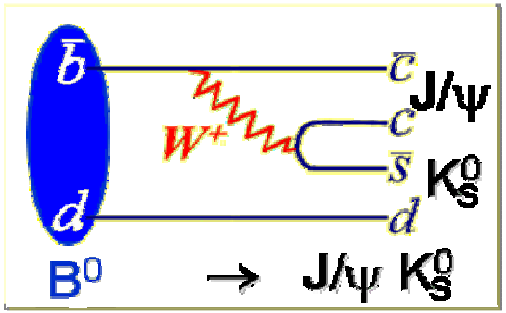
HINTS OF NEW PHYSICS IN B_s ?



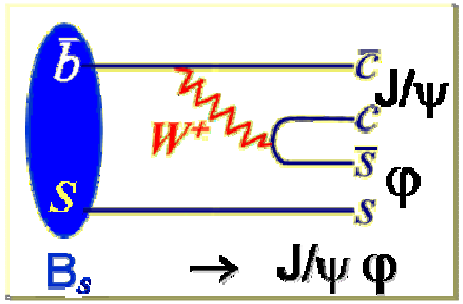
$|V_{ts}|/|V_{td}| \approx 5$

first evidence: 2006
CDF & D0 @ TEVATRON
mixing rate:
$\Delta m_s = 17.77 \pm 0.12\ ps^{-1}$

Consistent with indirect measurements from other constraints on CKM elements:
$\Delta m_s = 18.6 \pm 2.3\ ps^{-1}$



$d \Rightarrow s$



2007-2008

first constraints from CDF & D0

$A_{CP}(\Delta t) \Rightarrow S_{J/\psi K^0} \Rightarrow \arg(V_{td})$ $\qquad$ $A_{CP}(\Delta t) \Rightarrow S_{J/\psi\varphi} \equiv \sin(2\beta_s) \Rightarrow \arg(V_{ts}) \overset{SM}{\cong} 0$

Combined analysis of the available B_s measurements $\Rightarrow$ **$\arg(V_{ts}) \neq 0$ $>3\sigma$**

M. Bona *et al.* (UTfit Colab.), arXiv:0803.0659 [hep-ph] (March 2008)

BEAUTY IN THE LHC ERA


BEAUTY IN THE LHC ERA

❑ If new physics found at LHC

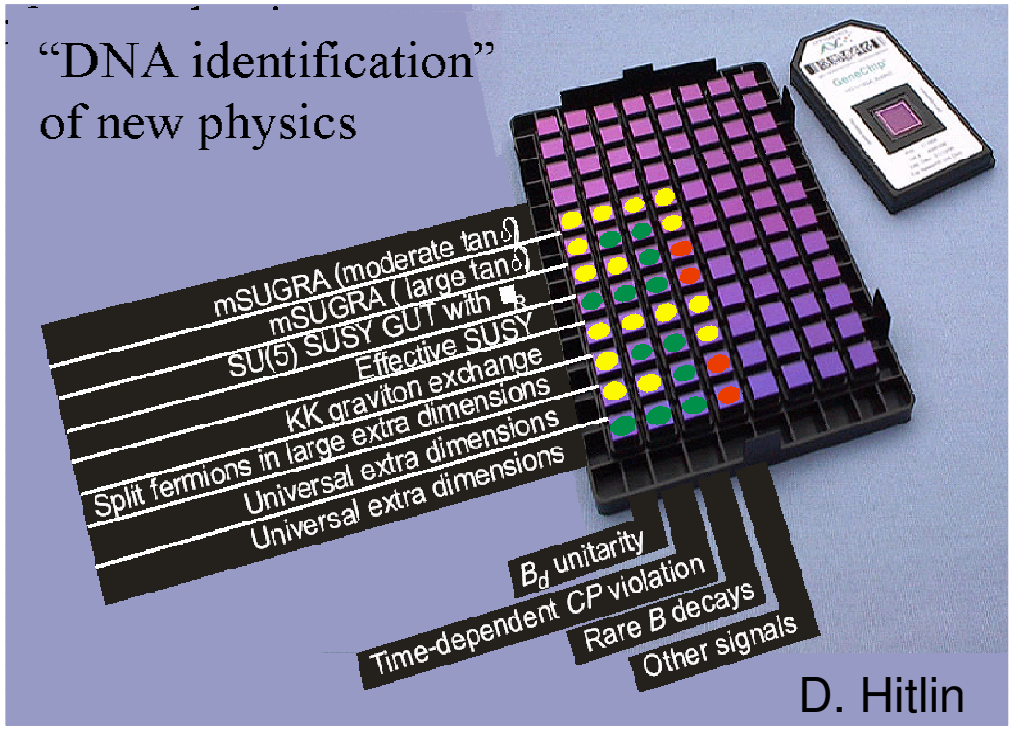
⇒ the effects in B/D/K/τ decays;

→ flavour structure of new physics?

→ CP violation in new physics?

❑ Otherwise…

⇒ Search for deviations from SM in flavor physics will be one of the best ways to find new physics.



KEY MEASUREMENTS

- Unitarity triangle with O(1%) precision:
  tree ($|V_{ub}|$, γ) *vs loop* ($|V_{td}|$, β)

- Inclusive measurements $b \to u$, $b \to s\gamma$, $b \to d\gamma$, $b \to sl^+l^-$

Indirect measurement from other CKM elements: $\sin(2\beta)=0.736\pm0.042$

direct measurements from $A_{CP}(\Delta t)$ in $B \to I_{CP}$ (preferred by theory): $\sin(2\beta)=0.668\pm0.028$

- Non SM CP phase: "$|V_{ub}|$ tension"
  2.9 σ deviation

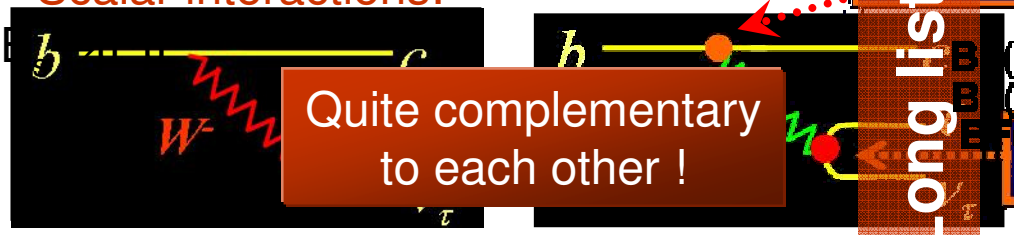
high precision $b \to s$ studies, β_s,

M. Neubert, Moriond 2007

- Non SM right-handed currents:
  CPV in $B \to K^*\gamma$;

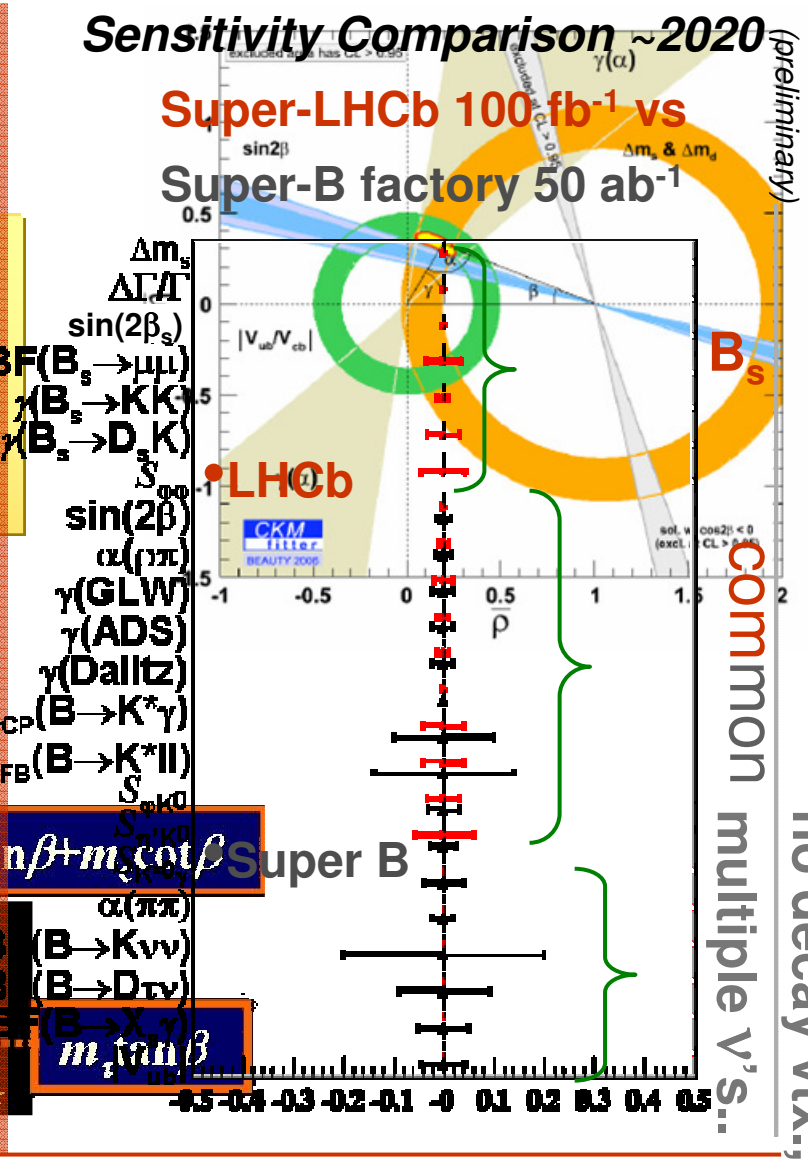
- Charged Higgs:
  searches in $B \to \tau\nu_\tau$ *and* $B \to D^{(*)}\tau\nu_\tau$;

- Scalar interactions:



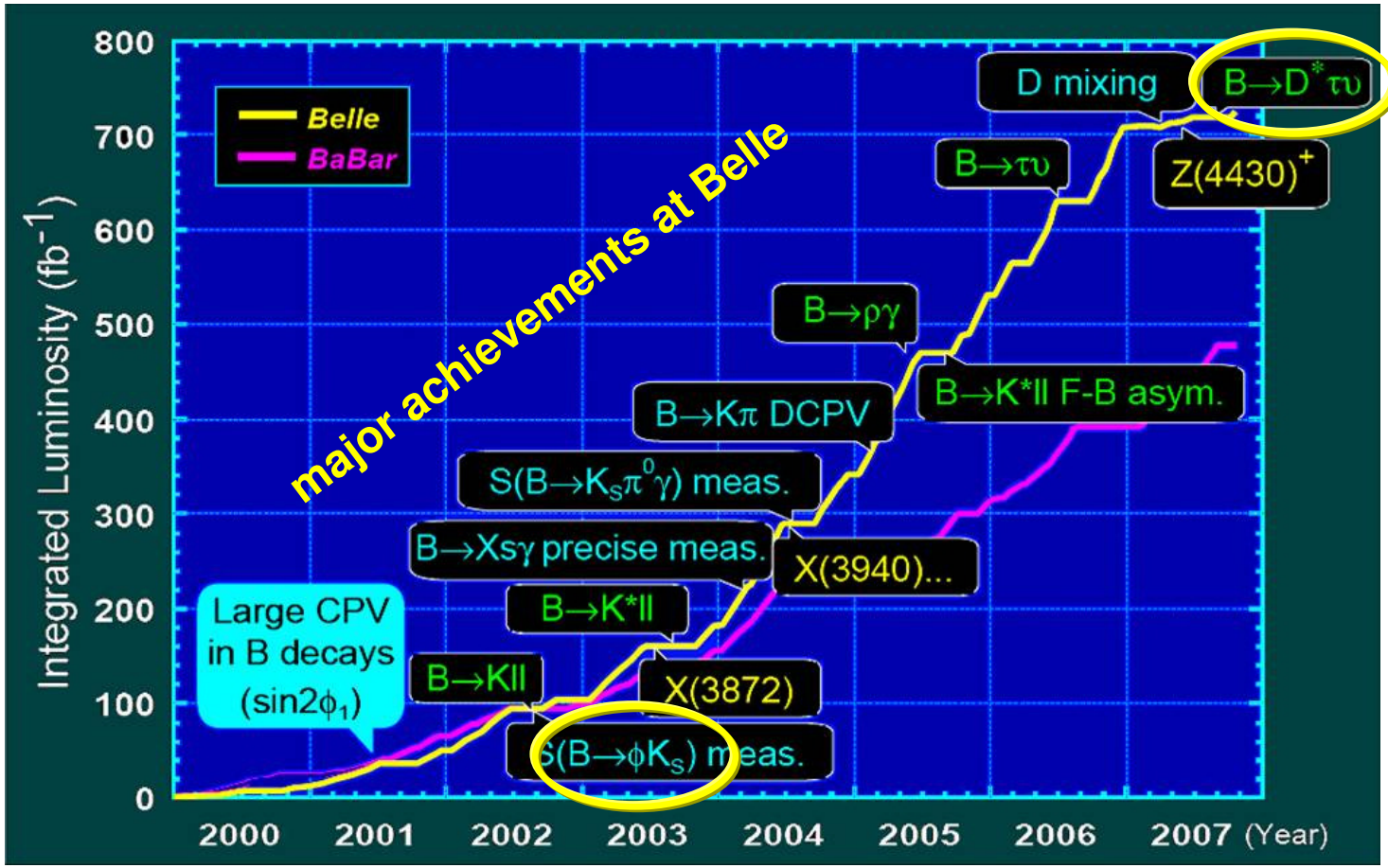
Quite complementary to each other !

Long list of important measurements



By S. Stone,
SuperB numbers : M Hazumi

TOWARDS SuperBelle



A. Matyja *et al.* (Belle Collab.), Phys. Rev. Lett. **99,** 191807 (2007)

K.F. Chen, **A. Bożek** *et al.* (Belle Collab.), Phys. Rev. Lett. **91,** 201801 (2003)

Polarization measurements in B→φK*

The needed decay modes & techniques established at B-factories

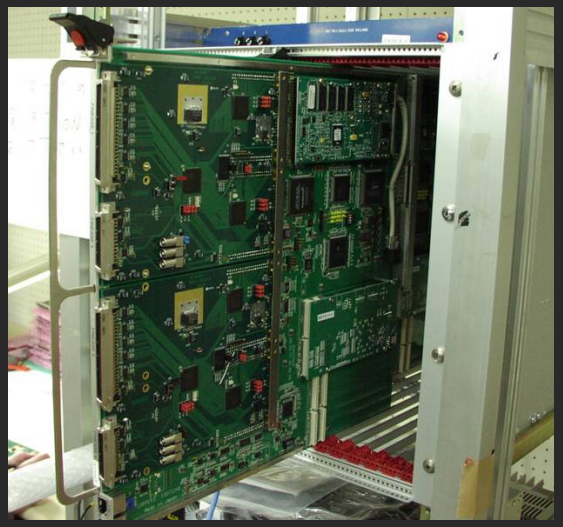
BEAUTY IN POLAND

only current activities in dedicated beauty experiments

KEKB / Belle

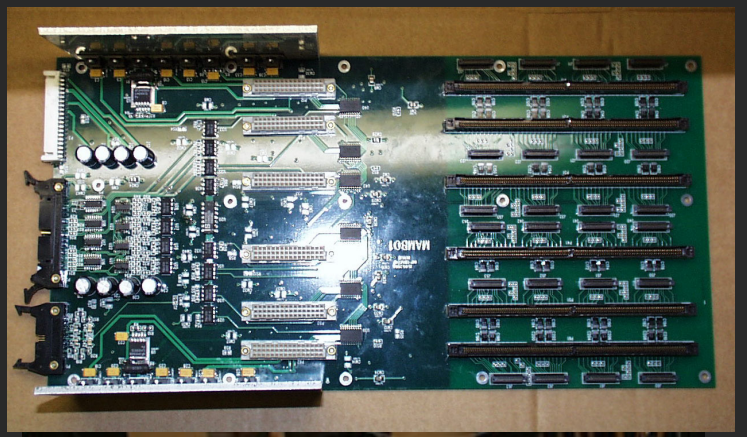
13 countries,
57 institutes

HALNY
- READOUT MODULES FOR SVD1



TESTS OF READOUT MODULES FOR SVD3

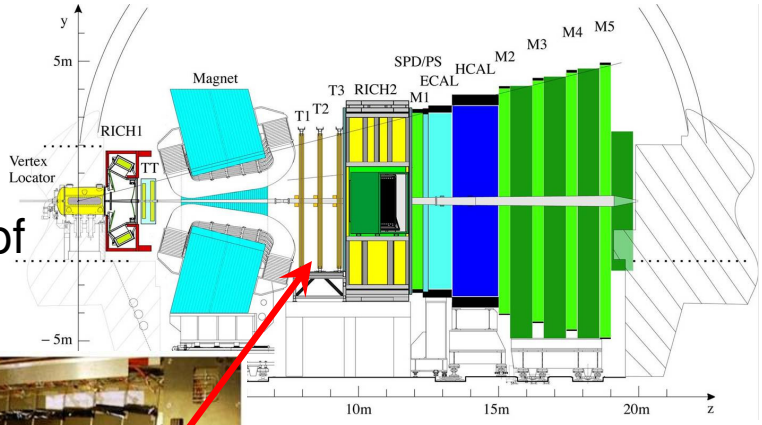
for SuperBelle

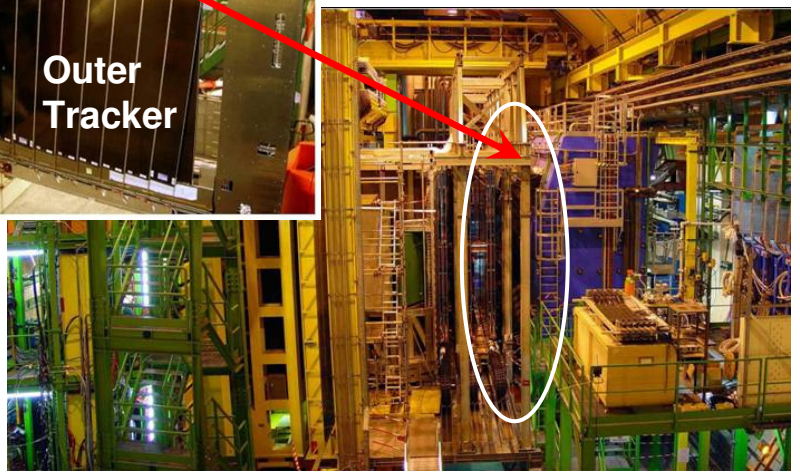


MASTER AND REPEATER BOARDS FOR SVD2

– Large Hadron Collider beauty experiment

- Study of CP violation for B and B_s mesons.
- Search for rare B i B_s decays.
  - Precision measurements to find the effects of New Physics
- Polish teams in LHCb
  - **Krakow – IFJ PAN (G. Polok) and WFiIS AGH (B.Muryn)**
  - **Warsaw – IPJ (M. Szczekowski)**
- Contribution (from 1999)
  - **Design and production of Outer Tracker**
  - **A system for monitoring of OT layers position**
  - **“Timing and Fast Control” for DAQ**
  - **Development of trigger algorithms**
  - **Simulation and reconstruction software**
  - **Tools for data analysis**





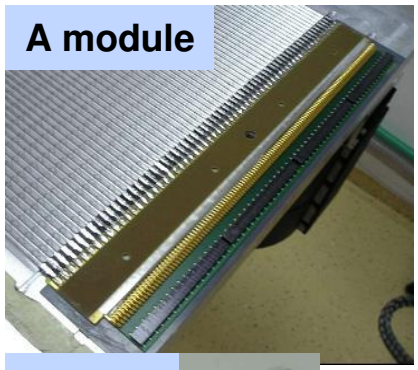
Construction of Outer Tracker

Production of panels

Production of modules

Tests

A module



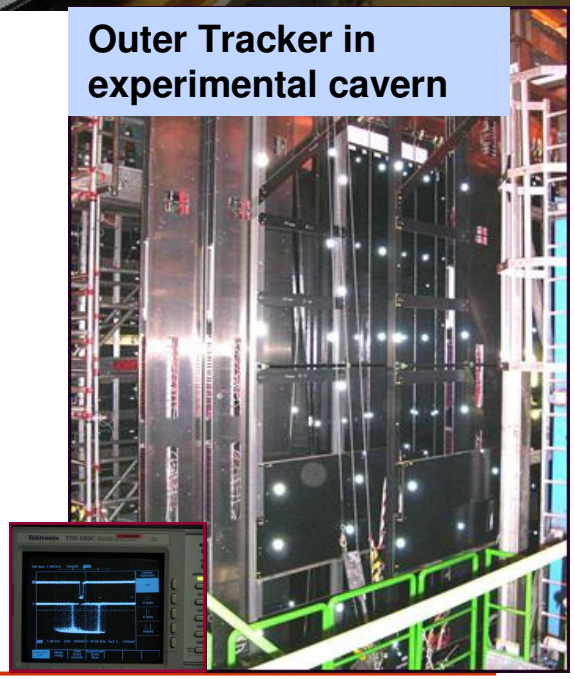
A straw

- **Polish contribution**
  - Prototypes of OT module
  - Technology of production
  - Production of panels (1000 m^2)
  - Production of modules
  - Design of readout electronics
  - Design of OT mechanical support
  - Position monitoring system

Present status

- OT installation finished
- Connection of electronics in final phase
- Integration with central DAQ system advanced – detection of cosmic rays.

Outer Tracker in experimental cavern



SUMMARY

- The flavor sector of the Standard Model passed fundamental tests; Kobayashi-Maskawa mechanism is a dominant source of CP violation.
(but we know this is not enough)

- Yet there are several measurements that are uncomfortable for the Standard Model:
  - "$B \to K\pi$ puzzle";
  - $A_{CP}(\Delta t)$ (and polarization) in $b \to s$;
  - constraints on β_s from B_s decays;
  - "V_{ub} tension";

  $\Rightarrow$ interesting questions to the next generation beauty experiments.

- Comprehensive and detailed studies of beauty will remain crucial in the LHC era.