CP Violation, B Physics and Future Facilities

Tom Browder (University of Hawaii)

Honolulu, HI USA

Tsukuba, Japan

Introduction/Review/Motivation

Complex phases in the weak interaction: V_{td} and V_{ts} and associated CPV asymmetries

Connections to the *charged Higgs*

Flavor Physics, The Next Generation:
Belle II and the LHCb upgrade

Apologies: In the limited time, I cannot cover all the new results from BaBar, Belle, LHCb, CMS, ATLAS, Tevatron …
I have borrowed slides from many excellent physicists

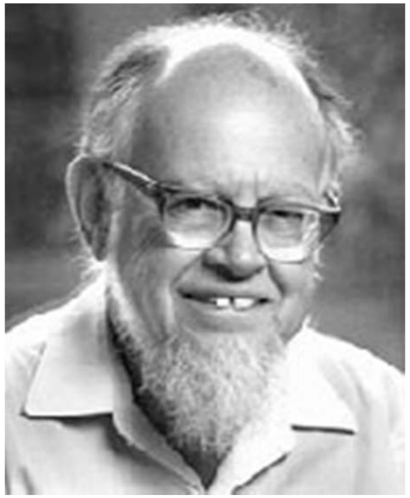
Amplitudes and *Phases* in the Weak Interaction

N. Cabibbo

M.Kobayashi

T.Maskawa

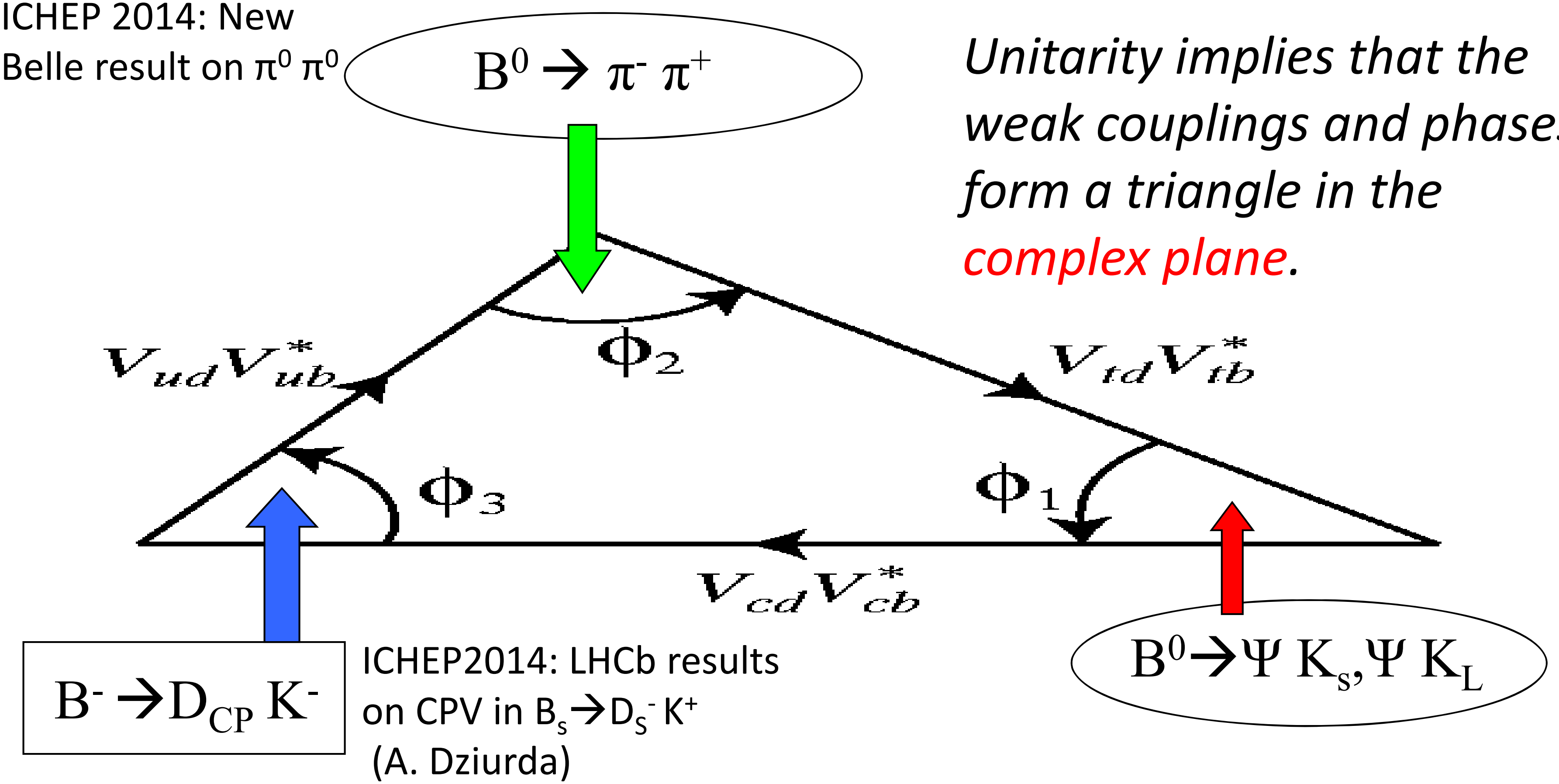
$$V_{\mathrm{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & \underline{V_{ub}} \\ V_{cd} & V_{cs} & V_{cb} \\ \underline{V_{td}} & V_{ts} & V_{tb} \end{pmatrix}$$



L. Wolfenstein

$$V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & \underline{A\lambda^3(\rho - i\eta)} \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ \underline{A\lambda^3(1-\rho-i\eta)} & -A\lambda^2 & 1 \end{pmatrix}$$

Three Angles: ($\varphi_1,\varphi_2,\varphi_3$) or (β, α, γ)



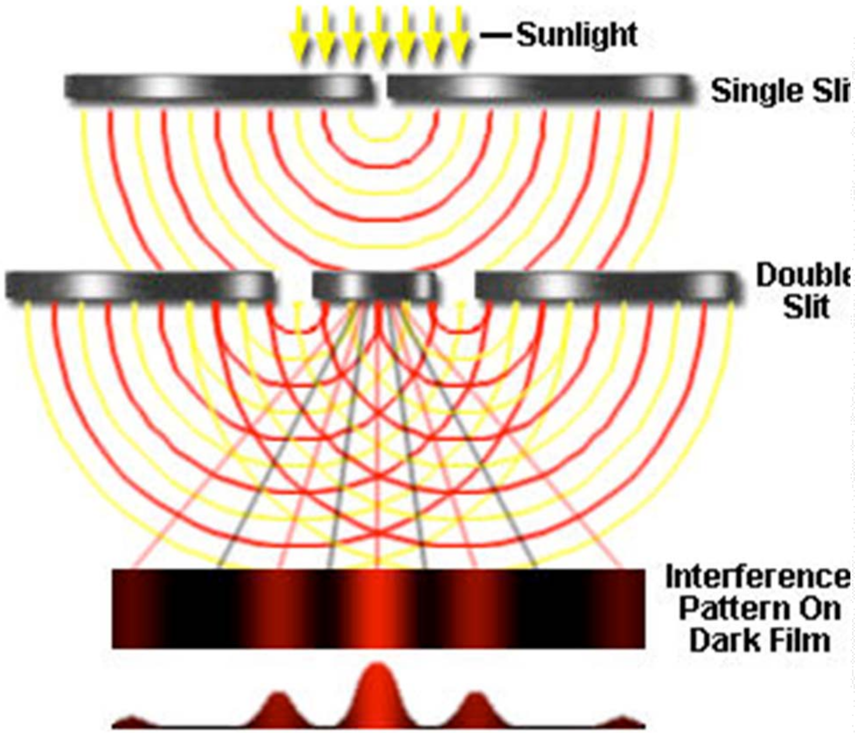
Unitarity implies that the weak couplings and phases form a triangle in the complex plane.

Big Questions: *Are determinations of angles consistent with determinations of the sides of the triangle ? Are angle determinations from loop and tree decays consistent ?*

Time-dependent *CP* violation is

"*A Double-Slit experiment*" with particles and antiparticles

QM interference between two diagrams



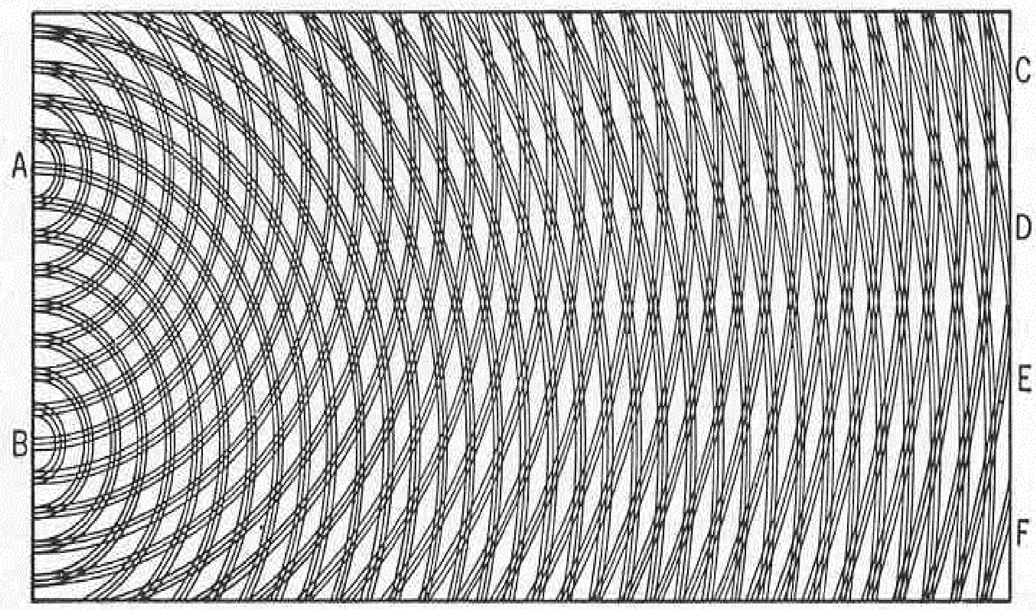
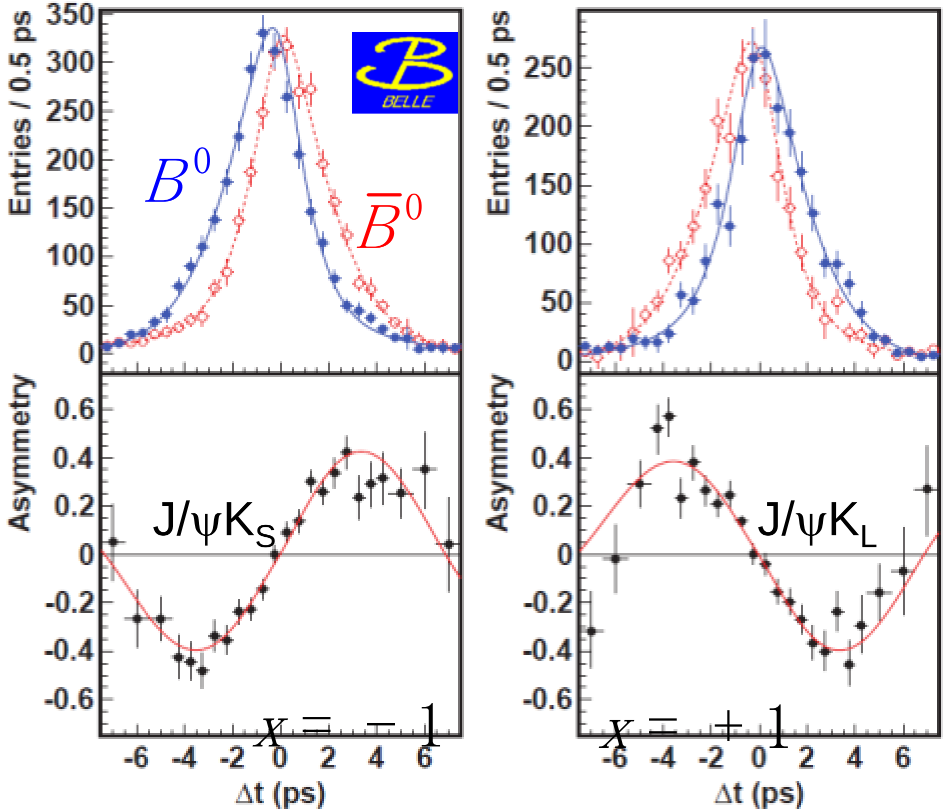
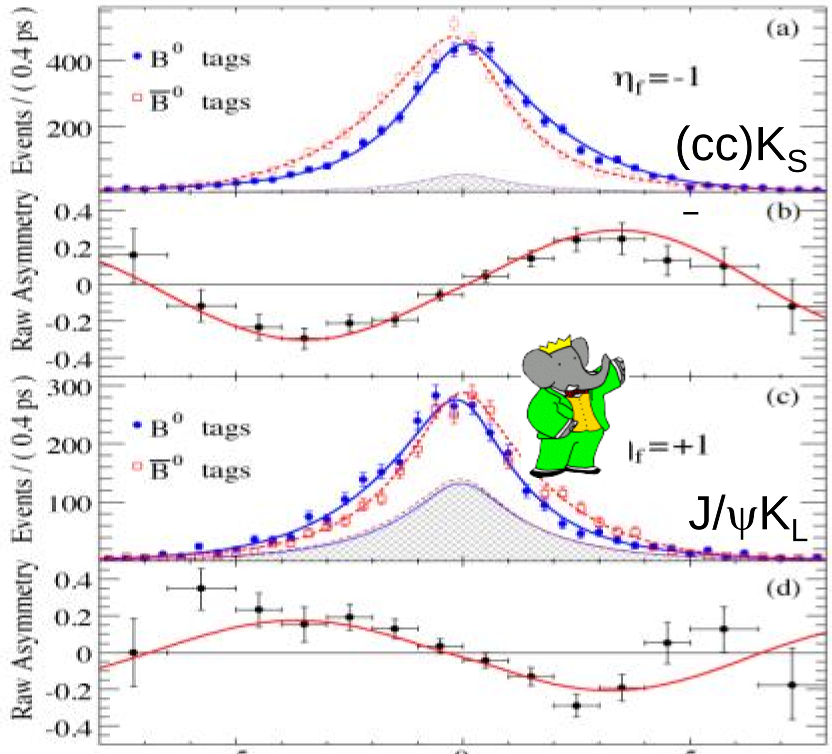


FIG. 1

Measures the phase of V_{td} or equivalently the phase of B_d–anti B_d mixing.

Measurement of $\sin(2\varphi_1)/\sin(2\beta)$ in Charmonium K^0 modes





$\sin 2\phi_1 = 0.667 \pm 0.023 \pm 0.012$

$A_f = 0.006 \pm 0.016 \pm 0.012$

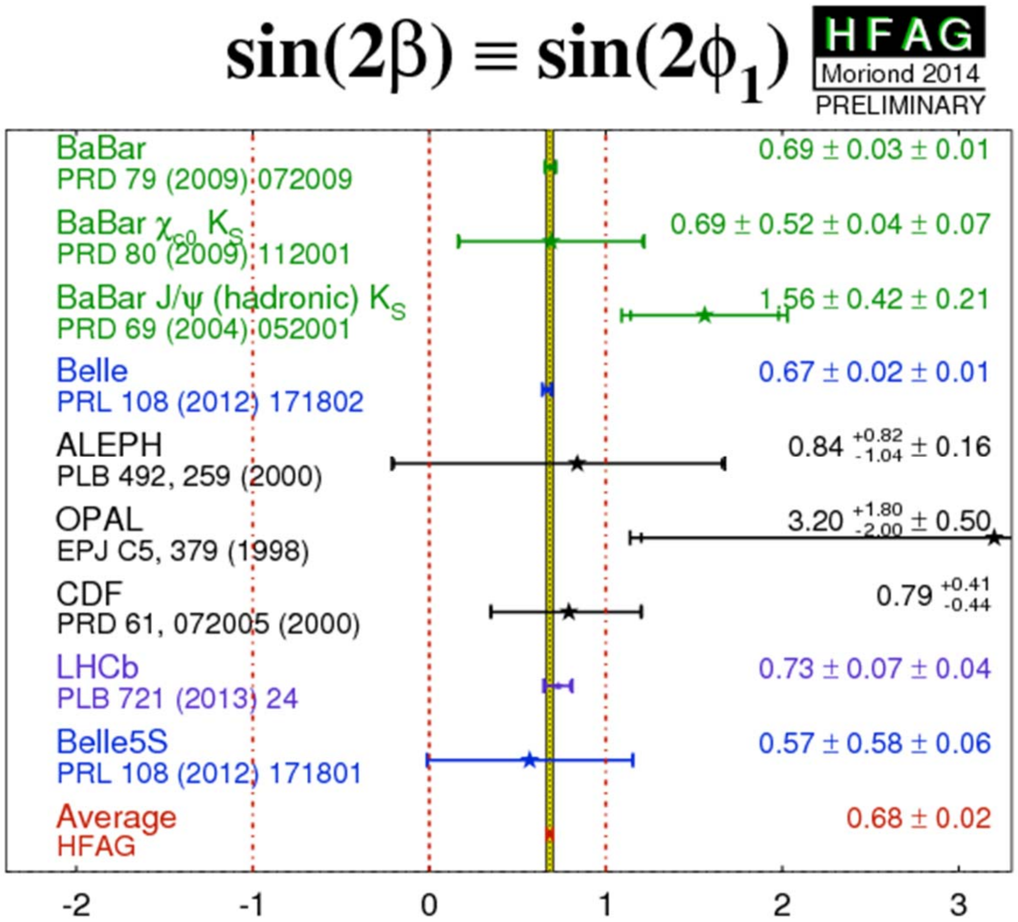
PRL108,171802 (2012)

$\sin 2\phi_1 = 0.687 \pm 0.028 \pm 0.012$

$A_f = -0.024 \pm 0.020 \pm 0.016$

PRD79,072009 (2009)

Overpowering evidence for CP violation (matter-antimatter asymmetries). >>>> The phase of V_{td} is in good agreement with Standard Model expectations



B factories: High precision CPV measurement and a calibration for NP.

2013: LHCb has joined the game.

J. Bernabeu *et al* point out that by comparing decays with t_tag > t_decay and vice versa, one could check for T violation at the B factories. N.B. *This does not assume the CPT theorem.*

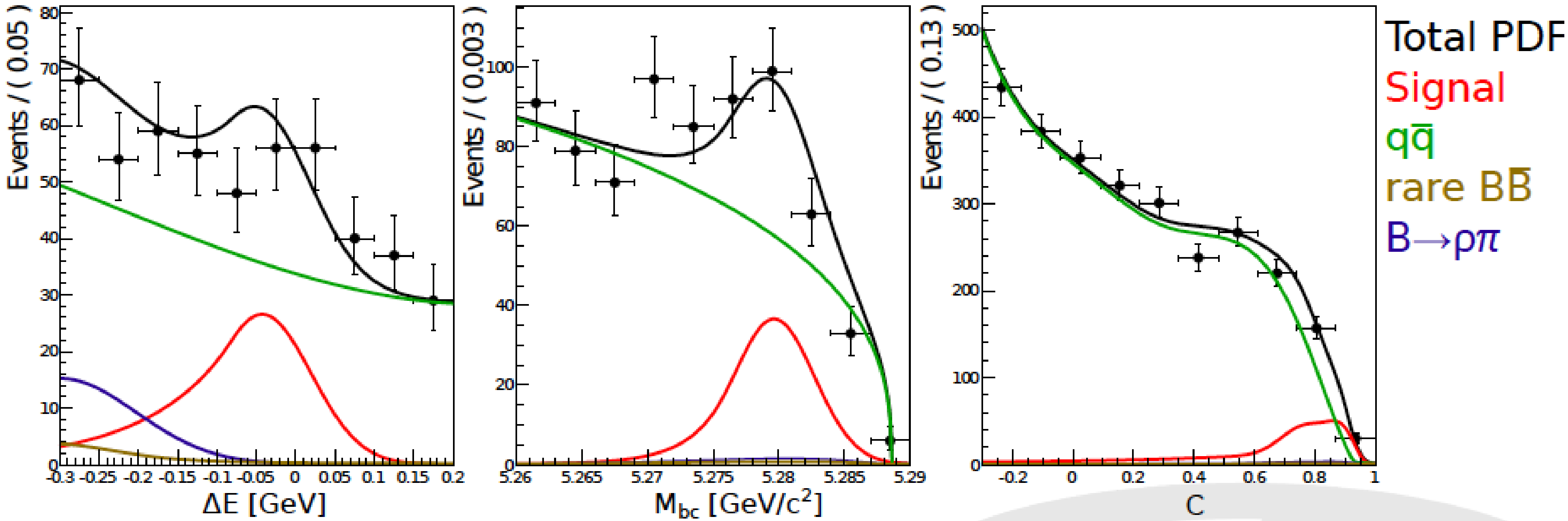
BaBar (Valencia) did this and found a 14σ signal for T violation !

M. Petric

New Belle result on $B \to \pi^0 \pi^0$

Timing eliminates calorimeter pile-up bkg

$B^0 \to \pi^0\pi^0$ – fit results (Preliminary)

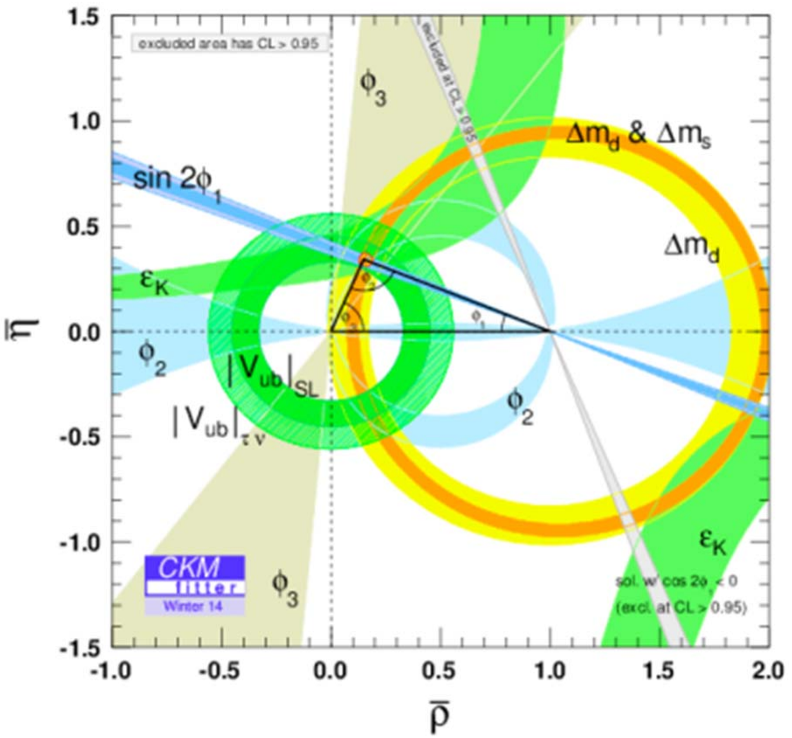


$$\mathcal{B}\left(B^0 \to \pi^0\pi^0\right) = (0.90 \pm 0.12 \pm 0.10) \times 10^{-6} \quad (6.7\sigma)$$

A difficult mode for hadron colliders

Results from Global Fits to Data (CKMFitter Group)

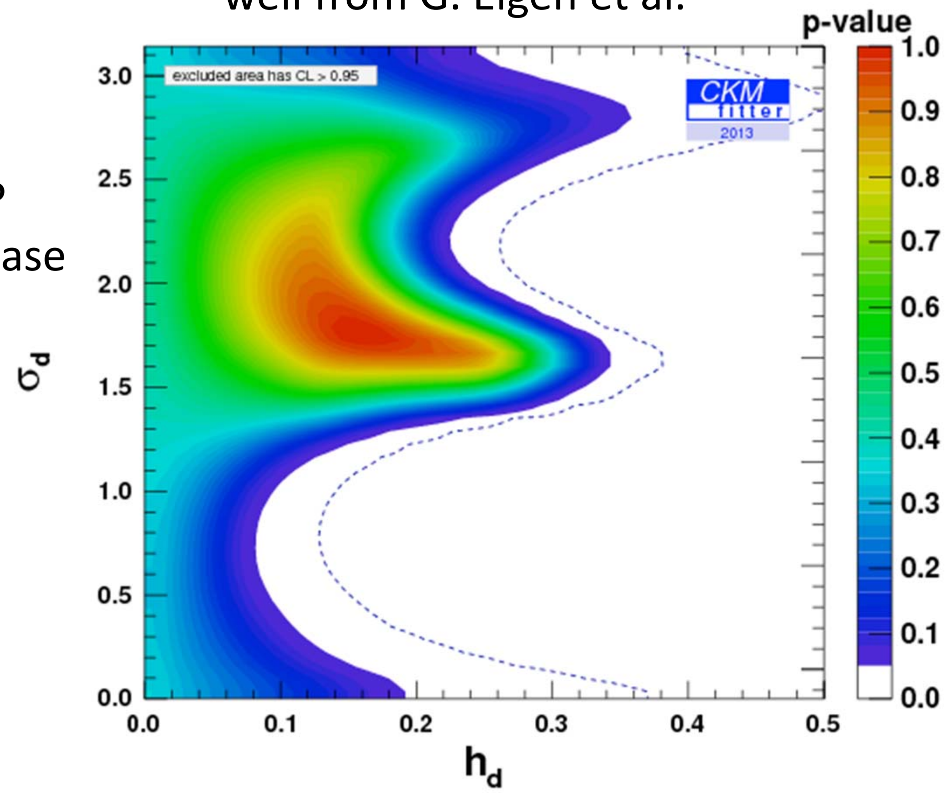
Great progress on φ_3 or γ (first from B factories and now in the last two years from LHCb (several new results at ICHEP2014). <u>These measure the phase of V_{ub}</u>



Looks good
(except for an issue with $|V_{ub}|$)

ICHEP2014: Similar results from UTFIT (D. Derkach) as well from G. Eigen et al.

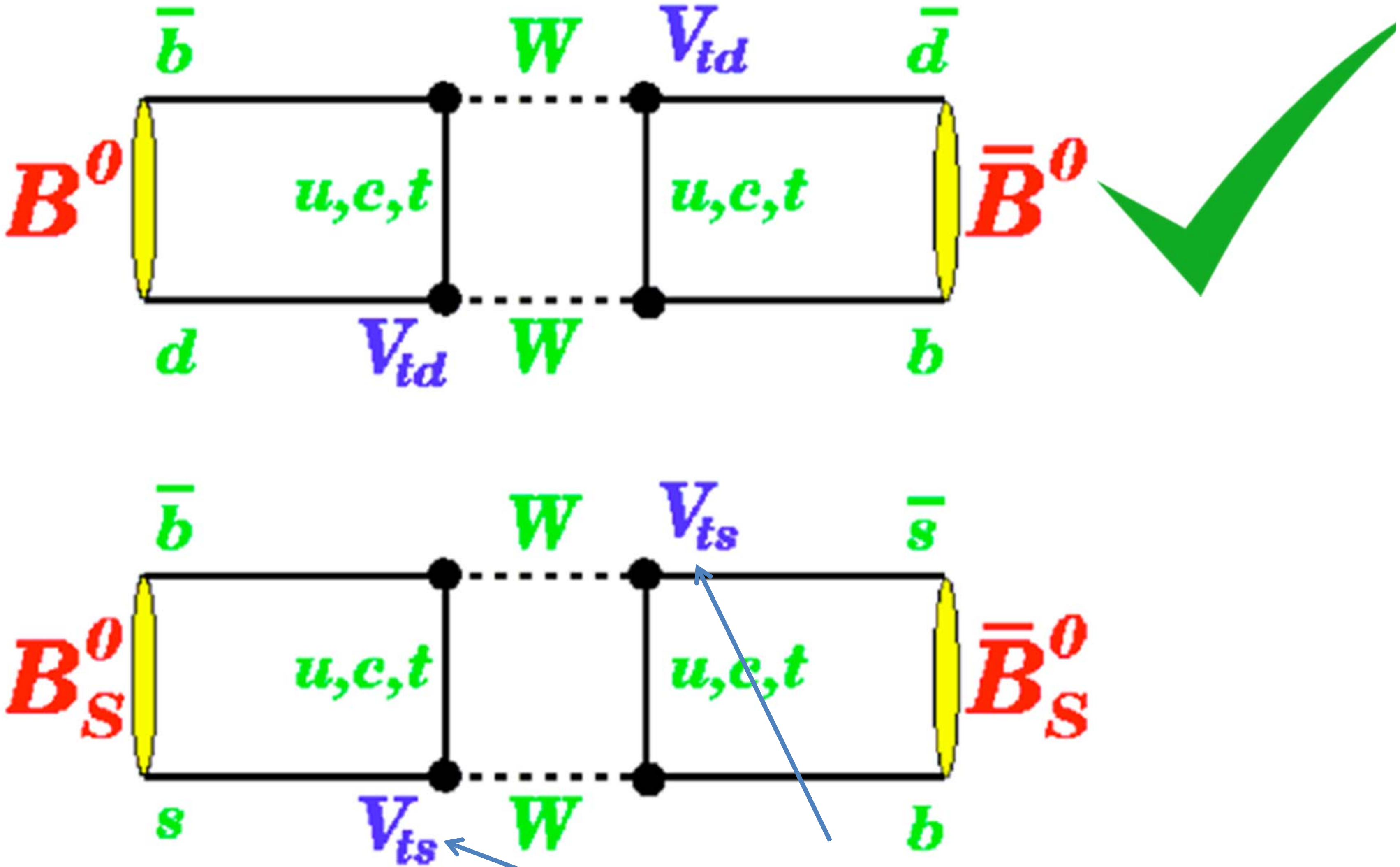
NP Phase



NP/SM amplitude ratio

But a 10-20% NP amplitude in B_d mixing is perfectly compatible with all current data.

Boxes

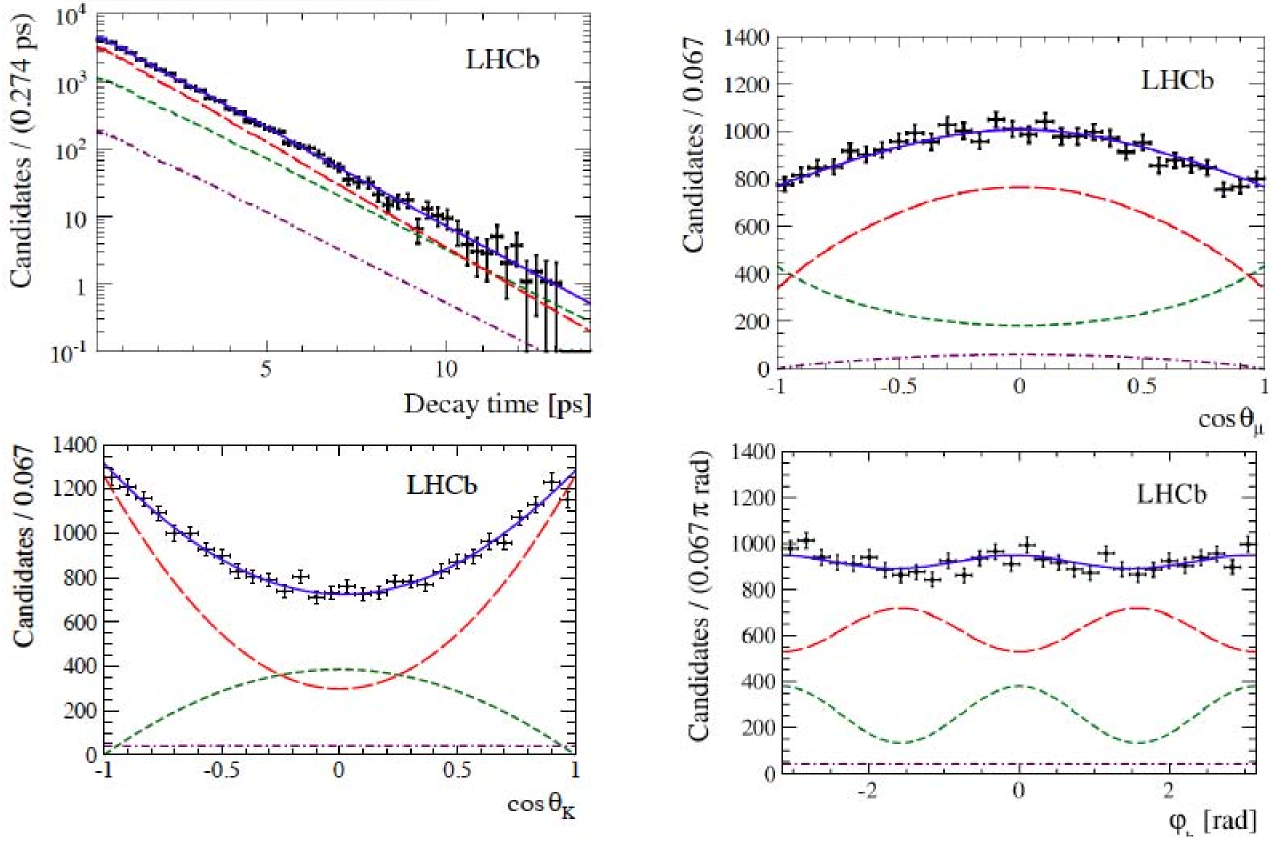


Although B factories can run on the Upsilon(5S), LHCb dominates here

No phase expected from SM but possible from NP particles

$B_s \to J/\psi\phi$ angular and decay time projections

PRD 87 (2013)112010,arXiv:1304.2600



$$\Phi_s = +0.07 \pm 0.09 \pm 0.01\, rad$$

$B_s \to J/\psi\varphi$ is a pseudo-scalar to V V decay (mixture of two CP eigenstates). This requires multi-dimensional angular analysis.

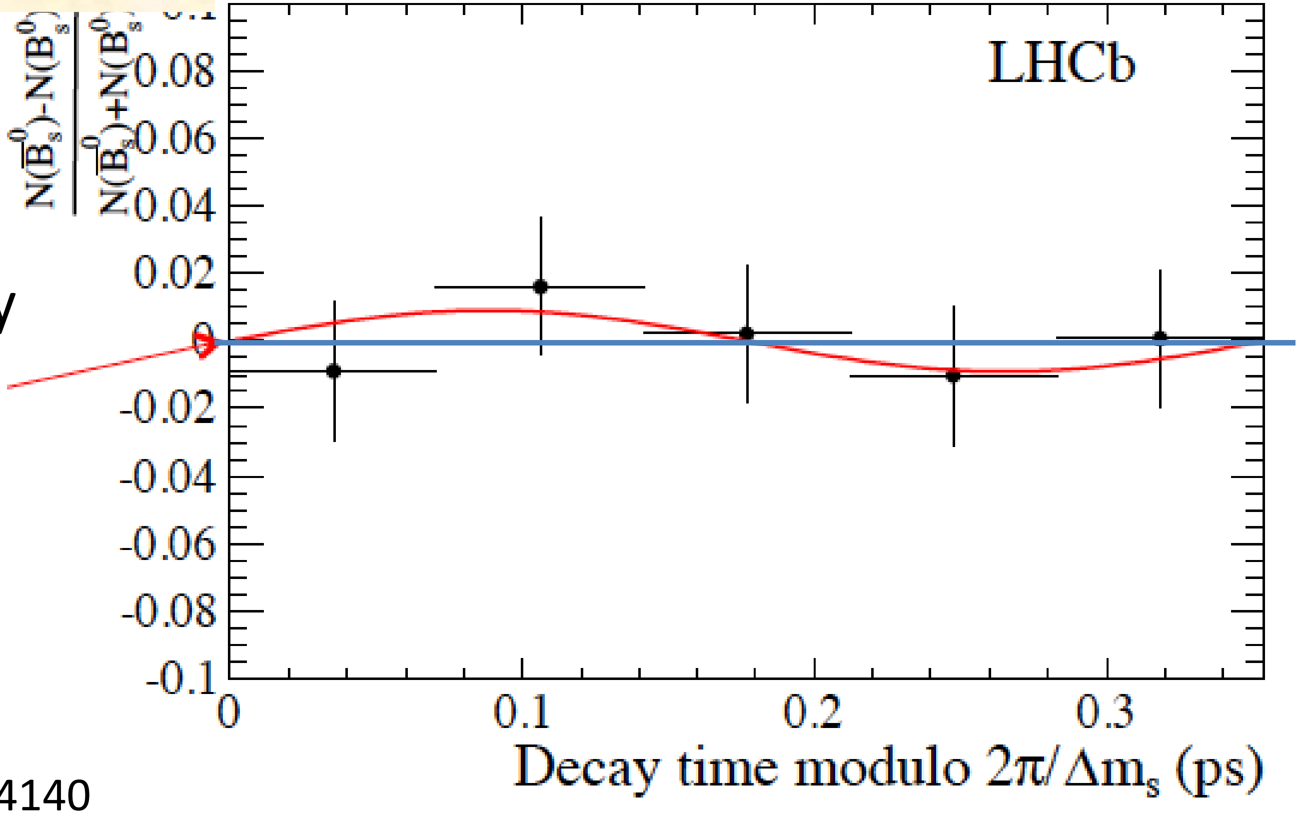
However, $B_s \rightarrow J/\psi\ f_0(980)$ is a pure CP eigenstate since the f_0 (980) is a scalar.

Stone & Zhang pointed out that this mode provides more statistics and a more straightforward analysis. Phys. Rev. D79 (2009) 074024.

Φ_s=(70±68±8) mrad

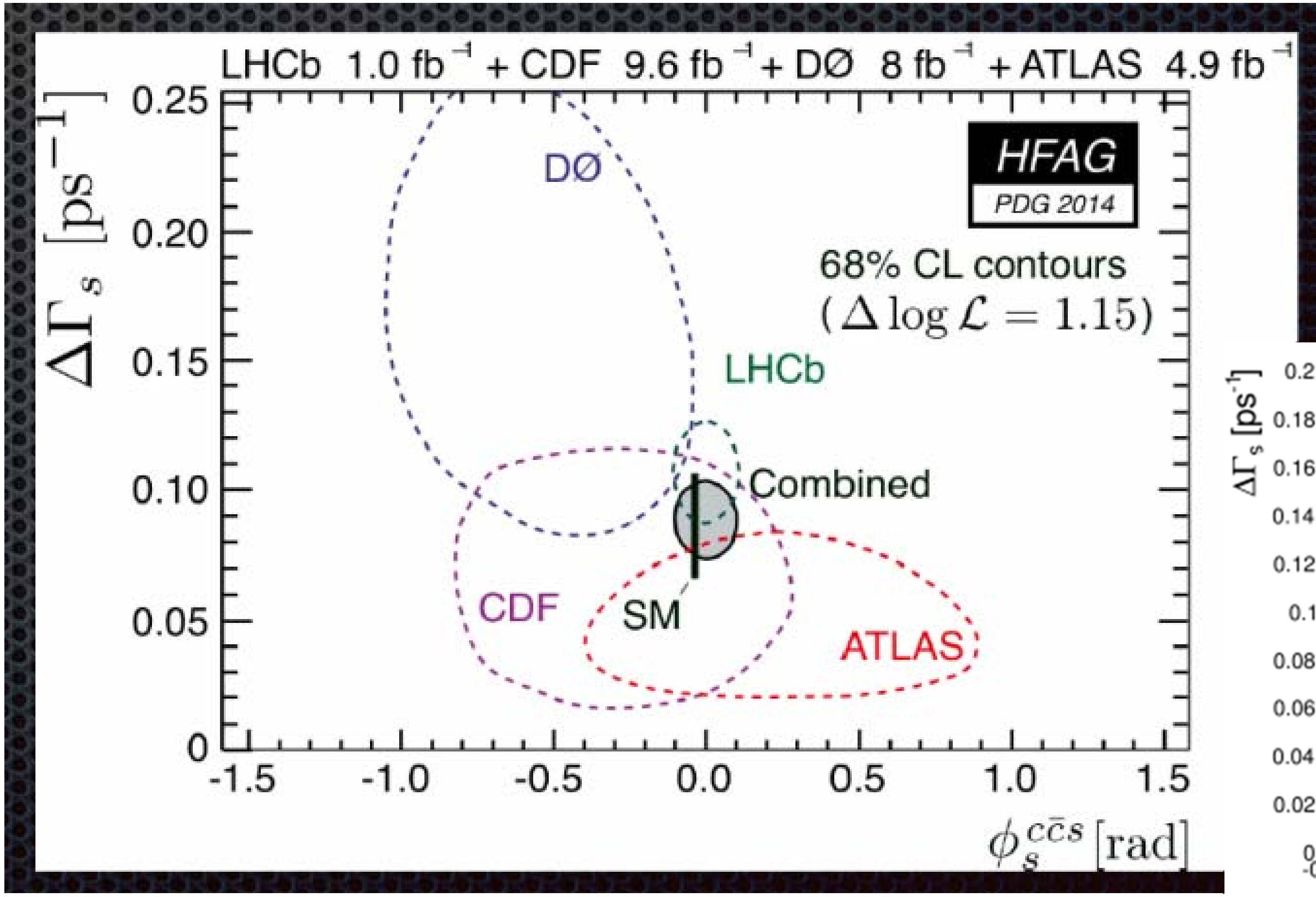
Red curve: expectation for Φ_s = 70 mrad

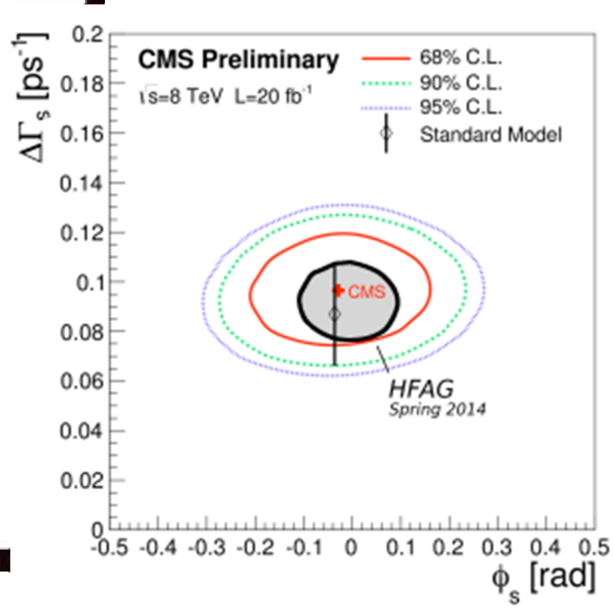
Asymmetry



arXiv: 1405.4140

Results on the phase of B_s-anti B_s mixing (i.e. phase of V_{ts})

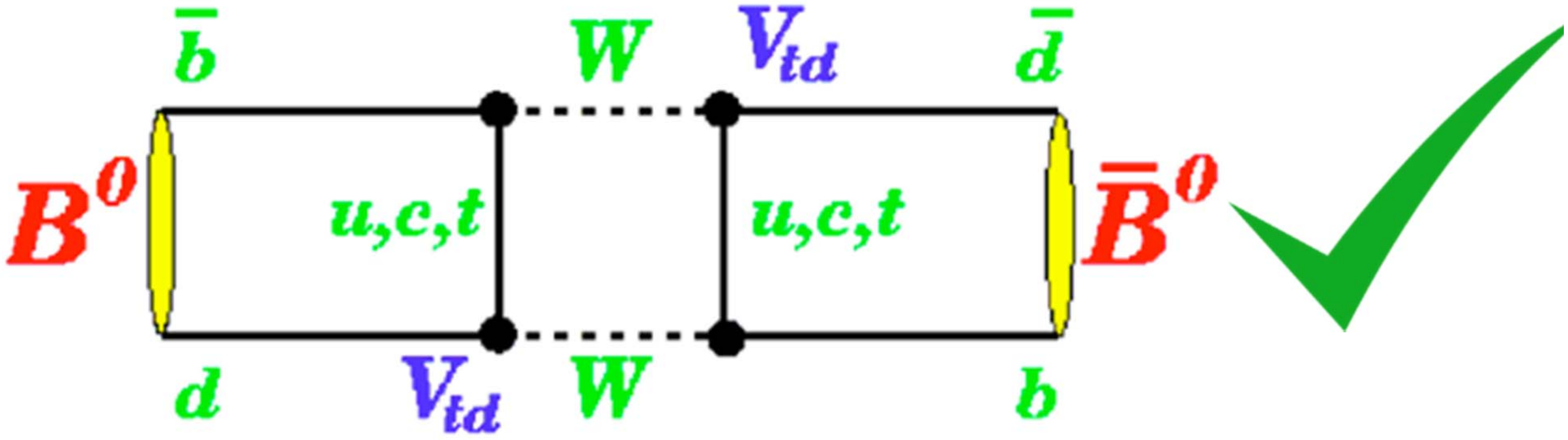


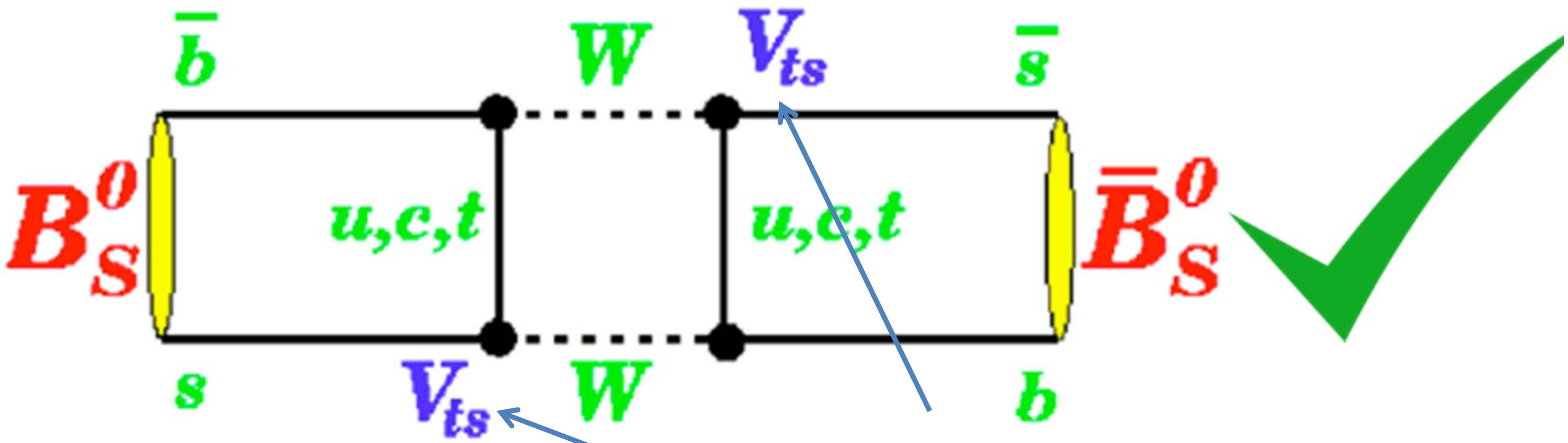


R. Aaij: Does not include arXiv: 1405.4140 using $J/\psi\pi\pi$ decays, which are dominantly S-wave.

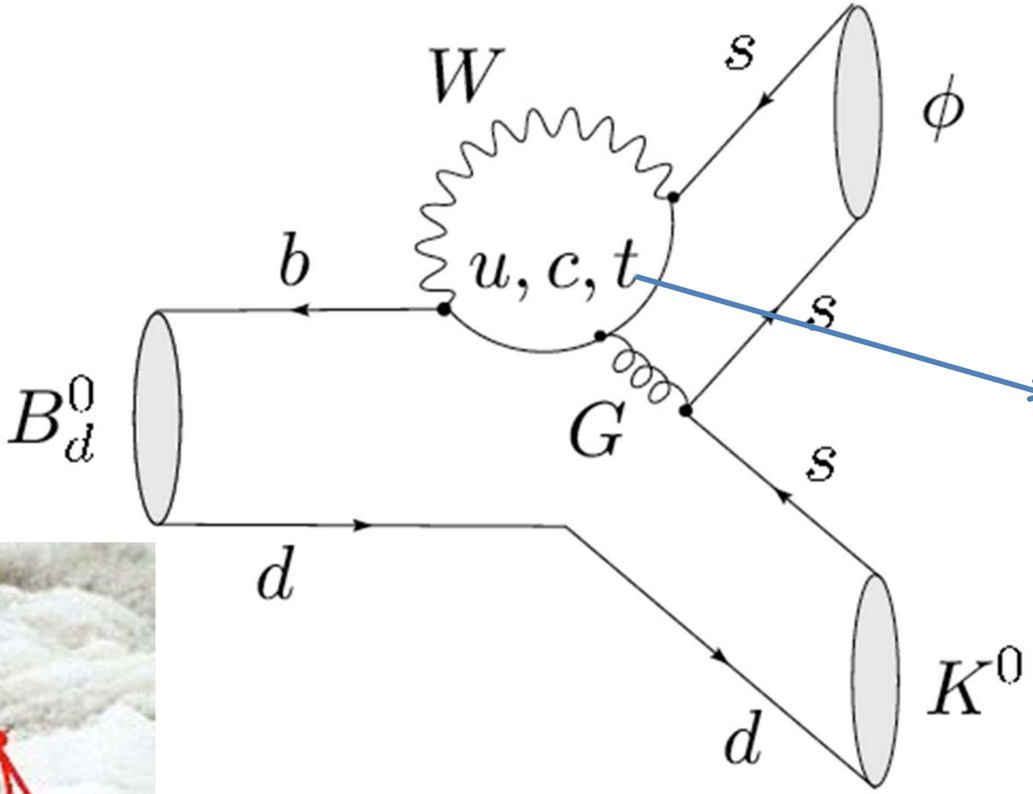
Does not include new CMS result at ICHEP2014 (G. Fedi)

Boxes

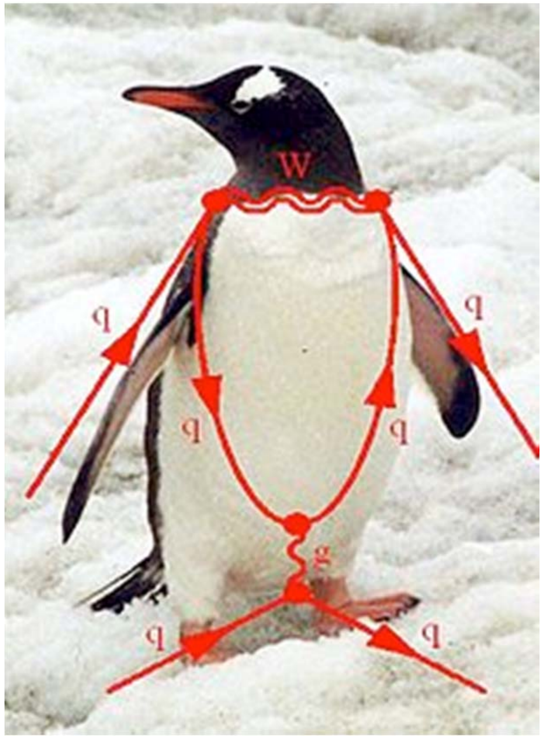


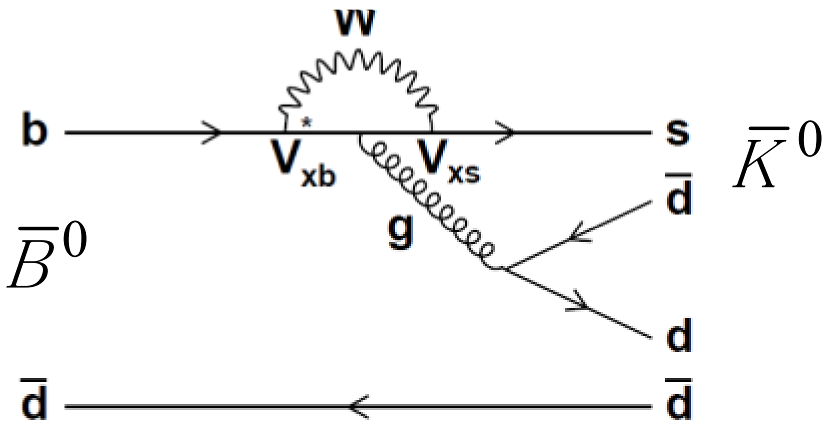


No phase expected from SM but possible from NP particles



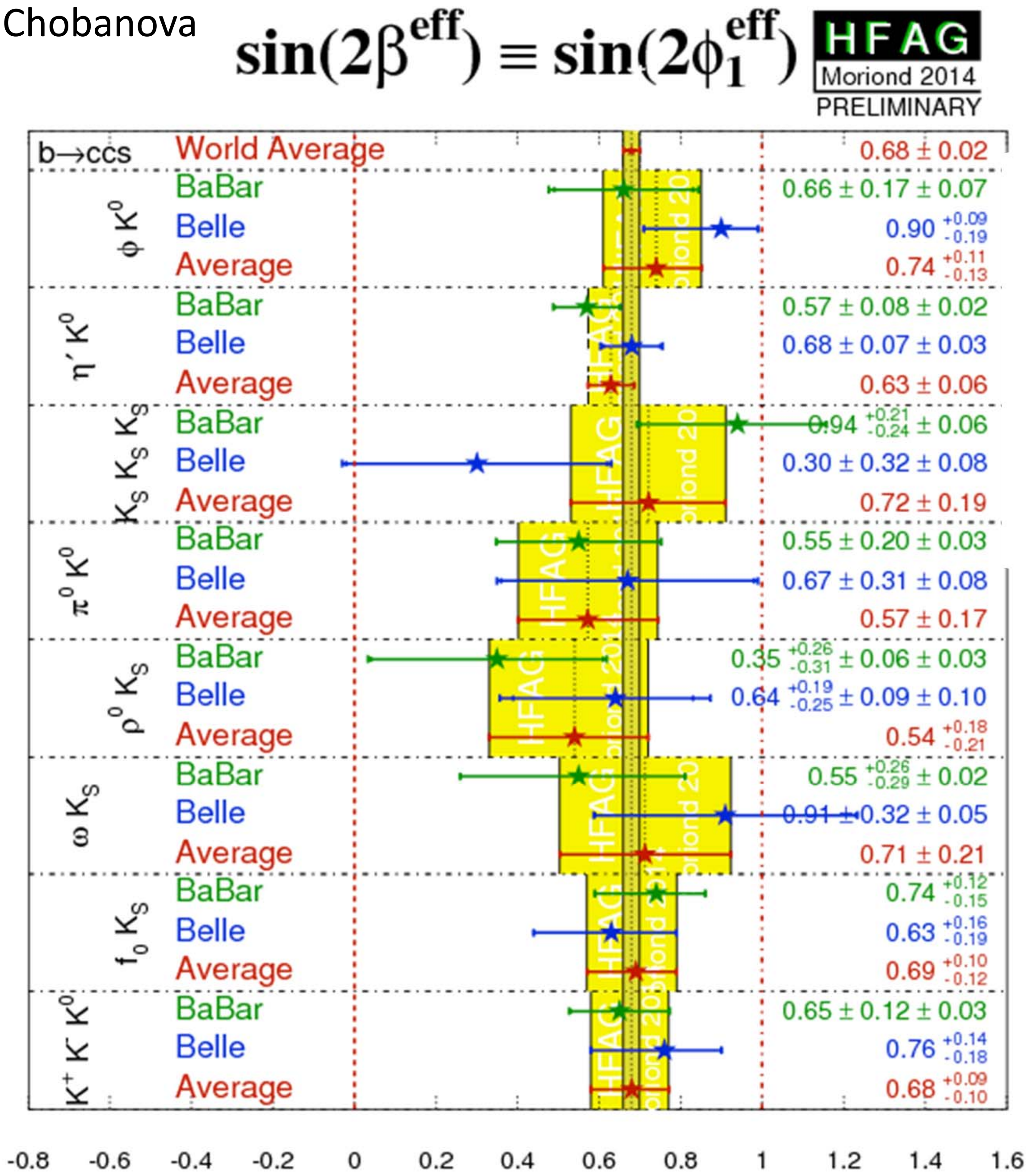
Phase of V_{ts}



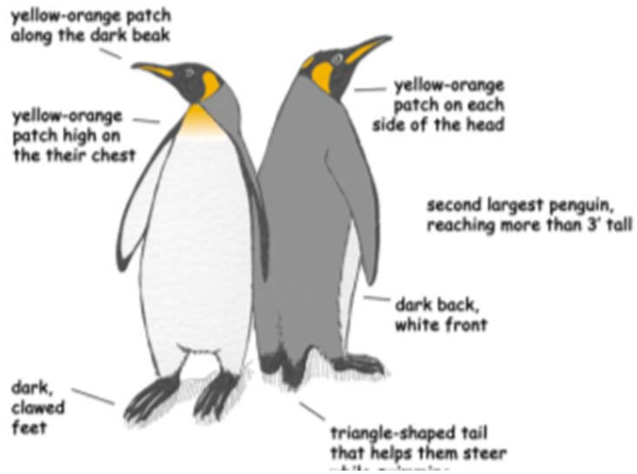


ICHEP2014: New Belle results on $B \to \omega K_S$, $B \to \eta' K_S$

Talk by
V.Chobanova



New Physics Phases in Penguin b→s decays



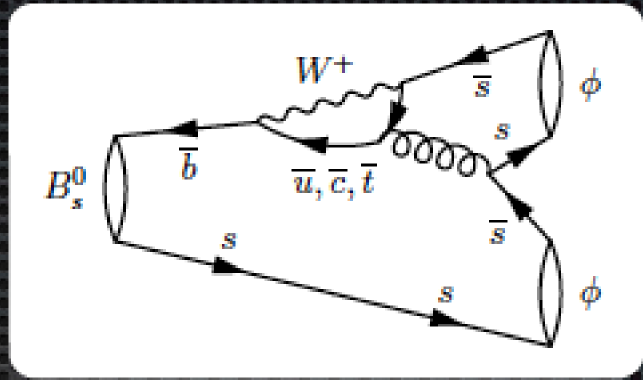
<u>No evidence for NP at current level of sensitivity</u>

LHCb is absent from this game (lower K_S eff and flavor tagging eff) but contributes in Bs modes.

M. Needham

But LHCb dominates these B_s modes

Again, NP Penguin phase is found to be consistent with zero



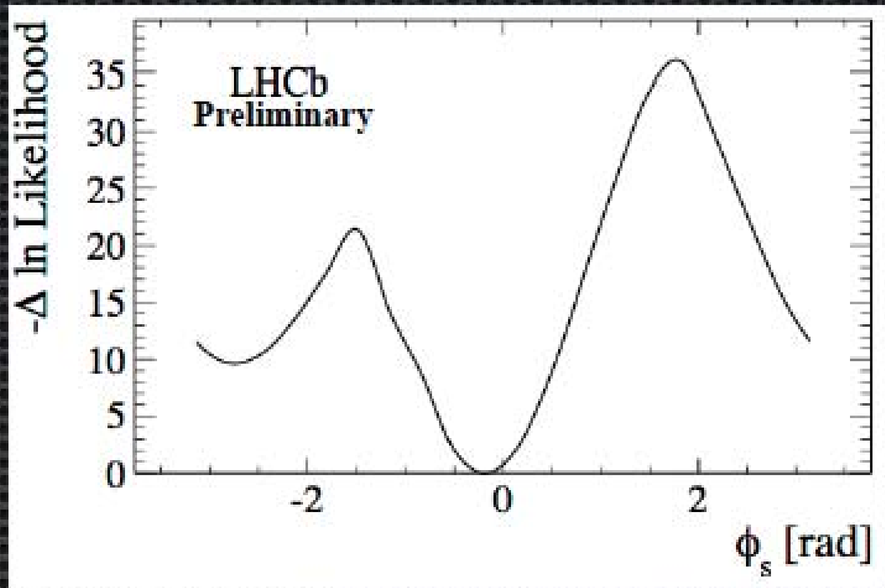
$B_s \to \varphi\varphi$ - Time-Dependent Results

Results are found to be:

$\phi_s = -0.17 \pm 0.15 \pm 0.03$
$\lambda = 1.04 \pm 0.07 \pm 0.03$

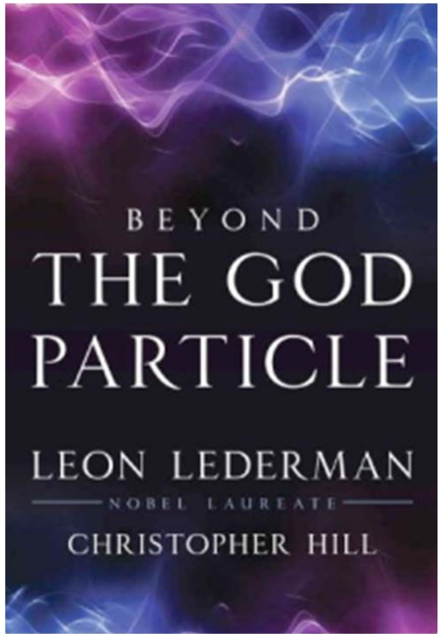
$|A_0|^2 = 0.364 \pm 0.012 \pm 0.009$
$|A_\perp|^2 = 0.305 \pm 0.013 \pm 0.005$

First uncertainty statistical and second systematic

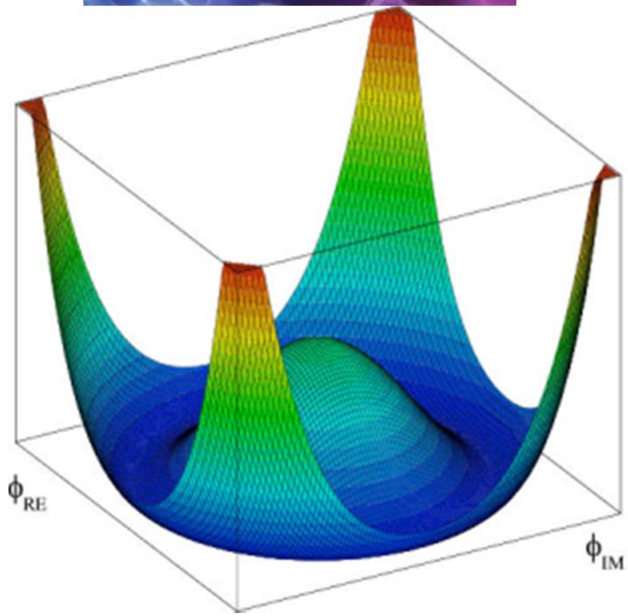


“Missing Energy” Decays

The BEH boson is now firmly established by experimental results from ATLAS and CMS.



Does the GP (Brout-Englert-Higgs particle) have a “brother” i.e. the charged Higgs ?

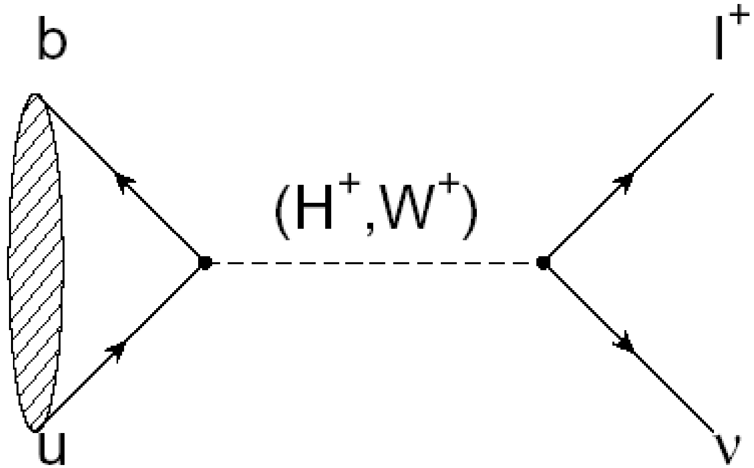


Measurements at B factories and direct searches at hadron colliders take *complementary* approaches to this important question.

$B^+ \rightarrow \tau^+ \nu_\tau$

(Decays with *Large* Missing Energy)

Sensitivity to new physics from a <u>*charged Higgs*</u>



$$\mathcal{B}(B^+ \to \tau^+ \nu_\tau) = \frac{G_F^2 m_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}_{(B\to\tau\nu)} = \mathcal{B}_{SM} \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)$$

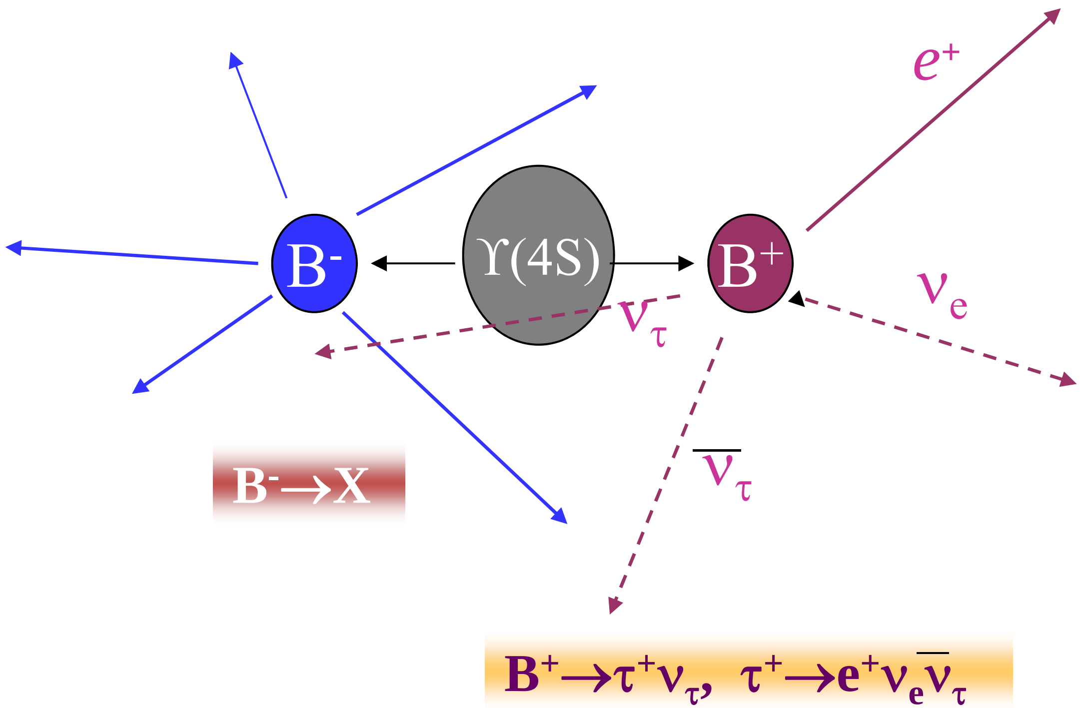
The B meson decay constant, determined by the B wavefunction at the origin

($|V_{ub}|$ taken from indep. measurements.)

Consumer's guide to charged Higgs

- *Higgs doublet of type I* (couples with equal strength to upper and lower generations)
- *Higgs doublet of type II* (couples with different strength to u and d-type quarks, $\tan(\beta) = v_u/v_d$ (favored NP scenario e.g. MSSM)
- *Higgs doublet of type III* (not type I or type II; anything goes)

*Why measuring **B–>τ ν** is non-trivial*



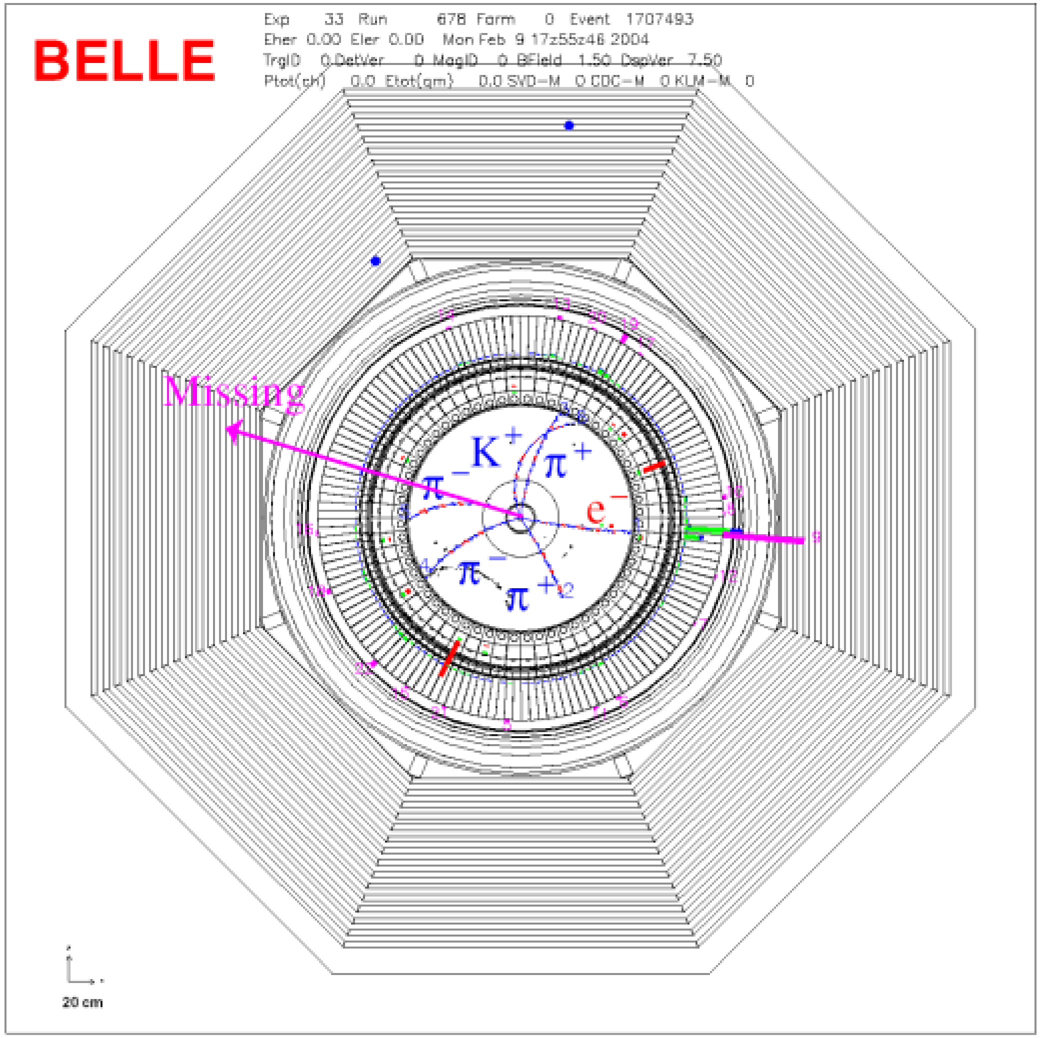
Most of the sensitivity is from tau modes with 1-prong

The experimental signature is rather difficult:
B decays to a single charged track + nothing

(This may be hard at a hadron collider)

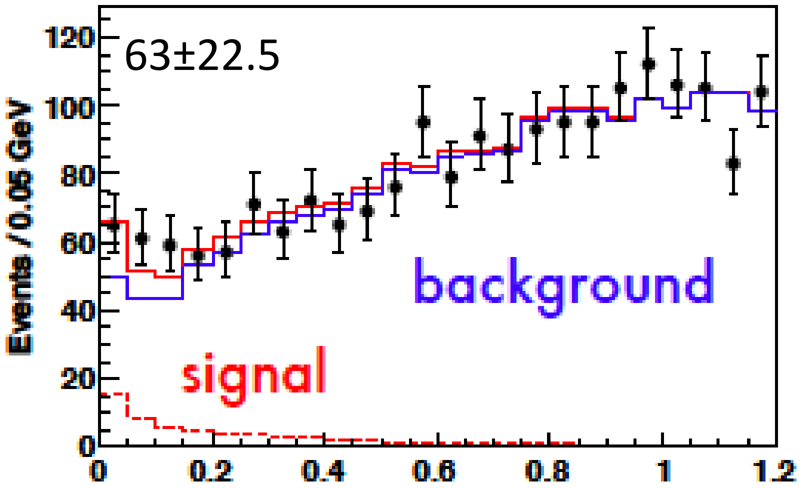
Example of a Missing Energy Decay ($B^- \rightarrow \tau^- \nu_\tau$) in Data

$$B^+ \rightarrow D^0\pi^+$$
$$(\rightarrow K\pi^-\pi^+\pi^-)$$
$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$



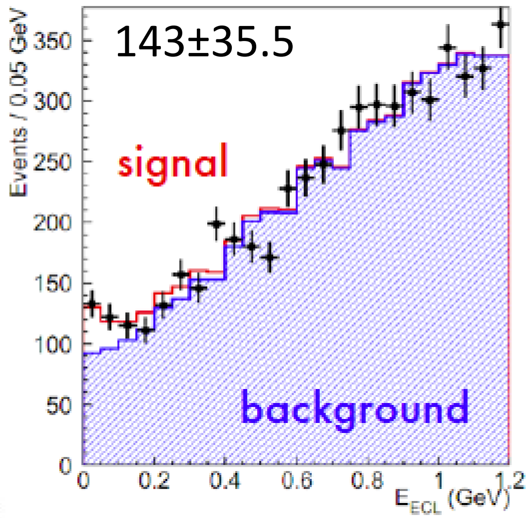
The clean e+e- environment makes this possible

Example: Belle measurement with full data sample and hadronic tags



Idea: With the “single B meson beam”, we look for a single track from a τ, missing energy/momentun and extra calorimeter energy close to zero.

Semileptonic tags



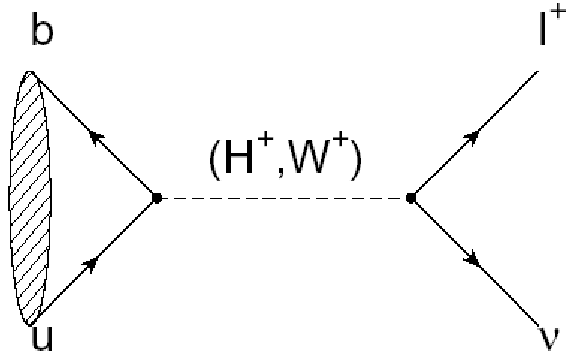
With the full B factory statistics only “evidence”. No single observation from either Belle or BaBar.

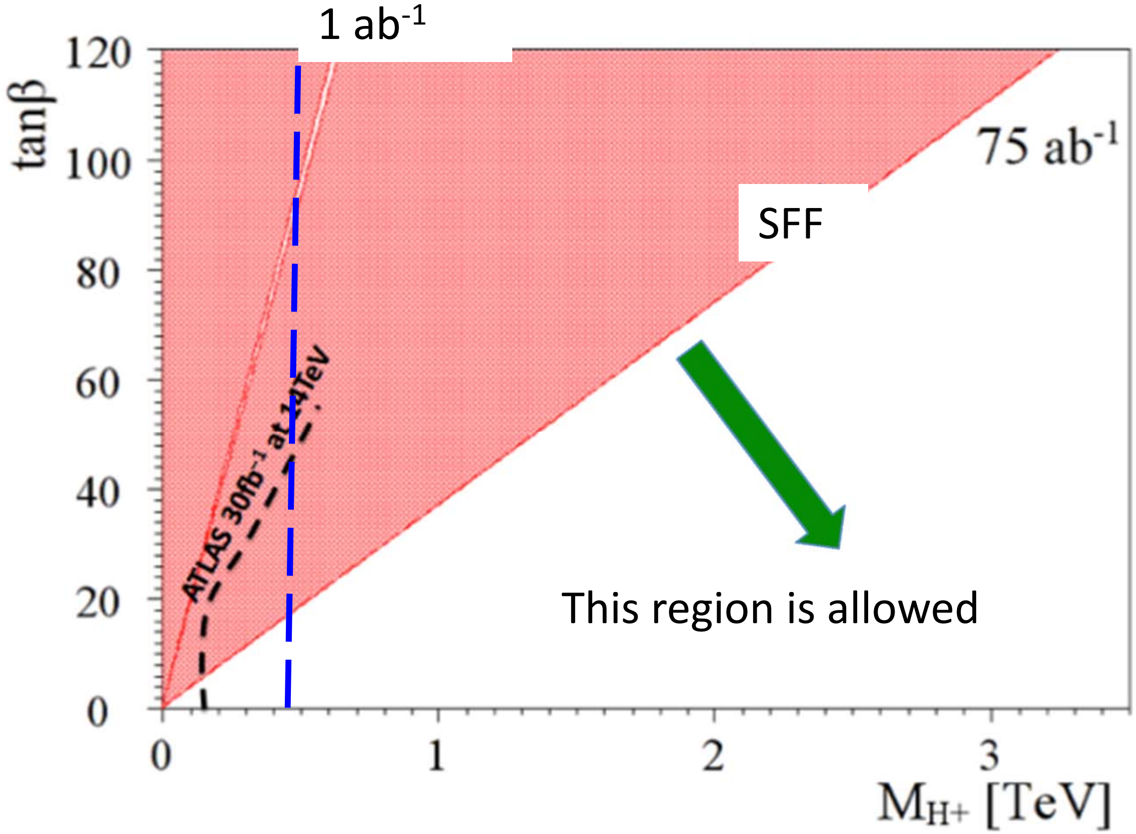
The horizontal axis is the “Extra Calorimeter Energy”

Complementarity of e+ e- factories and LHC

(Slide adapted from A. Bevan)

The current combined limit places a stronger constraint than direct searches from LHC exps. for the next few years.

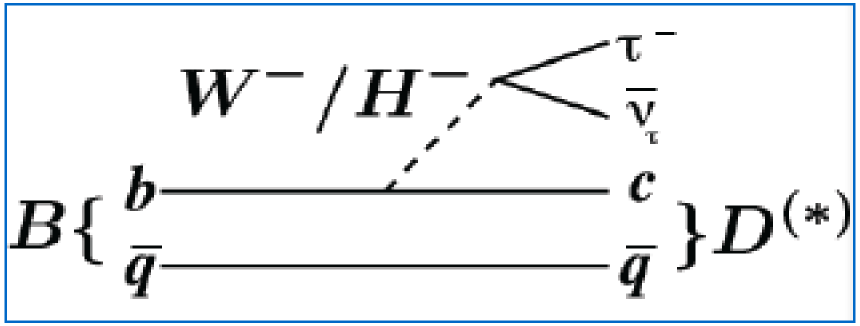


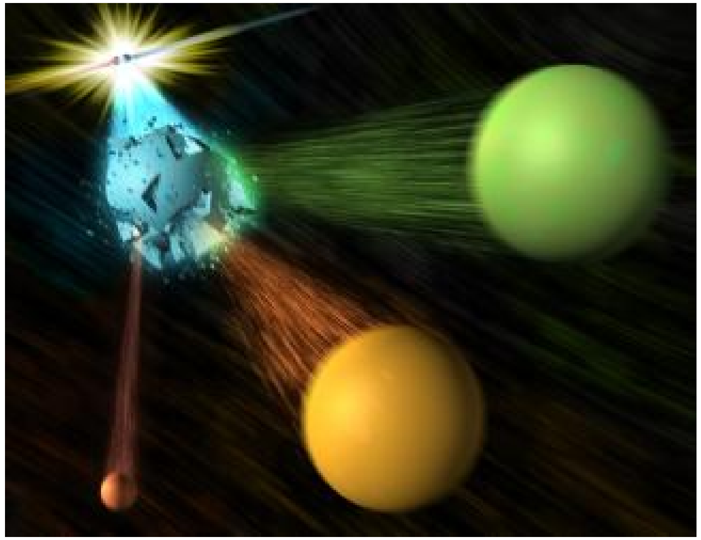


$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

Currently inclusive b to sγ rules out m_{H+} below ~400 GeV/c^2 range (independent of tanβ)

http://arxiv.org/abs/1208.2788





$$\mathcal{R}(D^{(*)})_{2HDM} = \mathcal{R}(D^{(*)})_{SM} + A_{D^{(*)}} \frac{\tan^2\beta}{m_{H^+}^2} + B_{D^{(*)}} \frac{\tan^4\beta}{m_{H^+}^4}$$

	Dτν	D*τν
$A_{D^{(*)}}$ (GeV^2)	-3.25 ± 0.32	-0.230 ± 0.029
$B_{D^{(*)}}$ (GeV^4)	16.9 ± 2.0	0.643 ± 0.085

$$R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)}$$

⟶ Signal

⟶ Normalization ($l = e$ or μ)

Slide adapted from A. Soffer

Example from a recent BaBar paper

Signals in B→D$^{(*)}$ τυ (489±63, 888±63)

Missing mass variable:

$m_{miss}^2 = p_{miss}^2 = (p[e^+e^-] - p_{tag} - p_{D(*)} - p_l)^2$

P_l^* = momentum of lepton in B rest frame

Production of B meson pairs at threshold is critical to the separation of backgrounds from the missing energy/ momentum signal.

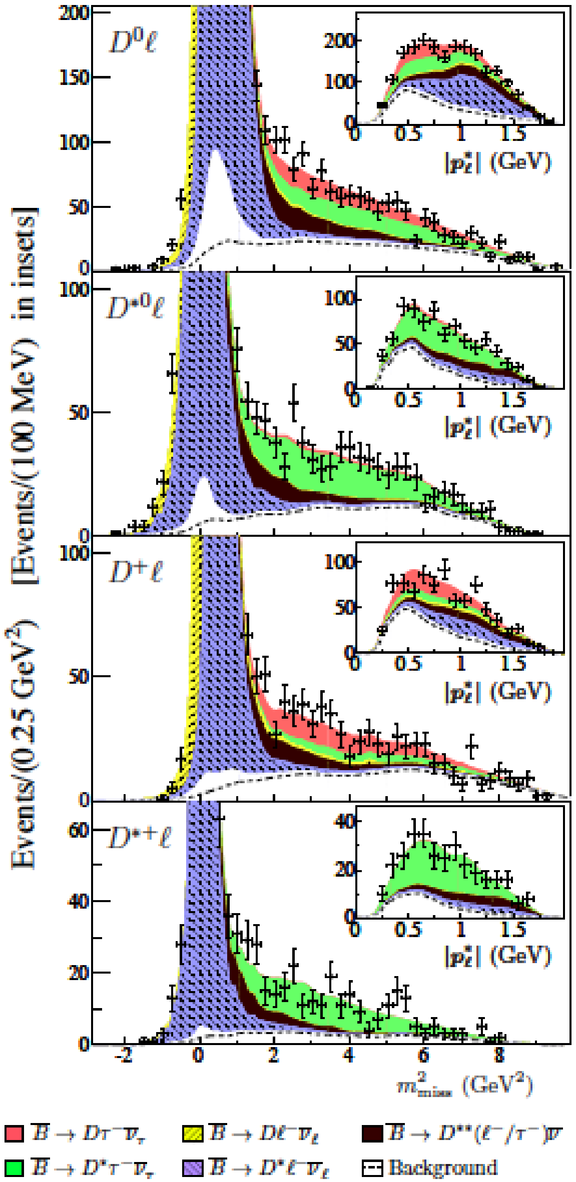


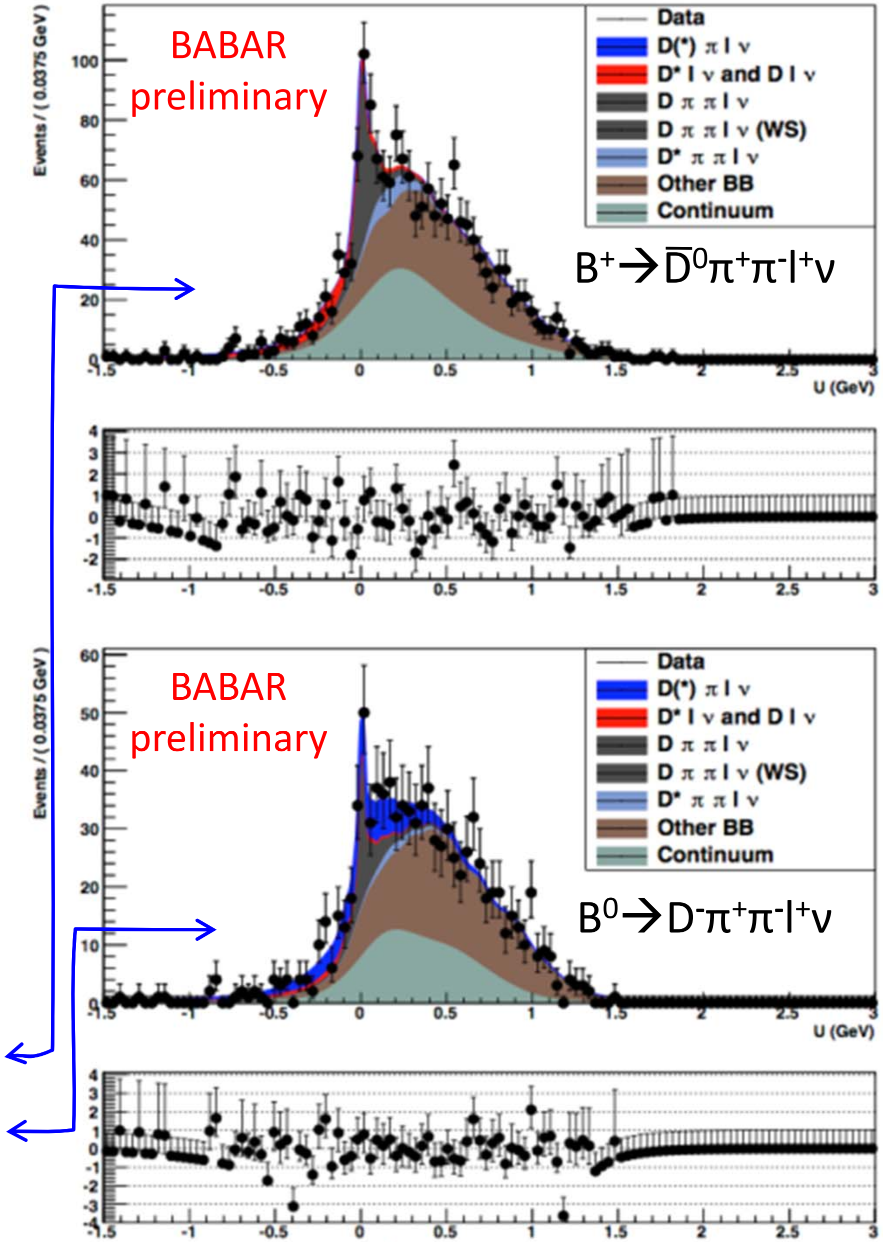
FIG. 1. (Color online) Comparison of the data and the fit projections for the four $D^{(*)}\ell$ samples. The insets show the $|p^*_\ell|$ projections for $m^2_{miss} > 1\,\text{GeV}^2$, which excludes most of the normalization modes. In the background component, the region above the dashed line corresponds to charge cross-feed, and the region below corresponds to continuum and $B\overline{B}$.

BABAR@ICHEP2014: multi-body semi-leptonic b→c decays

- Background for $B \to D^{(*)}\tau\nu$ analysis
- Fully reconstruct tag B and semileptonic signal decays,

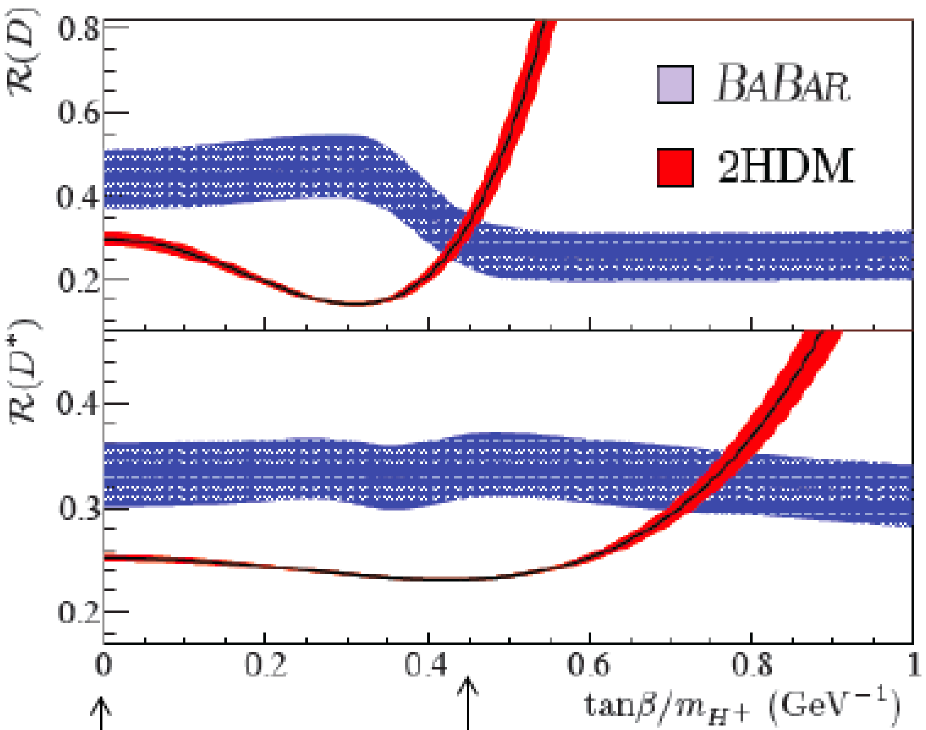
  $B \to D^{(*)}\pi^+\pi^- l\nu$
- Averaging B^+ and B^0, significance is 5.1σ for $D\pi^+\pi^- l\nu$, 3.5σ for $D^*\pi^+\pi^- l\nu$
- $B \to D^{(*)}\pi\pi l\nu$ decays (including π^0) fill ~1/2 of gap $\mathcal{B}(b \to cl\nu) - \Sigma\, \mathcal{B}(B \to X_c l\nu)$
- Parallel contribution by Thomas Lück

Mode	Signal	BF×10^4 (quoted for B^+)	Signif
$D^0\pi^+\pi^-$	189 ±39	21.0 ±4.5 ±2.8 ±1.2	4.4σ
$D^+\pi^+\pi^-$	57 ±20	11.4 ±4.1 ±2.6 ±0.6	2.6σ
$D^{*0}\pi^+\pi^-$	75 ±36	9.2 ±4.4 ±2.0 ±0.3	1.9σ
$D^{*+}\pi^+\pi^-$	58 ±19	13.2 ±4.5 ±2.4 ±0.3	2.9σ



$U\ (= E_{miss} - |\mathbf{p}_{miss}|)$

Limits on type-II 2HDM

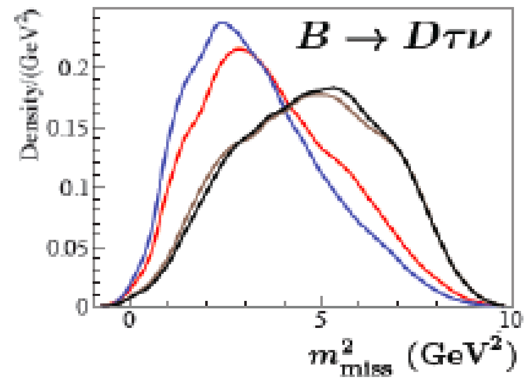


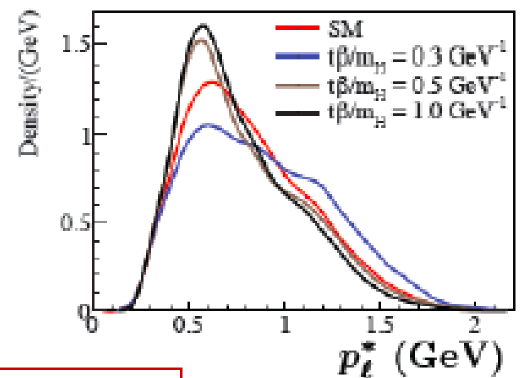
$\tan\beta/m_{H^+} =$
0.44 ± 0.02 GeV^{-1}

$\tan\beta/m_{H^+} =$
0.75 ± 0.04 GeV^{-1}

SM

2HDM modifies fit-variable distribution and hence the efficiency

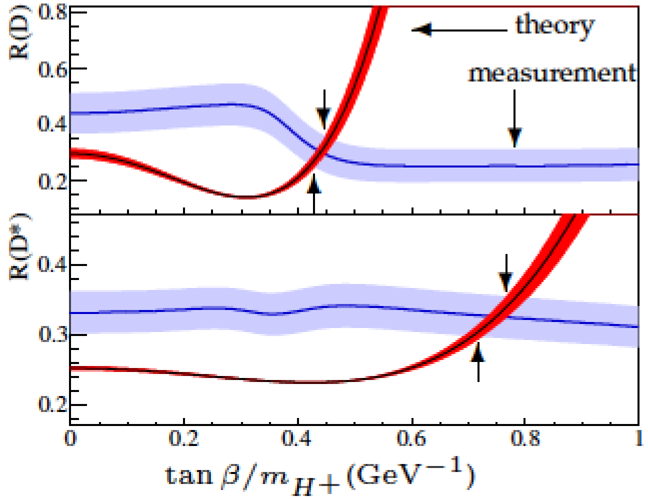




Best point is $\tan\beta/m_{H+} = 0.45$ GeV^{-1}, excluded at 99.8% CL (3.1 σ).
All other values (with $m_{H+} > 15$ GeV) are worse.

BaBar collaboration, Phys. Rev. Lett. 109, 101802 (2012)

"However, the combination of R(D) and R(D*) excludes the type II 2HDM charged Higgs boson with a 99.8% confidence level for any value of tan(β)/m_{H+}"



In other words, found NP but have *killed* the 2HDM NP model.

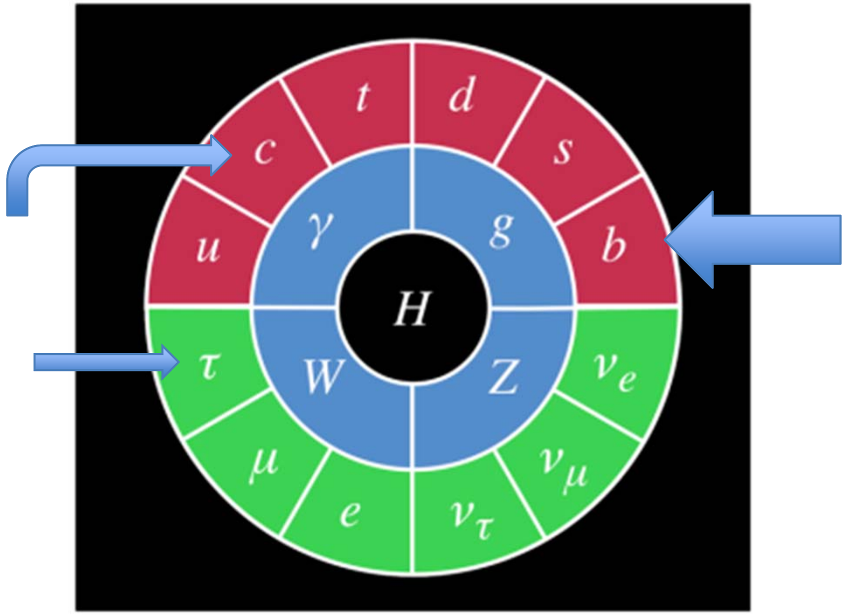
A few points:

(0) Still waiting for the Belle update (PRD 82,.072005 (2010))

(1) If the R values fluctuate back down in the future, this *will allow NP from type II charged Higgs to be viable.*

(2) It is *obvious* that we need two orders of magnitude of data to solve these issues related to the charged Higgs.

2014 is the 50th anniversary of the discovery of CP violation in the kaon sector [see http://pprc.qmul.ac.uk/research/50-years-cp-violation



<u>The Next Generation</u>

Belle II and the LHCb upgrade

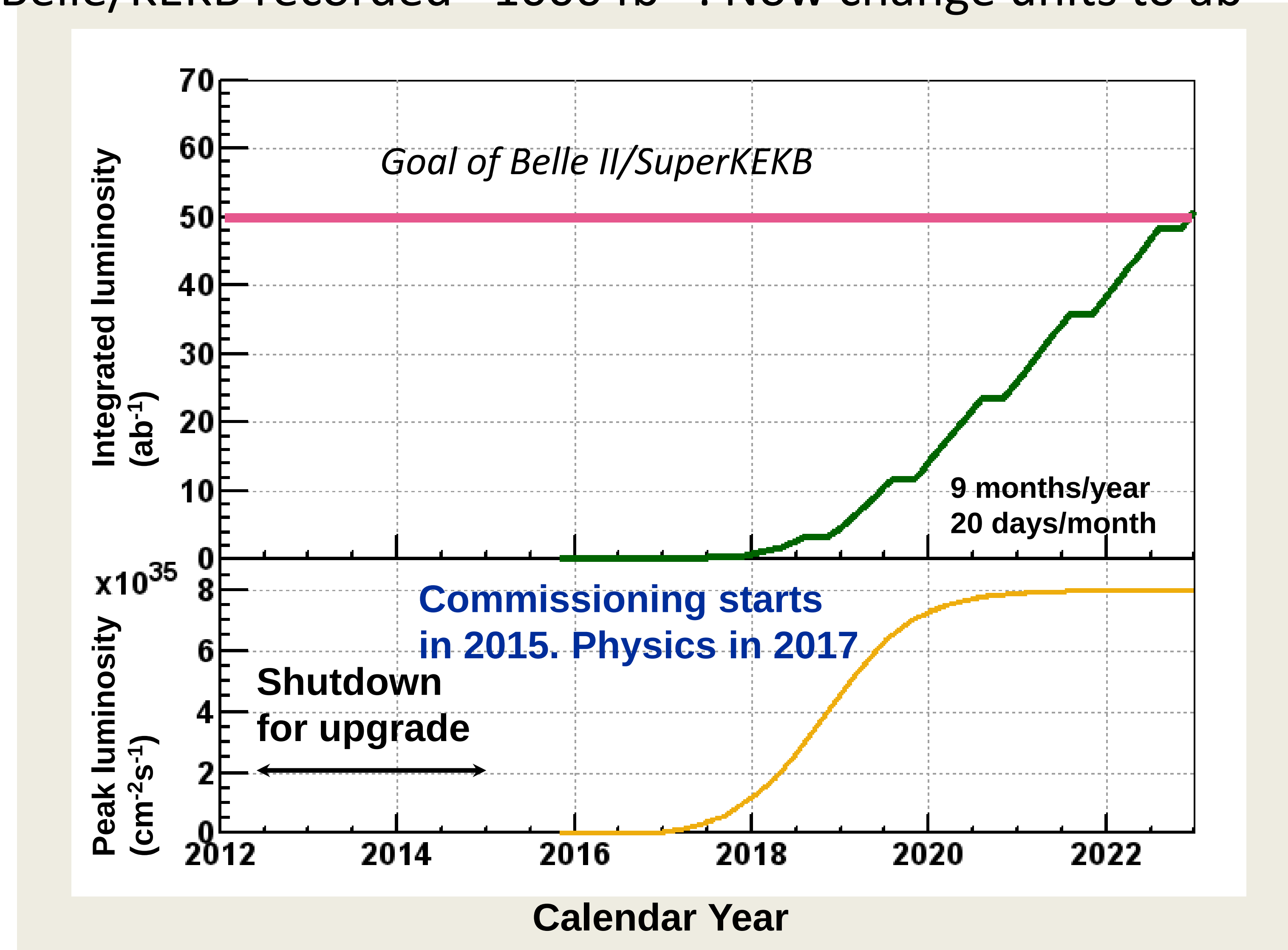
<u>US P5 report (p. v): "Explore the unknown: new particles, interactions, and physical principles"</u>

Physics Reach of Belle II and the LHCb upgrade

Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\|V_{us}\|$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\|V_{cb}\|$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\|V_{ub}\|$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K_S^0\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $\mathrm{A_{FB}}(\mathrm{B} \to \mathrm{K}^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\|q/p\|_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

SuperKEKB luminosity projection

Belle/KEKB recorded ~1000 fb^{-1} . Now change units to ab^{-1}



Compare the Parameters for KEKB and SuperKEKB

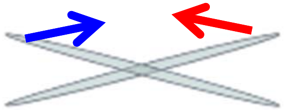
	KEKB Design	KEKB Achieved : with crab	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y / \varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(mm)	1.9	0.94	0.048/0.062
σ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

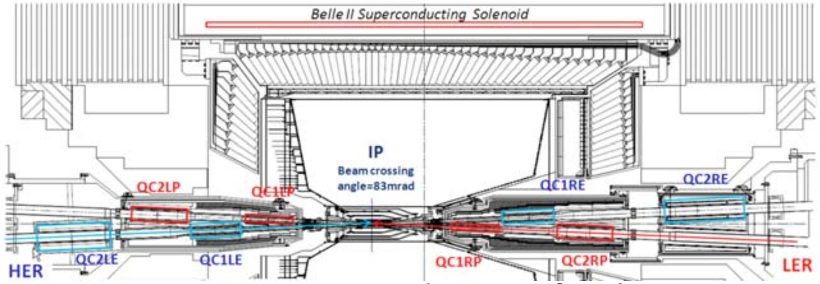
Nano-beams are the key (vertical spot size is ~50nm !!)

This is not a typo

K-I. Kanazawa@ICHEP2014

Colliding bunches





New superconducting final focusing magnets near the IP

e^+ 3.6A

e^- 2.6A

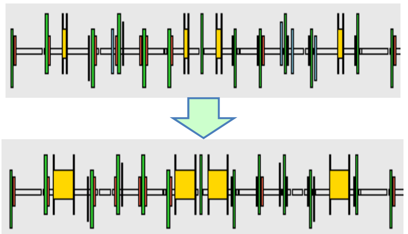
Redesign the lattice to reduce the emittance (replace short dipoles with longer ones, increase wiggler cycles) (*all magnets installed 8/2014*)

KEKB to SuperKEKB

- ◆Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- ◆Beam current X 2

$$L = \frac{\gamma_\pm}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

40 times higher luminosity
$2.1\times10^{34} \rightarrow 8\times10^{35}\ \mathrm{cm^{-2}s^{-1}}$



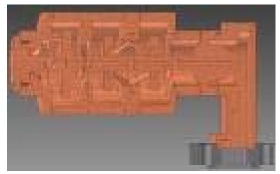
Reinforce RF systems for higher beam currents

Improve monitors and control system

Injector Linac upgrade

Upgrade positron capture section

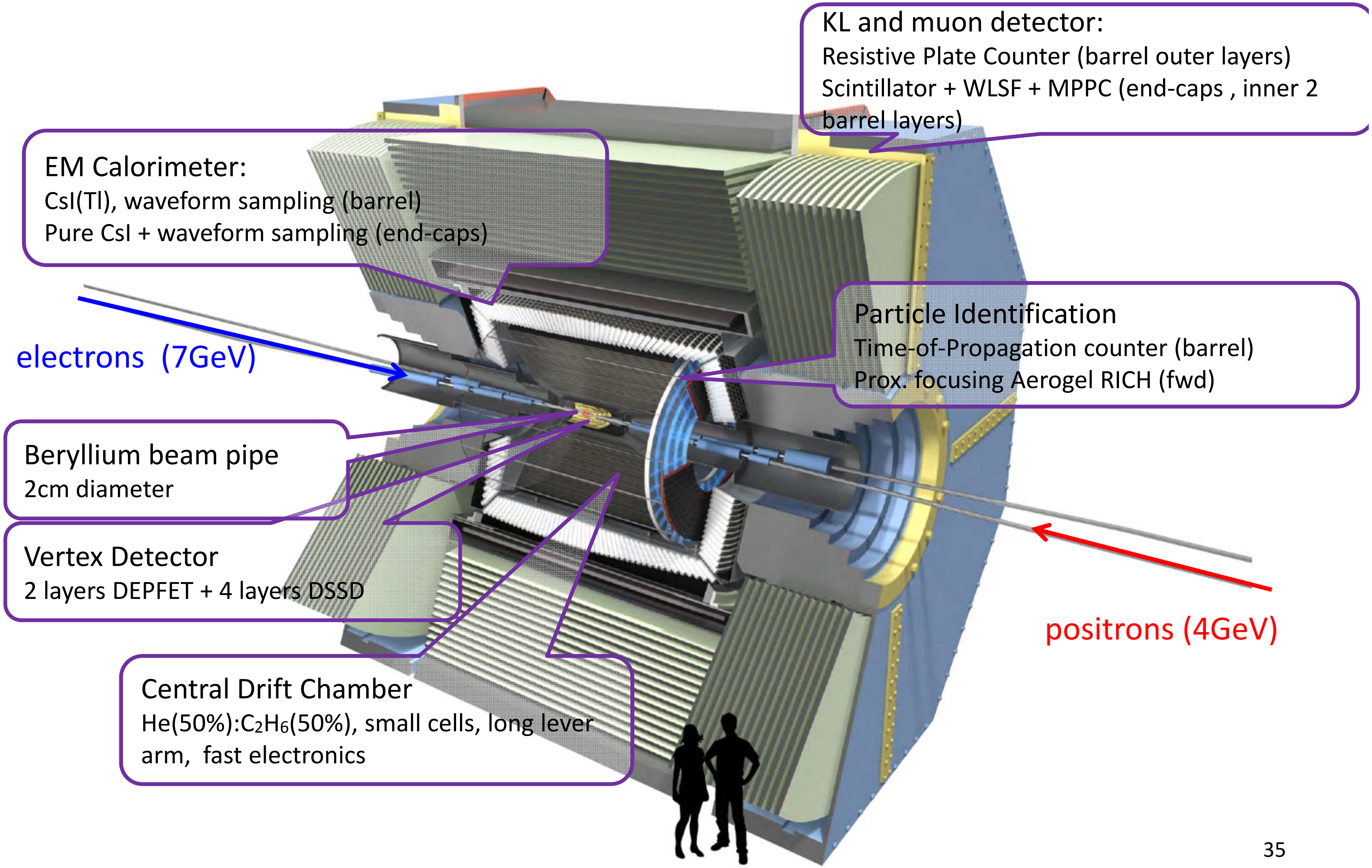
Low emittance RF electron gun



Replace beam pipes with TiN-coated beam pipes with antechambers (*85% installed*)

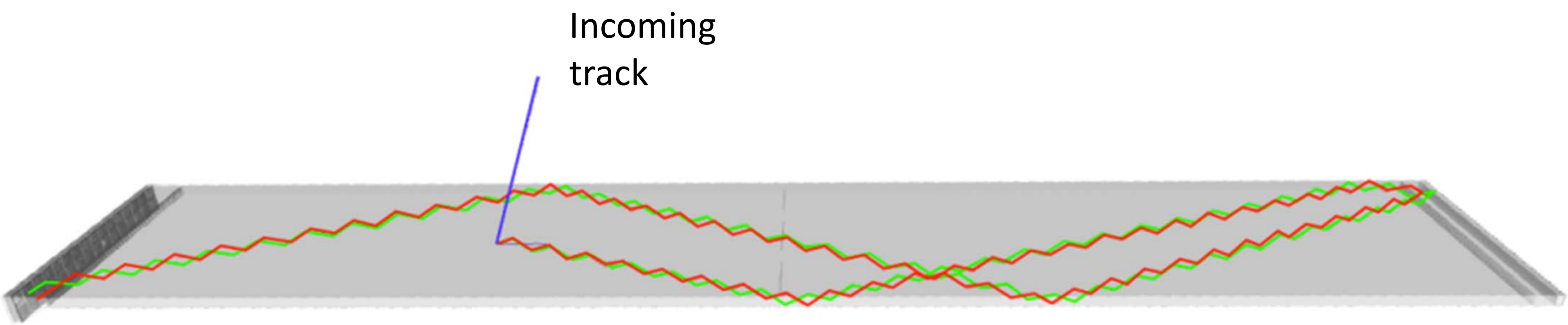
New e+ Damping Ring constructed

Belle II Detector

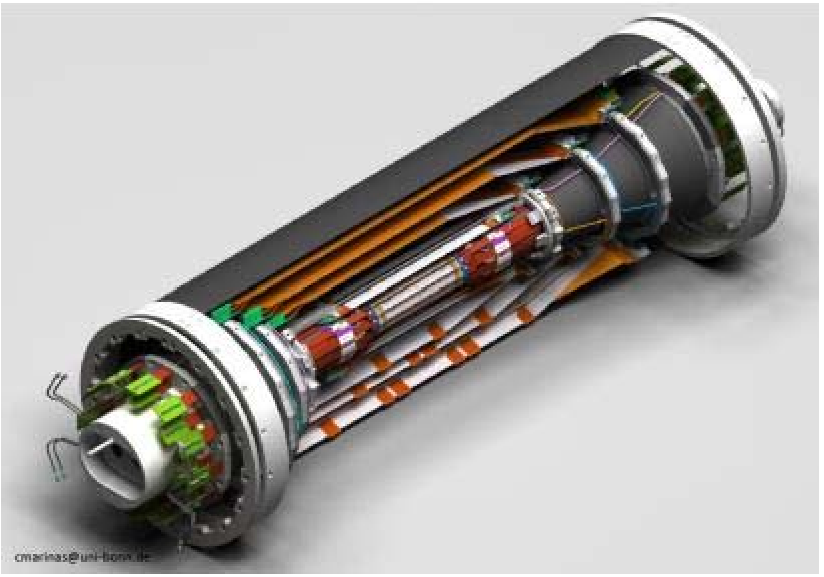


Barrel PID

A GEANT4 event display of a 2 GeV pion and kaon interacting in a TOP quartz bar. (Japan, US, Slovenia, Italy)



Vertexing/Inner Tracking



Beampipe r= 10 mm

DEPFET pixels (Germany, Czech Republic…)

- Layer 1 r=14 mm
- Layer 2 r= 22 mm

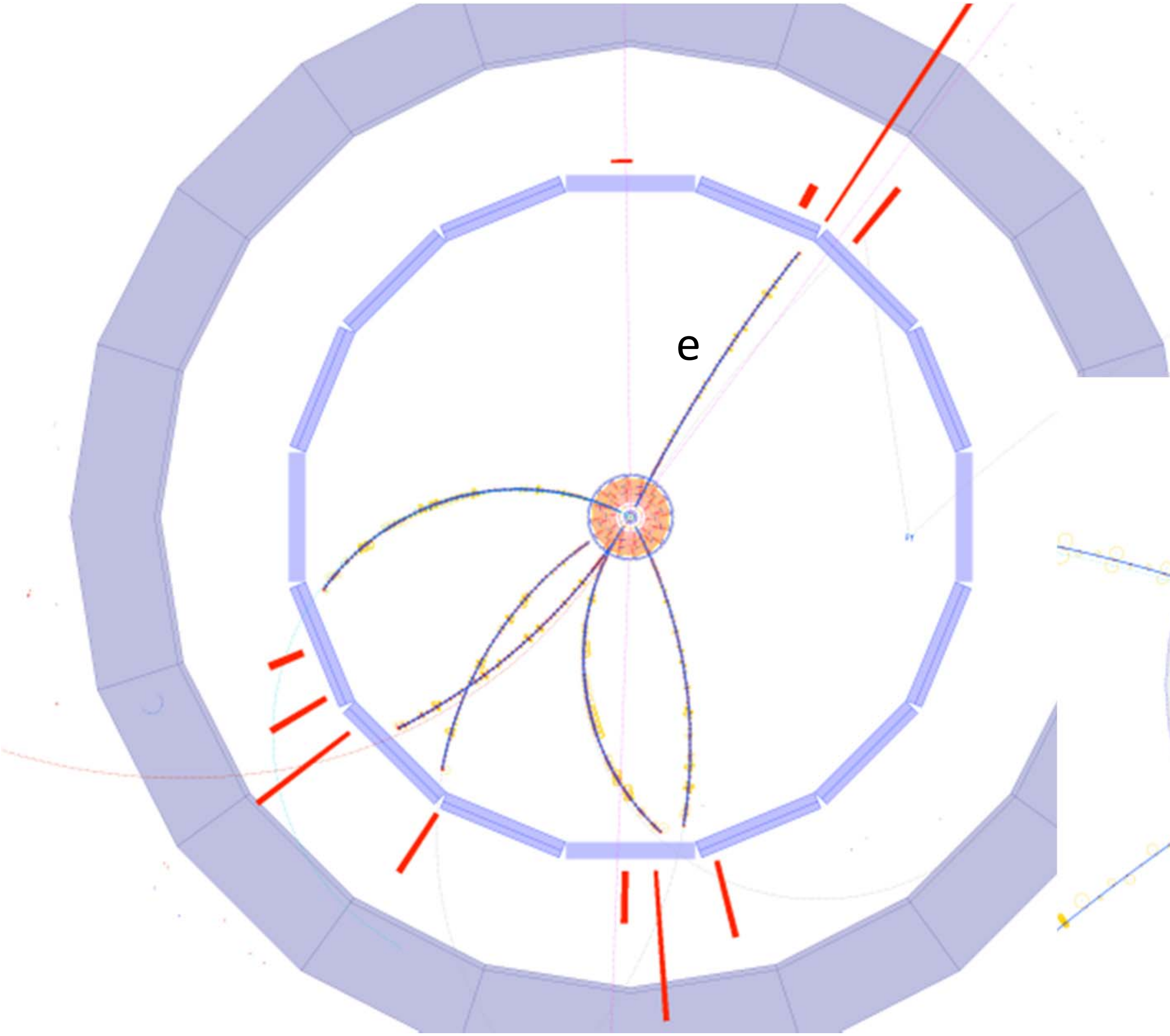
DSSD (double sided silicon detectors) FWD/BWD Italy

- Layer 3 r=38 mm (Australia)
- Layer 4 r=80 mm (India)
- Layer 5 r=115 mm (Austria)
- Layer 6 r=140 mm (Japan)

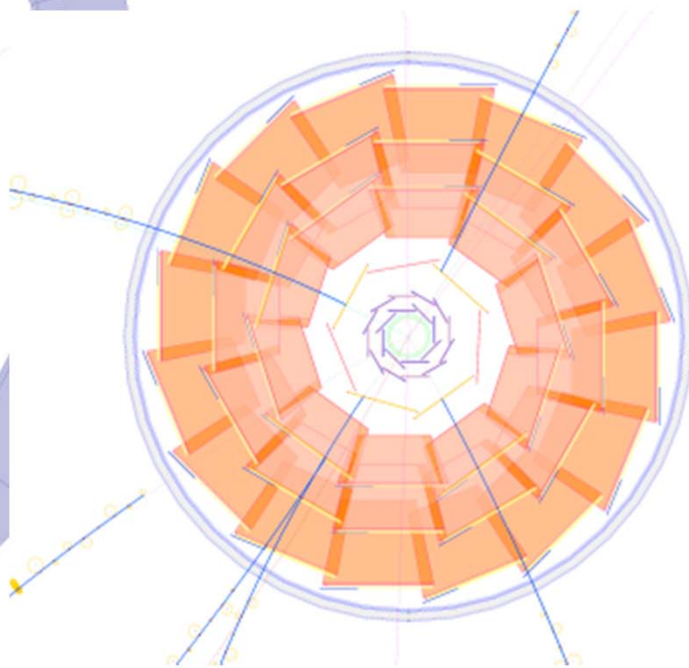
+Poland, Korea

“Missing Energy Decay” in a Belle II GEANT4 MC

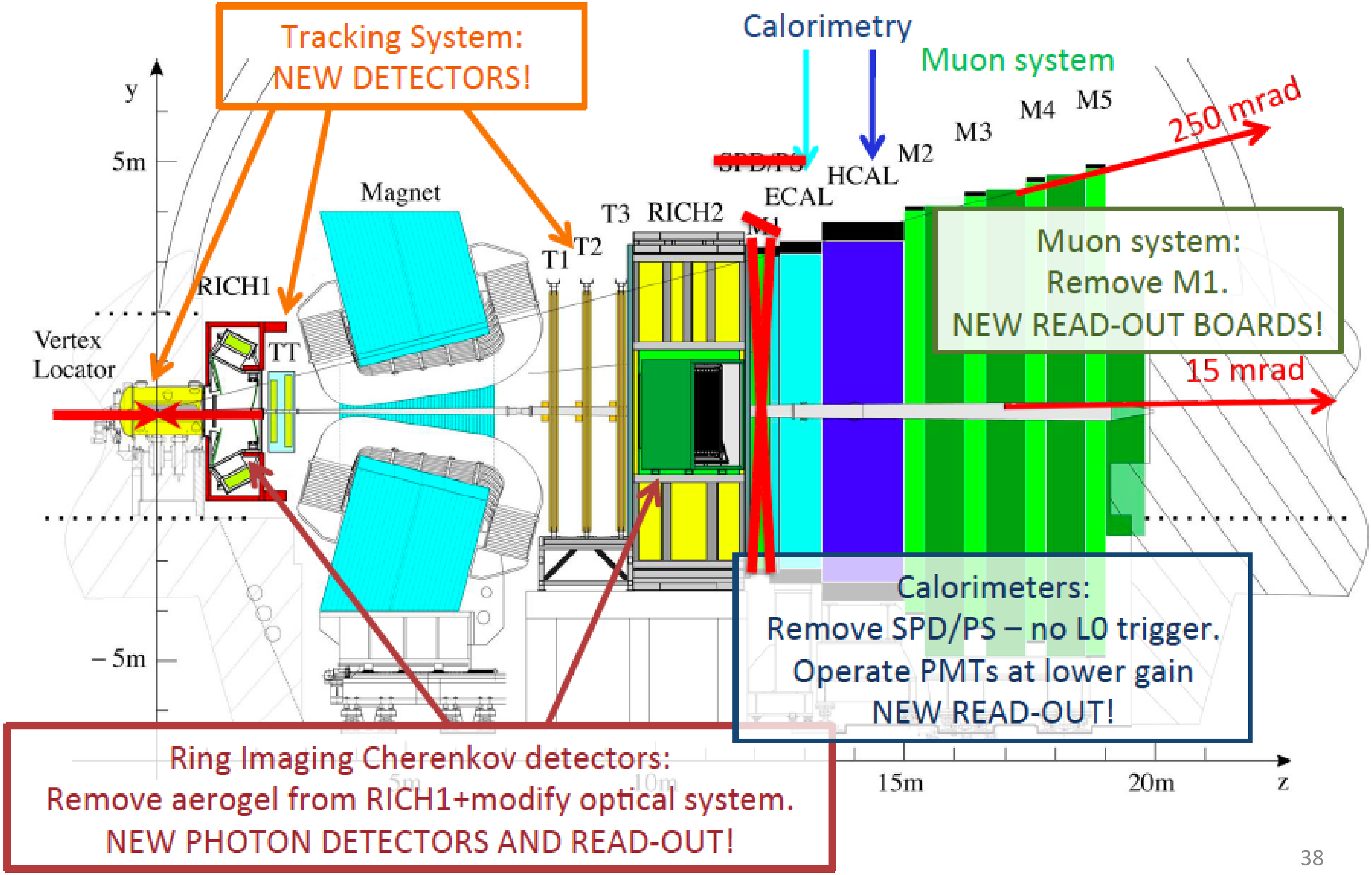
B→τν, τ→eνν B→Dπ, D→Kπππ



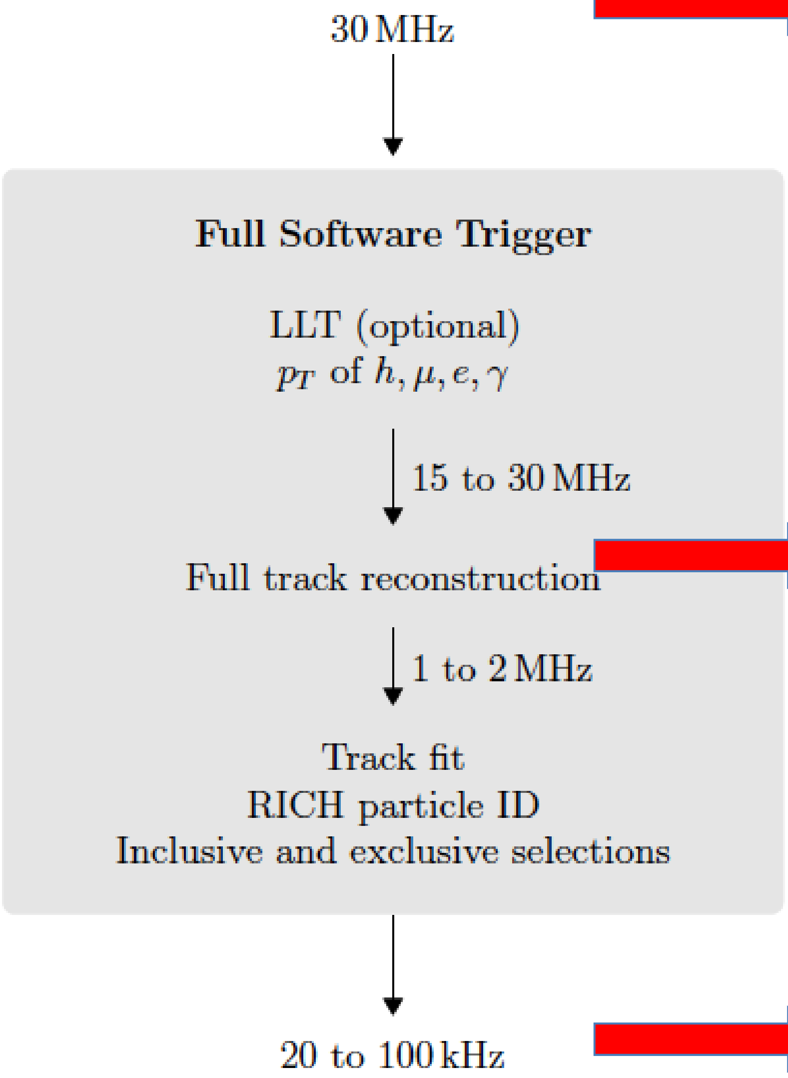
Zoomed view of the vertex region



Upgraded LHCb detector



Upgrade Trigger



- Trigger-less read-out.
- Zero suppression in front-ends.
- Full detector data to Full Software Trigger.
- Inelastic collision rate is 30 MHz.

- Low level trigger as throttle.
- Partial information from muon system and calorimeters.

- Full event reconstruction.
- Run-by-run detector calibration.

- Perform simplified Kalman track fit.
- Add RICH information.
- Inclusive and exclusive selections.

- 2 – 10 GBytes/s to storage.

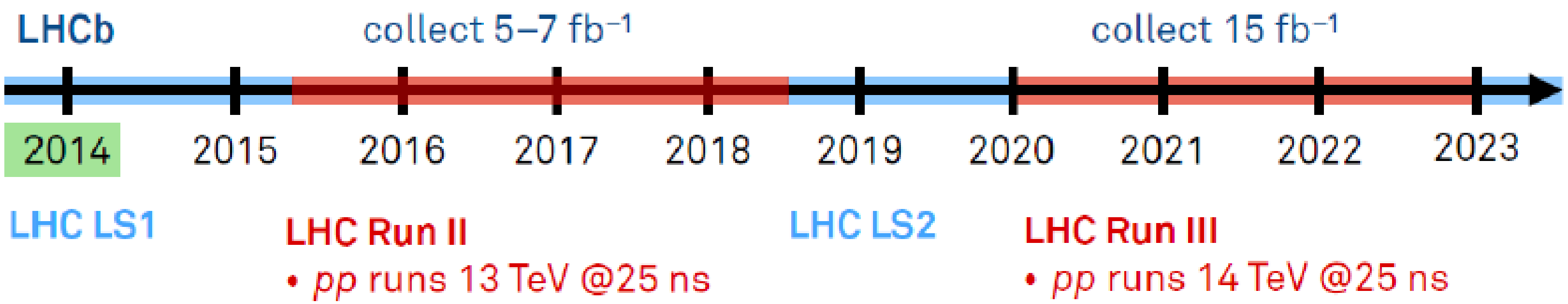
LHCb upgrade schedule

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Schedule / timeline

Run at ~4 x 10^{32} /cm^2 /sec

Expect (1-2) x 10^{33} /cm^2 /sec



LHC LS3
HL-LHC

- Collect 50 fb^{-1} after upgrade.
- Continue taking data during HL-LHC.

Conclusion/Next Generation.

- 2014 is the 50^{th} anniversary of the discovery of CP violation in the kaon sector.
- The e+ e- B factories confirmed that the KM phase is responsible for most of the observed CPV.
- LHCb has ruled out large CPV phases from NP in the B_s sector.
- Nevertheless, 10-20% NP effects are consistent with all current data.
- “Missing energy decays” provide important constraints on the charged Higgs.

Belle II roll-in in early 2017 with first physics runs and the LHCb upgrade in ~2020. These facilities will inaugurate a new era of flavor physics and the study of CP violation.

Backup slides

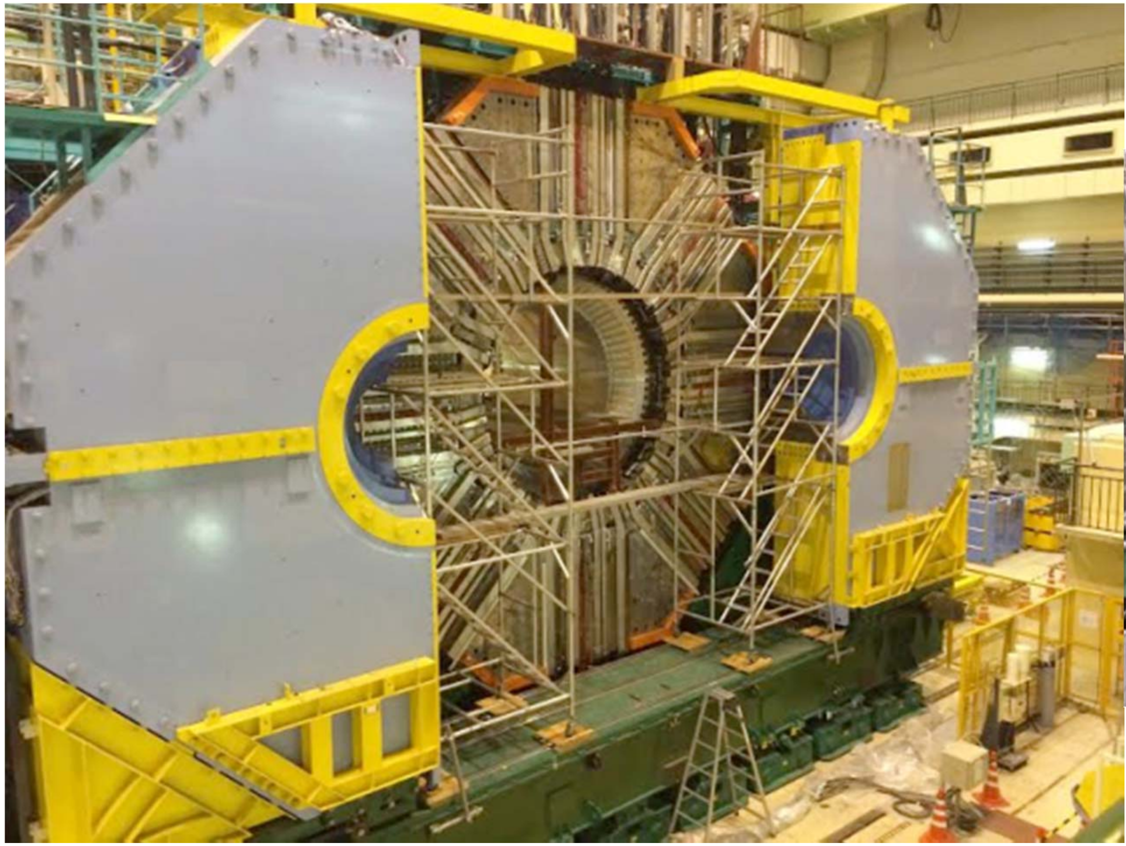
New Reference *for the Next Generation*

The Physics of the B Factories
http://arxiv.org/abs/1406.6311

This work is on the Physics of the B Factories. Part A of this book contains a brief description of the SLAC and KEK B Factories as well as their detectors, BaBar and Belle, and data taking related issues. Part B discusses tools and methods used by the experiments in order to obtain results. The results themselves can be found in Part C.

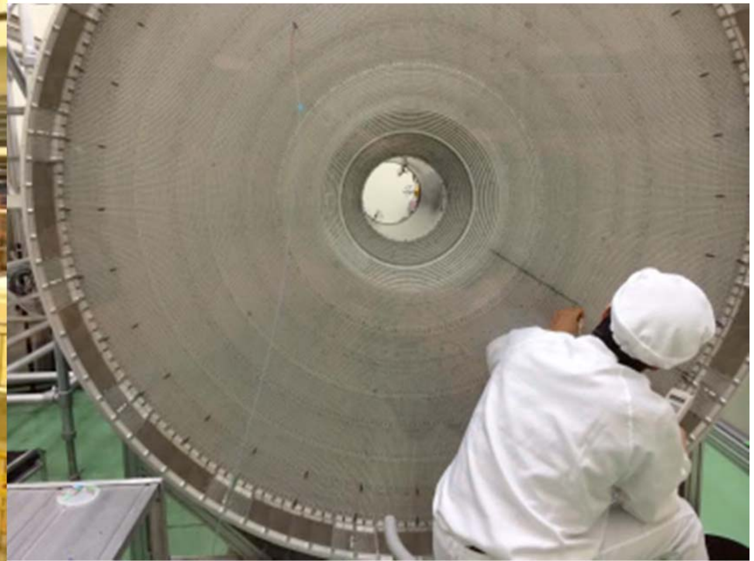
Comments: 928 pages
Subjects: High Energy Physics - Experiment (hep-ex); High Energy Physics - Phenomenology (hep-ph)
Report number: SLAC-PUB-15968, KEK Preprint 2014-3

The scene at KEK in June 2014



Tsukuba Hall

Belle II detector with barrel KLM upgrade and forward muon endcap upgrade now installed. Next is the backward KLM upgrade.



Fuji Hall

Central Drift Chamber

More backup

J. Bernabeu and F. Martinez-Vidal, to appear in RMP 2014

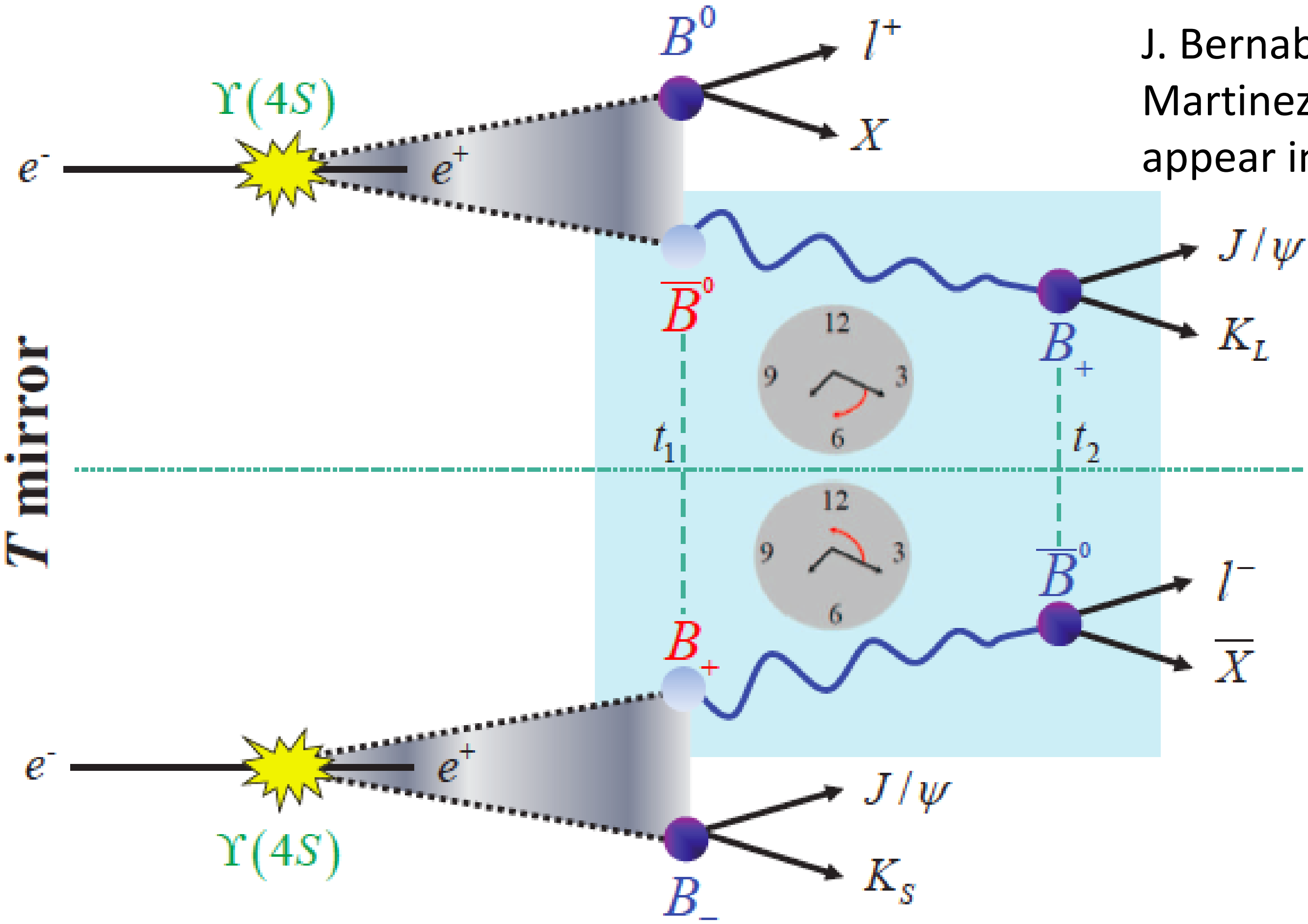
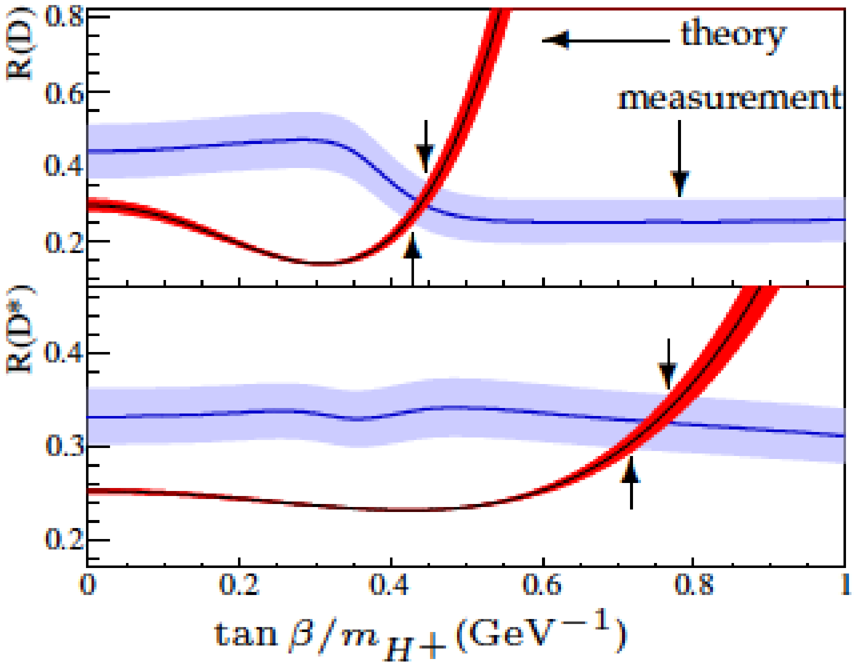


FIG. 11. Foundations of the time-reversal experiment. Electron-positron collisions at the asymmetric B factory produce $\Upsilon(4S)$ resonances, each of which decays through strong interaction in an entangled pair of B mesons. When one B meson decays at t_1, the identity of the other is "tagged" without measuring it specifically. In the top panel, the B meson observed to decay to the final state $\ell^+ X$ at t_1 transfers information to the (still living) partner meson and dictates that it is in a $\overline{B}^0$ state. This surviving meson tagged as $\overline{B}^0$ is observed later at t_2, encapsulating a time ordering, to decay into a final state $J/\psi K^0_L$ that filters the B meson to be in a B_+ state, a linear combination of B^0 and $\overline{B}^0$ states. This case corresponds to a transition $\overline{B}^0 \to B_+$. To study time reversal we have to compare the rate at which this transition occurs to the rate of the time-reversed transition, $B_+ \to \overline{B}^0$ (bottom panel). Adapted from[2].

Comparison of BaBar and Belle (not updated)

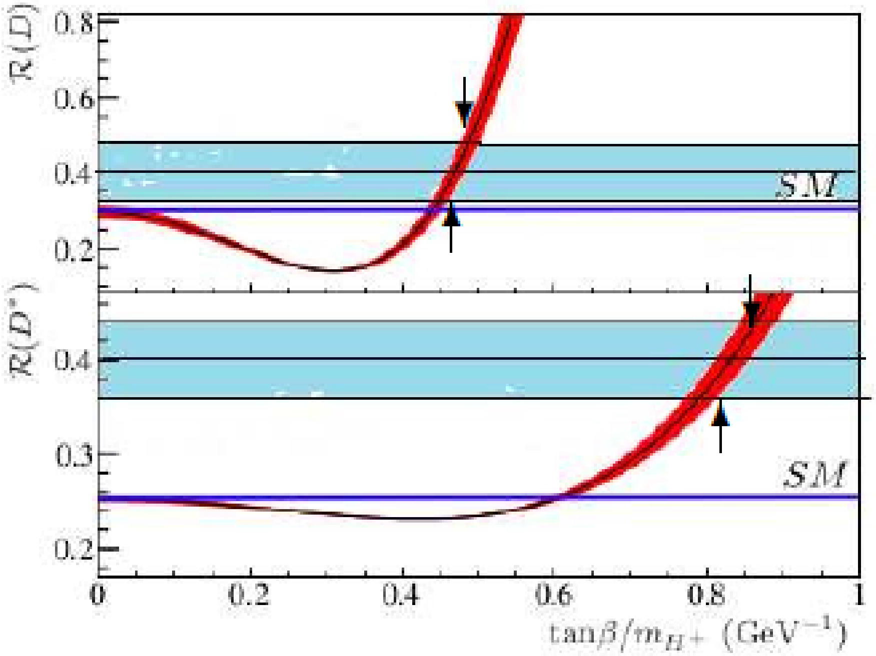
BaBar

$B \to \bar{D}^{*()} \tau \nu_\tau$



Belle

$B \to \bar{D}^{*()} \tau \nu_\tau$



New CMS Bs mixing result

Signal model

We use the same notations as LHCb [arXiv:1304.2600]:

$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} = X(\Theta, \alpha, t) = \sum_{i=1}^{10} O_i(\alpha, t).g_i(\Theta),$$

$$O_i(\alpha, t) = N_i e^{-\Gamma_s t}\left[a_i \cosh(\frac{1}{2}\Delta\Gamma_s t) + b_i \sinh(\frac{1}{2}\Delta\Gamma_s t) + c_i \cos(\Delta m_s t) + d_i \sin(\Delta m_s t)\right]$$

i	$g_i(\theta_T, \psi_T, \phi_T)$	N_i	a_i	b_i	c_i	d_i
1	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$	$\lvert A_0(0)\rvert^2$	1	D	C	$-S$
2	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T)$	$\lvert A_\parallel(0)\rvert^2$	1	D	C	$-S$
3	$\sin^2\psi_T\sin^2\theta_T$	$\lvert A_\perp(0)\rvert^2$	1	$-D$	C	S
4	$-\sin^2\psi_T\sin 2\theta_T\sin\phi_T$	$\lvert A_\parallel(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_\parallel)$	$S\cos(\delta_\perp-\delta_\parallel)$	$\sin(\delta_\perp-\delta_\parallel)$	$D\cos(\delta_\perp-\delta_\parallel)$
5	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin^2\theta_T\sin 2\phi_T$	$\lvert A_0(0)A_\parallel(0)\rvert$	$\cos(\delta_\parallel-\delta_0)$	$D\cos(\delta_\parallel-\delta_0)$	$C\cos(\delta_\parallel-\delta_0)$	$-S\cos(\delta_\parallel-\delta_0)$
6	$\frac{1}{\sqrt{2}}\sin 2\psi_T\sin 2\theta_T\sin\phi_T$	$\lvert A_0(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_0)$	$S\cos(\delta_\perp-\delta_0)$	$\sin(\delta_\perp-\delta_0)$	$D\cos(\delta_\perp-\delta_0)$
7	$\frac{2}{3}(1-\sin^2\theta_T\cos^2\phi_T)$	$\lvert A_S(0)\rvert^2$	1	$-D$	C	S
8	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin^2\theta_T\sin 2\phi_T$	$\lvert A_S(0)A_\parallel(0)\rvert$	$C\cos(\delta_\parallel-\delta_S)$	$S\sin(\delta_\parallel-\delta_S)$	$\cos(\delta_\parallel-\delta_S)$	$D\sin(\delta_\parallel-\delta_S)$
9	$\frac{1}{3}\sqrt{6}\sin\psi_T\sin 2\theta_T\cos\phi_T$	$\lvert A_S(0)A_\perp(0)\rvert$	$\sin(\delta_\perp-\delta_S)$	$-D\sin(\delta_\perp-\delta_S)$	$C\sin(\delta_\perp-\delta_S)$	$S\sin(\delta_\perp-\delta_S)$
10	$\frac{4}{3}\sqrt{3}\cos\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$	$\lvert A_S(0)A_0(0)\rvert$	$C\cos(\delta_0-\delta_S)$	$S\sin(\delta_0-\delta_S)$	$\cos(\delta_0-\delta_S)$	$D\sin(\delta_0-\delta_S)$

$$C = \frac{1-|\lambda|^2}{1+|\lambda|^2}, \qquad S = -\frac{2|\lambda|\sin\phi_s}{1+|\lambda|^2}, \qquad D = -\frac{2|\lambda|\cos\phi_s}{1+|\lambda|^2}$$

$|\lambda|$ includes possible contribution from CP violation in direct decay, we assume $|\lambda| = 1$ and we assign a systematics.

$\Delta\Gamma_s > 0$: we use previous LHCb results. α physics parameters ($\Delta\Gamma_s$, ϕ_s, $c\tau$, $|A_0|^2$, $|A_S|^2$, $|A_\perp^2|$, $\delta_\parallel$, $\delta_{S\perp}$, $\delta_\perp$)

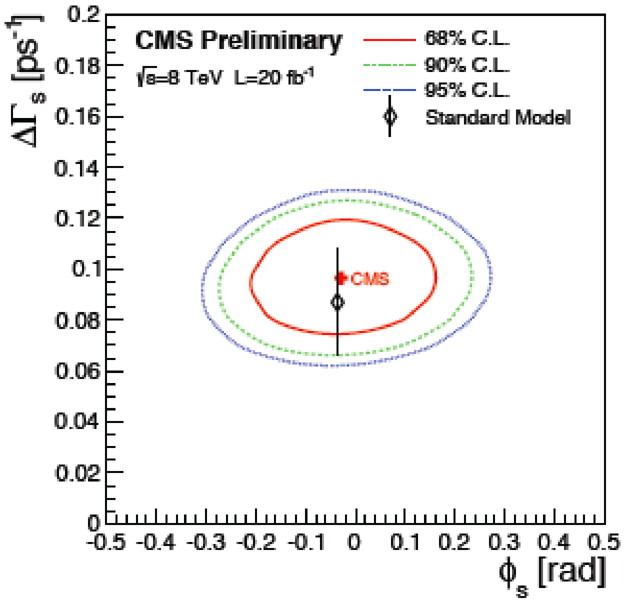
Results summary

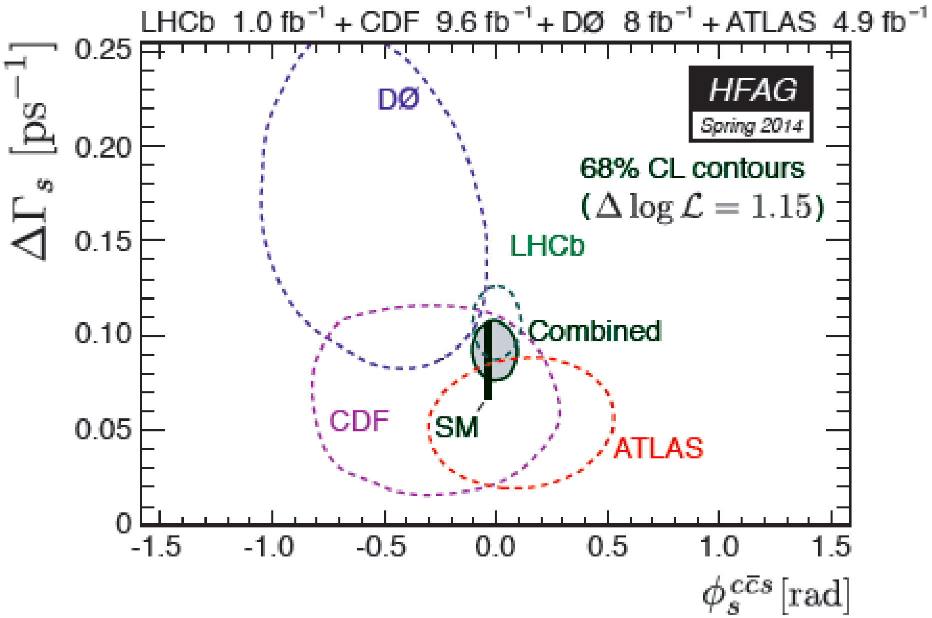
- Analysing the 2012 CMS data (20.0 fb^{-1}), we selected 49k B_s signal events. We obtain:

$$\phi_s = -0.03 \pm 0.11\ (stat.) \pm 0.03\ (syst.)\ rad$$

$$\Delta\Gamma_s = 0.096 \pm 0.014\ (stat.) \pm 0.007\ (syst.)\ ps^{-1}$$

- Contour plot (stat. only), constraining $\Delta\Gamma_s > 0$:



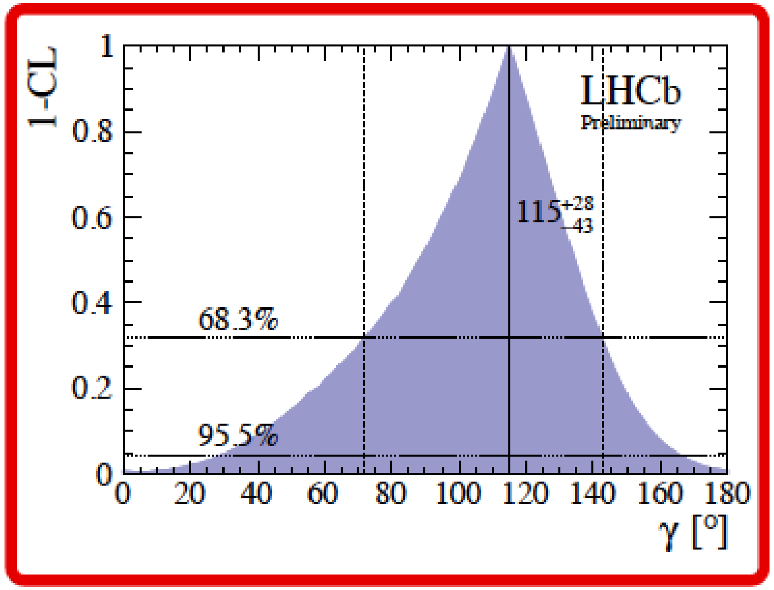


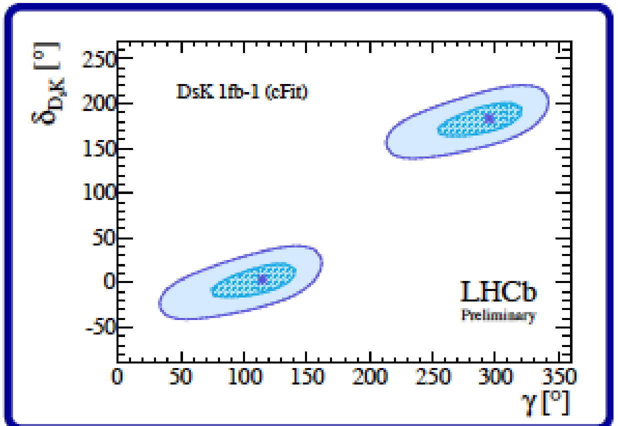
New LHCb γ results

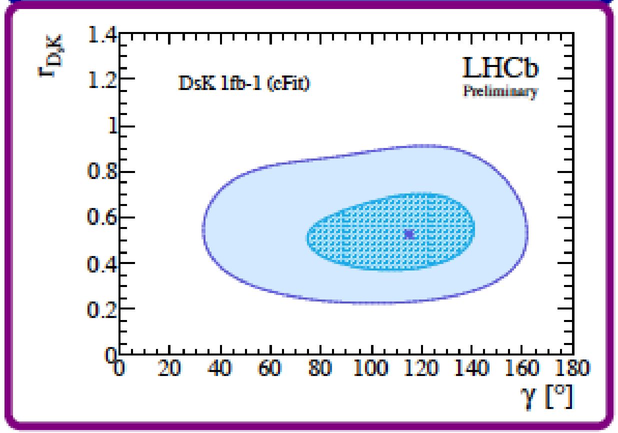
Measurement of γ angle

LHCb-PAPER-2014-038

- γ angle extraction based on cFit results.
- Statistical and systematic uncertainties and correlations are taken into account.
- Constraint: $|C|^2 + |S_f|^2 + |A_f^{\Delta\Gamma}|^2 = 1$







$$\gamma = (115^{+28}_{-43})^\circ$$
$$\delta_{D_sK} = (3^{+19}_{-20})^\circ$$
$$r_{D_sK} = 0.53^{+0.17}_{-0.16}$$

gamma @ LHCb

W. Qian at ICHEP2014

- Many modes discovered and studied mainly based on 1fb^{-1} and to be updated with full datasets (3 fb^{-1})
- gamma combination with part of current measurements

1 fb^{-1} GLW/ADS on $B^{\pm} \to Dh^{\pm}$, $D \to hh$ — Phys. Lett. B 712 (2012) 203

1 fb^{-1} ADS on $B^{\pm} \to Dh^{\pm}$, $D \to K\pi\pi\pi$ — Phys. Lett. B 723 (2013) 44

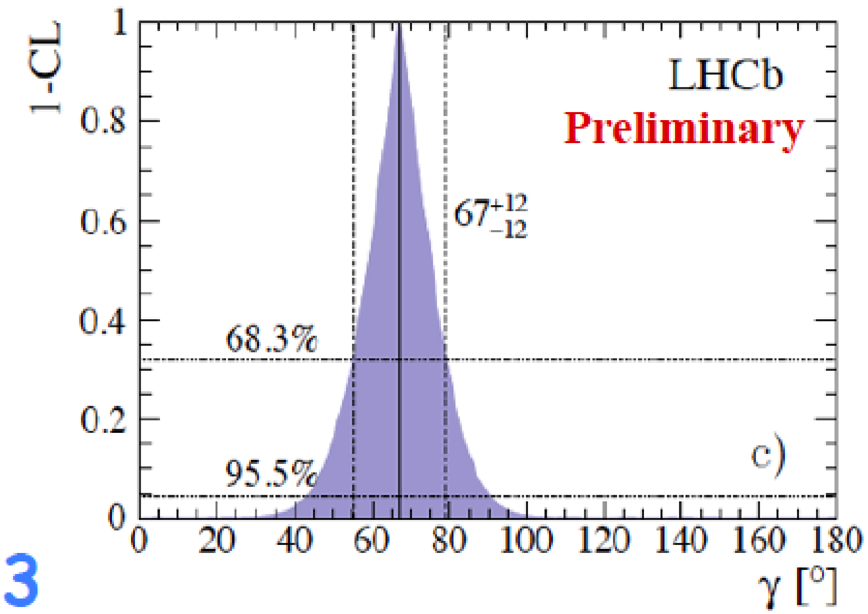
1 fb^{-1}+ 2 fb^{-1} GGSZ (MI) on $B^{\pm} \to DK^{\pm}$, $D \to Kshh$ — Phys. Lett. B 718 (2012) 43, LHCb-CONF-2013-004

CLEO inputs on D system nuisance parameters — CLEO Collaboration, Phys. Rev. D80 (2009) 031105

(Interesting proposals to use D mixing to further constrain, i.e. $K3\pi$) — S. Harnew, J. Rademacker Phys. Lett. B 728 (2014) 296

Additional D mixing constrain from LHCb — Phys. Rev. Lett. 110 (2012) 101802

Direct CP violation in $D \to KK$ and $D \to \pi\pi$ — HFAG



$$\gamma = (67 \pm 12)^\circ$$

$\gamma \in [55.1, 79.1]^\circ$ at 68% CL

$\gamma \in [43.9, 89.5]^\circ$ at 95% CL

$\delta_B^K = (114.3^{+12}_{-13})^\circ$

$\delta_B^K \in [101.3, 126.3]^\circ$ at 68% CL

$\delta_B^K \in [88.7, 136.3]^\circ$ at 95% CL

$r_B^K = 0.0923^{+0.0078}_{-0.0080}$

$r_B^K \in [0.0843, 0.1001]$ at 68% CL

$r_B^K \in [0.0762, 0.1075]$ at 95% CL

LHCb-CONF-2013-006

Combining with B-factories:

CKMFitter

$$\gamma = (70.0^{+7.7}_{-9.0})^\circ$$

UTfit

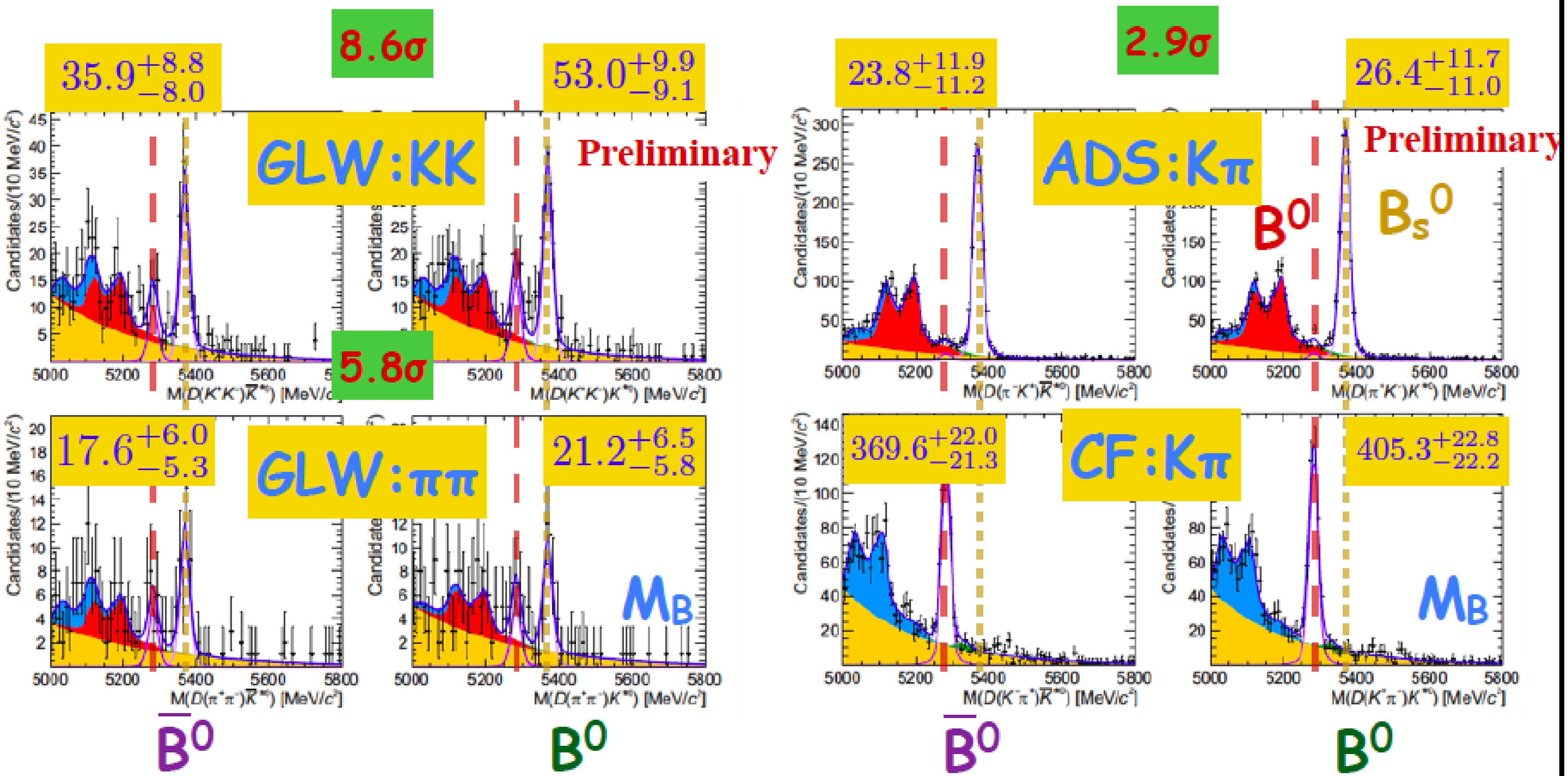
$$\gamma = (68.3 \pm 7.5)^\circ$$

W. Qian@ICHEP2014

GLW/ADS Analysis of $B^0 \to DK^{*0}$

LHCb-PAPER-2014-028; 3 fb^{-1}

➢ Similar as $B^+ \to DK^+$, γ could also be measured with self-tagged neutral B decays; Diluted due to resonance shape of K^*



Results and Interpretation of $B^0 \to DK^{*0}$

LHCb-PAPER-2014-028; 3 fb^{-1}

- **12 ratios made according to yields from B^0 and B_s^0**

stat. sys.

GLW

$$\frac{N(\overline{B}^0) - N(B^0)}{N(\overline{B}^0) + N(B^0)}$$

$$2 \times \frac{\Gamma(\overline{B}^0 \to D_{CP+}\overline{K}^{*0}) + \Gamma(B^0 \to D_{CP+}K^{*0})}{\Gamma(\overline{B}^0 \to D^0\overline{K}^{*0}) + \Gamma(B^0 \to \overline{D}^0 K^{*0})}$$

B^0:

$$\mathcal{A}_d^{KK} = -0.198\,^{+0.144}_{-0.145}\,^{+0.019}_{-0.020} \qquad \mathcal{A}_d^{\pi\pi} = -0.092\,^{+0.217}_{-0.217}\,^{+0.019}_{-0.019}$$

$$\mathcal{R}_d^{KK} = 1.054\,^{+0.165}_{-0.153}\,^{+0.044}_{-0.044} \qquad \mathcal{R}_d^{\pi\pi} = 1.214\,^{+0.283}_{-0.252}\,^{+0.053}_{-0.053}$$

B_s^0:

$$\mathcal{A}_s^{KK} = -0.044\,^{+0.073}_{-0.073}\,^{+0.019}_{-0.020} \qquad \mathcal{A}_s^{\pi\pi} = 0.064\,^{+0.130}_{-0.131}\,^{+0.018}_{-0.019}$$

B^0/B_s^0:

$$\mathcal{R}_{ds}^{KK} = 0.103\,^{+0.018}_{-0.016}\,^{+0.009}_{-0.009} \qquad \mathcal{R}_{ds}^{\pi\pi} = 0.147\,^{+0.040}_{-0.036}\,^{+0.012}_{-0.012}$$

ADS

$$\frac{\Gamma(\mathrm{ADS})}{\Gamma(\mathrm{CF})}$$

$$\frac{N(\overline{B}^0_{(s)}) - N(B^0_{(s)})}{N(\overline{B}^0_{(s)}) + N(B^0_{(s)})}$$

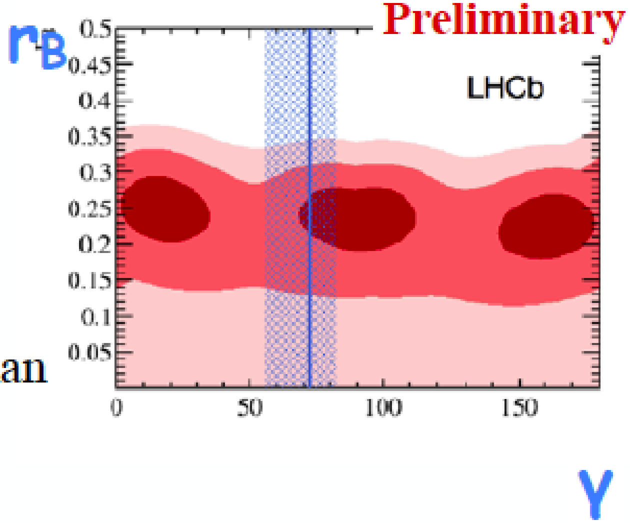
B^0:

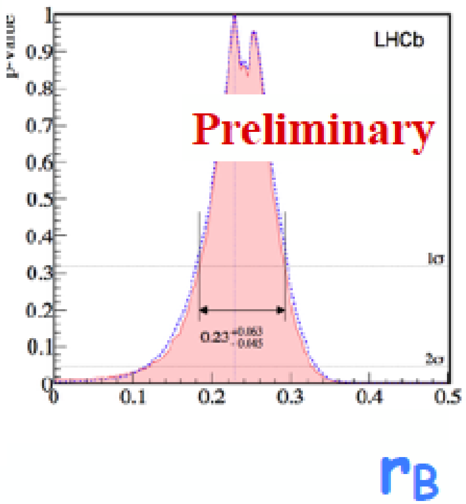
$$\mathcal{R}_d^{+} = 0.057\,^{+0.029}_{-0.027}\,^{+0.009}_{-0.012} \qquad \mathcal{R}_d^{-} = 0.056\,^{+0.032}_{-0.030}\,^{+0.009}_{-0.012}$$

B^0, B_s^0:

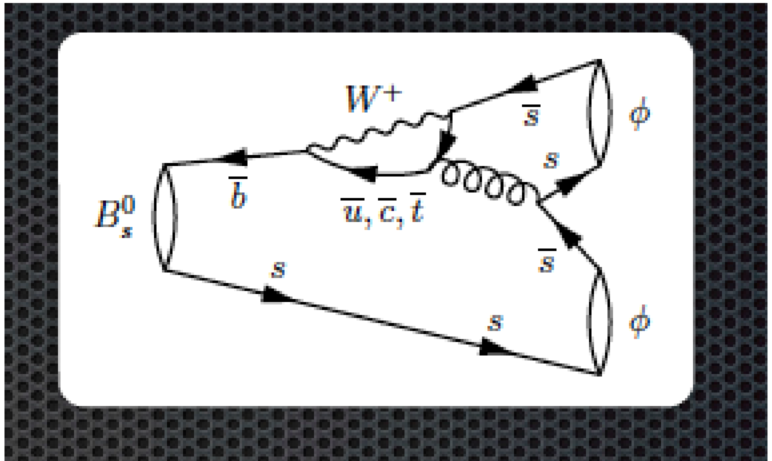
$$\mathcal{A}_d^{K\pi} = -0.032\,^{+0.041}_{-0.041}\,^{+0.019}_{-0.020} \qquad \mathcal{A}_s^{\pi K} = -0.014\,^{+0.025}_{-0.025}\,^{+0.019}_{-0.019}$$

- **Contribution to γ**
  - Dilution factor (0.95±0.03)from toy simulation which models $B^0 \to DK\pi$ resonances
  - Constrain on r_B in $B^0 \to DK^{*0}$
  - Compatible and more accurate than previous B-factory measurements

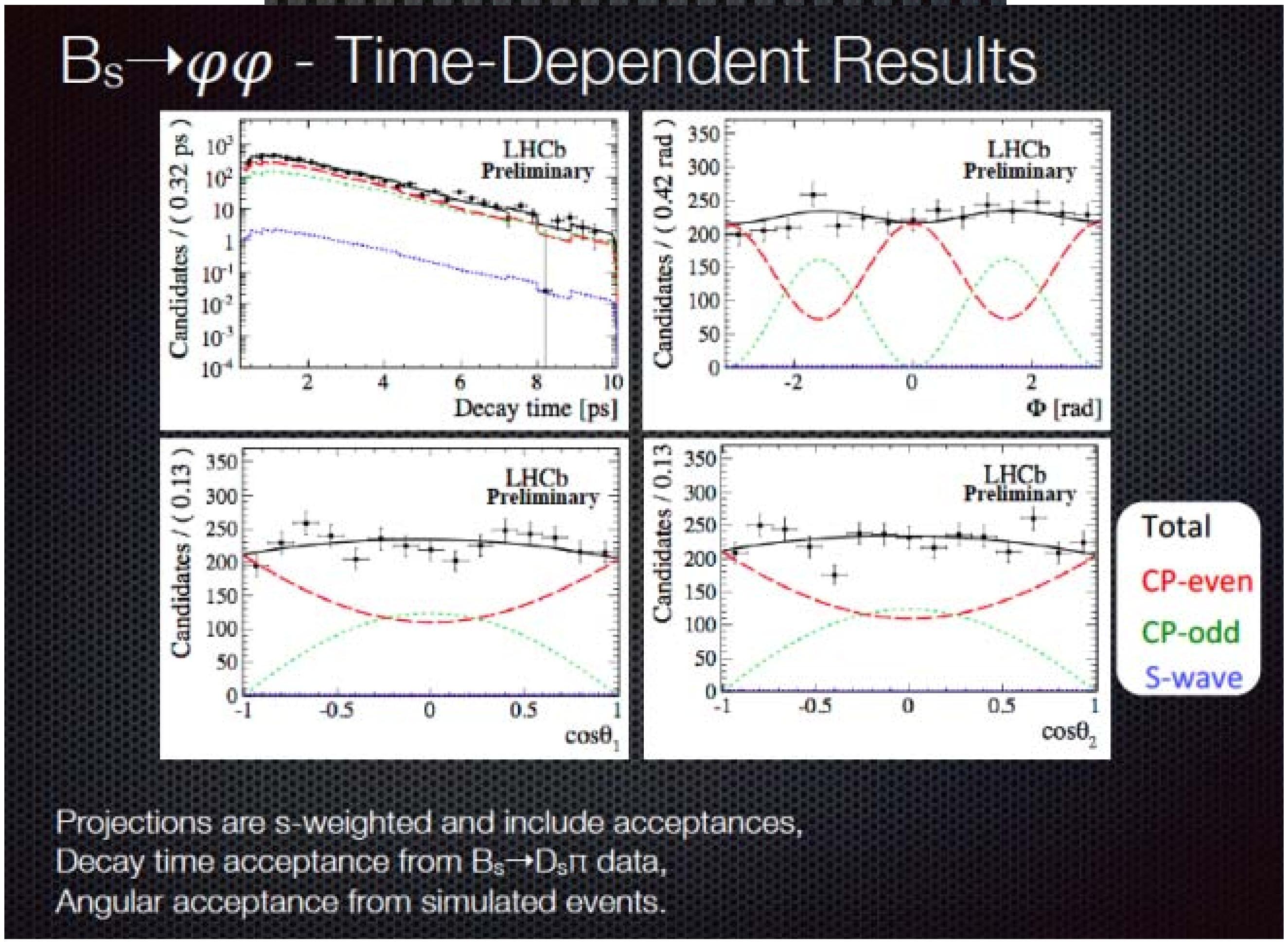




But LHCb dominates on these B_S modes



M.Needham@ICHEP2014



Belle results on γ at ICHEP2014

Y. Onuki @ICHEP2014

ADS Measurement for $B^0 \to [K\pi]_D K^{*0}$

$$\mathcal{R}_{DK^{*0}} = r_S^2 + r_D^2 + 2k r_S r_D \cos(\delta_S + \delta_D)\cos\phi_3\,, \quad r_S^2 \equiv \frac{\Gamma(B^0 \to D^0 K^+ \pi^-)}{\Gamma(B^0 \to \bar{D}^0 K^+ \pi^-)} = \frac{\int dp A_{b\to u}^2(p)}{\int dp A_{b\to c}^2(p)}$$

PRD80 (2009) 031102

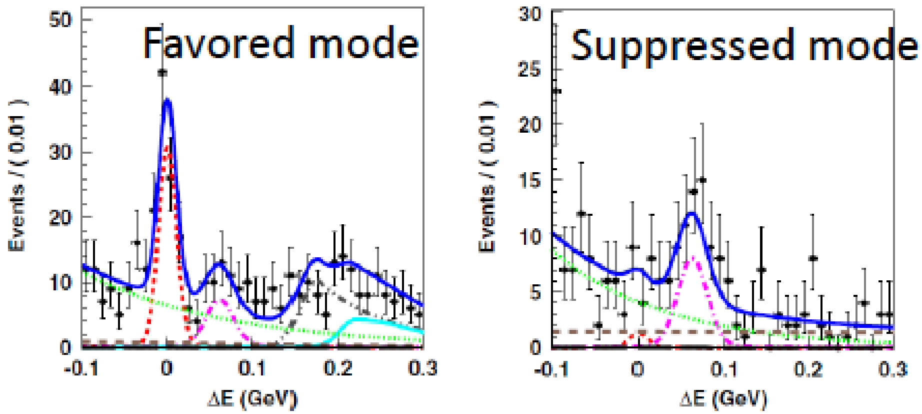
$R_{DK^*}=0.067\ ^{+0.070}_{-0.054} \pm 0.018$, $R_{DK^*}<0.244$@95%CL for $K\pi$ mode

r_S [0.07,0.41] (95%CL) r_S=0.26(most probable value) w/ combined $K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$

PRD86(2012)011101 772M

$R_{DK^*}=0.045\ ^{+0.056}_{-0.050}\ ^{+0.028}_{-0.018}$,

$R_{DK^*}<0.16$@95%CL for $K\pi$ mode



Approximation $R_{DK^*} \approx r_S^2$ since r_D=0.06 from J.Phys.G 33 1(2006)

Under this naïve assumption, $r_S \sim 0.21$

Combining the lower limit of r_S by BABAR and additional independent measurement by Belle It is possible that r_S bigger than the r_B ~0.1

Also refer previous Dr. Wenbin Qian's Talk

This motivate the Dalitz analysis for $B^0 \to [K_S\pi\pi]_D K^{*0}$

ADS Measurement for $B^- \rightarrow [K\pi\pi^0]_D K^-$

$$R_{ADS}^{K\pi\pi^0} = r_B^2 + r_D^2 + 2 r_B r_D R_{K\pi\pi^0} \cos(\delta_B + \delta_D^{K\pi\pi^0}) \cos\phi_3$$

$$A_{ADS}^{K\pi\pi^0} = 2 r_B r_D R_{K\pi\pi^0} \sin(\delta_B + \delta_D^{K\pi\pi^0}) \sin\phi_3 / R_{ADS}^{K\pi\pi^0}$$

Inclusive(≥3-body decay) ADS
PRD 68, 033003 (2003)

- Coherence factor $R_{K\pi\pi^0} e^{i\delta_D^{K\pi\pi^0}} = \frac{\int d\vec{m} A_{DCS}(\vec{m}) A_{CF}(\vec{m}) e^{i\delta(\vec{m})}}{\sqrt{\int d\vec{m} A^2_{DCS}(\vec{m}) \int d\vec{m} A^2_{CF}(\vec{m})}}$ $\vec{m} \equiv [m^2_{K\pi}, m^2_{K\pi^0}]$, $0 \le R_{K\pi\pi^0} \le 1$

  CLEO-c update ($R_{K\pi\pi^0}$, $\delta_D^{K\pi\pi^0}$) measurement

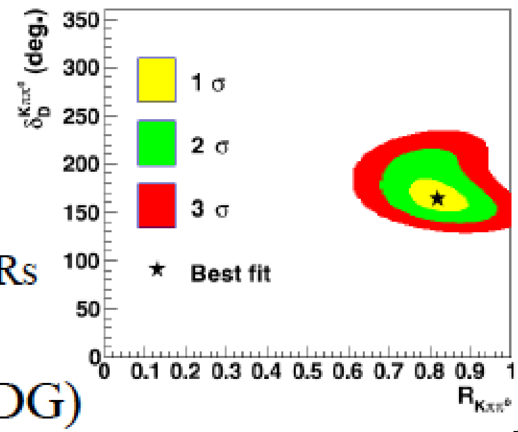
  PRD 80, 031105(R)

  $R_{K\pi\pi^0} = 0.84 \pm 0.07$, $\delta_D^{K\pi\pi^0} = 227^{+14}_{-17}$

  PLB 731(2014)197-203

  $R_{K\pi\pi^0} = 0.82 \pm 0.07$, $\delta_D^{K\pi\pi^0} = 164^{+20}_{-14}$

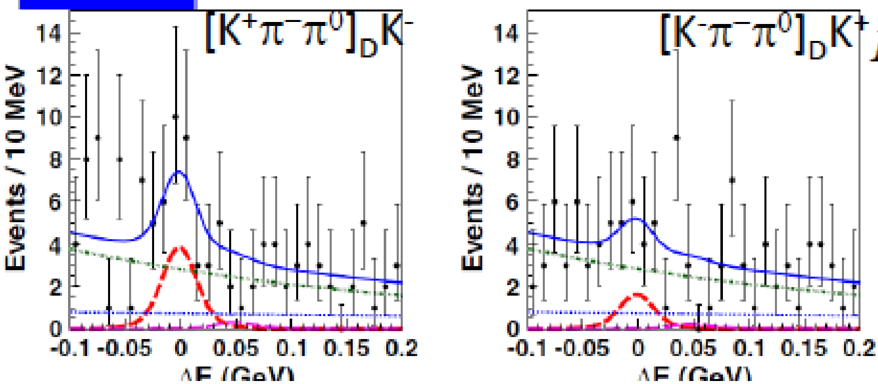
  Updates of Mixing params $\delta_D^{K\pi}$, $(r_D^{K\pi})^2$, BRs



- (r_B, δ_B) same as $[K\pi]_D K$, $r_D = (2.20 \pm 0.10) \times 10^{-3}$ (PDG)

BELLE

PRD88, 091104(R) (2013) 772M



$$A_{ADS}^{K\pi\pi^0} = 0.41 \pm 0.30(\text{stat}) \pm 0.05(\text{syst})$$

$$R_{ADS}^{K\pi\pi^0} = [1.98 \pm 0.62(\text{stat}) \pm 0.24(\text{syst})] \times 10^{-2}$$

First evidence of $[K\pi\pi^0]_D K$ at 3.2σ

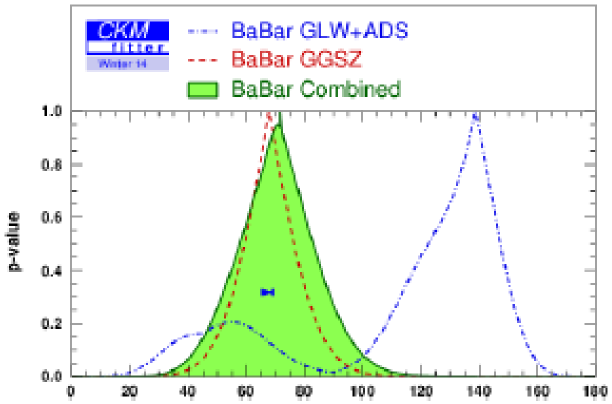
$B \rightarrow [K\pi\pi^0]_D K$ ADS result should use the CLEO-c updated parameters for γ/ϕ_3

Y. Onuki @ICHEP2014

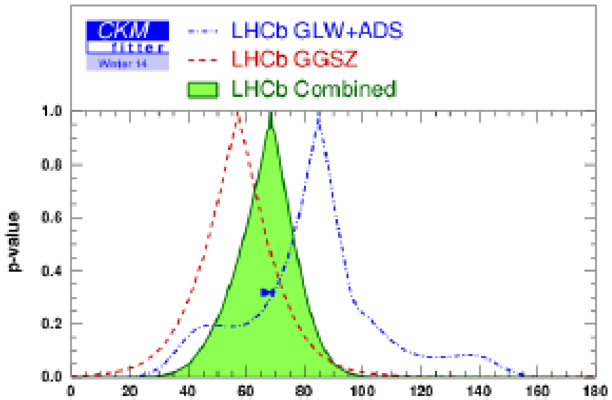
Y. Onuki
@ICHEP2014

Summary

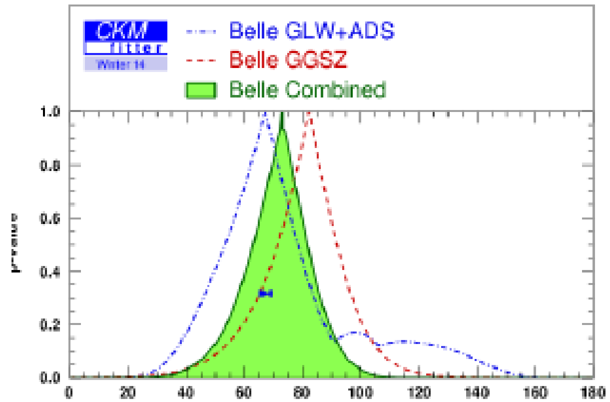
- Fruitful outputs: First evidence ADS $[K\pi]_D K$ and $[K\pi\pi^0]_D K$, Unique GLW CP- mode, First model independent Dalitz analysis…
- $B^0 \rightarrow [K\pi]_D K^{*0}$ ADS results may indicate bigger r_S value than the r_B. It is possible higher sensitivity of $\gamma/\phi 3$ than the $B^- \rightarrow [K_S\pi\pi]_D K^{*-}$
- $B \rightarrow [K\pi\pi^0]_D K$ ADS result should use the CLEO-c updated parameters for $\gamma/\phi 3$ determination.
- There is still a lot of modes playing an important role fo $\gamma/\phi 3$ determination from Belle



$\gamma[\text{BaBar}] = 72^{+17}_{-19}\,^{\circ}$



$\gamma[\text{LHCb}] = 68^{+12}_{-15}$



$\gamma[\text{Belle}] = 73^{+13}_{-15}\,^{\circ}$

- $B^0 \rightarrow [K_S\pi\pi]_D K^{*0}$ and $B^- \rightarrow [K_S K\pi]_D K^-$ Dalitz etc. analyses on going!

New BaBar result on CPV in $B \to K^* \pi$

Combined fit to B^+ and B^- samples

- About 32,000 candidates in the fitted sample
  Best fit: 1,014 ± 63 (stat.) signal events

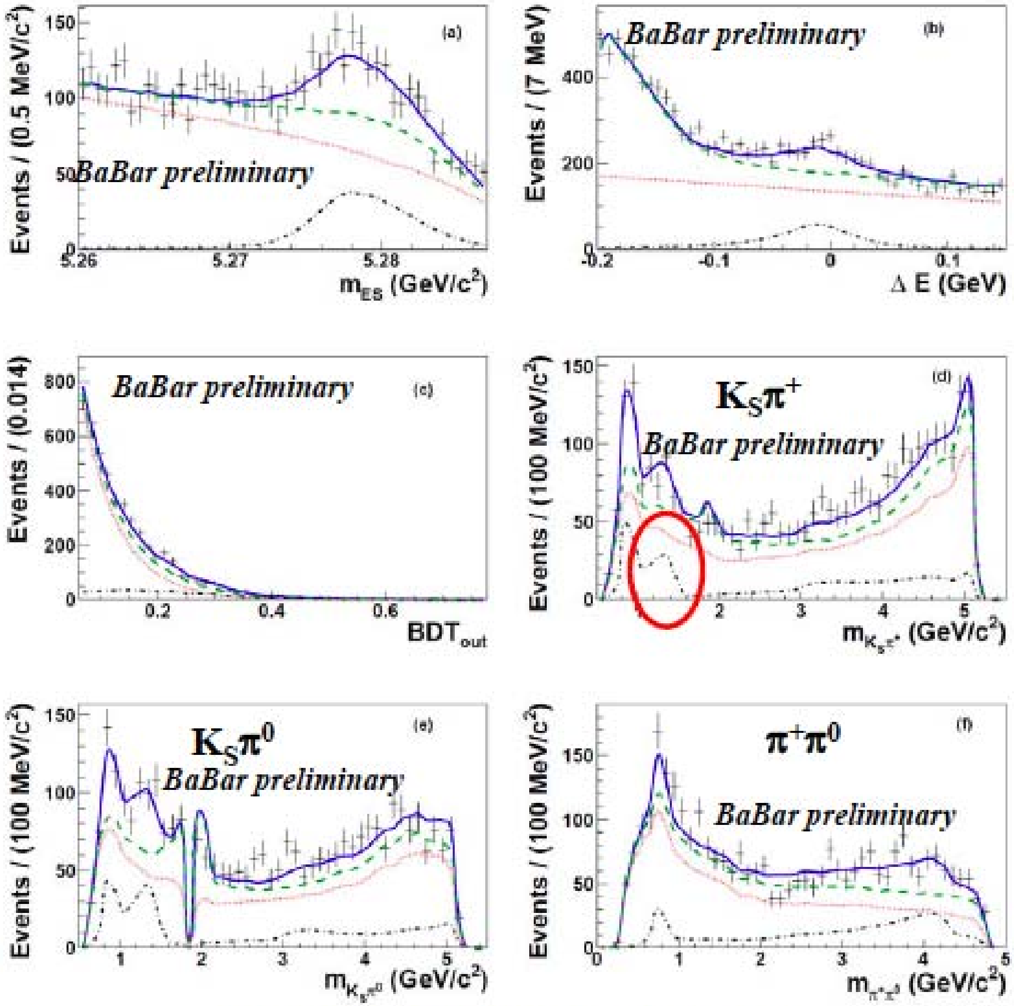
- First measurement of inclusive $K^0\pi^+\pi^0$ branching fraction:
  $(45.9{\pm}2.6{\pm}3.0{\pm}8.6)\times10^{-6}$

- First measurement of the $K^{*+}_0(1430)\pi^0$ branching fraction:
  $(17.2{\pm}2.4{\pm}1.5{\pm}1.8)\times10^{-6}$ (5.4σ)

- All significant branching fractions

Decay channel	$\mathcal{B}\,(10^{-6})$
$K^0\pi^+\pi^0$	$45.9 \pm 2.6 \pm 3.0 \pm 8.6$
BaBar preliminary	
$K^{*0}(892)\pi^+$	$14.6 \pm 2.4 \pm 1.4 \pm 0.5$
$K^{*+}(892)\pi^0$	$9.2 \pm 1.3 \pm 0.6 \pm 0.5$
$K_0^{*0}(1430)\pi^+$	$50.0 \pm 4.8 \pm 6.1 \pm 4.0$
$K_0^{*+}(1430)\pi^0$	$17.2 \pm 2.4 \pm 1.5 \pm 1.8$
$\rho^+(770)K^0$	$9.4 \pm 1.6 \pm 1.1 \pm 2.6$

→ Σ(resonance BFs) < inclusive BF due to destructive interferences



Signal-enhanced distributions

Simultaneous fit of the separate B^+ and B^- data samples

- Compute the inclusive & exclusive CP asymmetries (A_{CP})

- Parameterization of the coefficients for the 2-body resonant decay modes

$$c_j = (x_j + \Delta x_j) + i\,(y_j + \Delta y_j)\,, \qquad \bar{c}_j = (x_j - \Delta x_j) + i\,(y_j - \Delta y_j)\,,$$

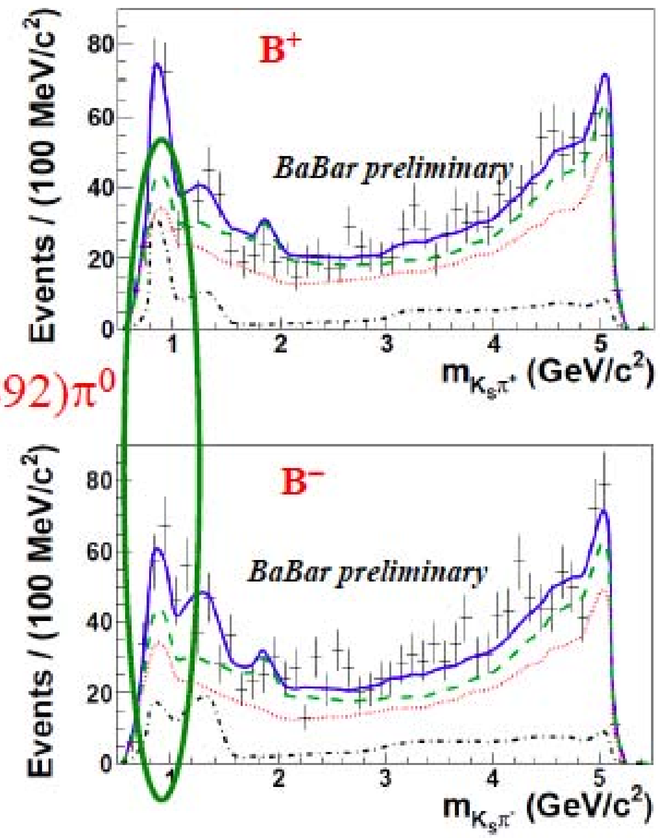
$\rightarrow A_{CP}$ computation

$$A_{CP,j} = \frac{|\bar{c}_j|^2 - |c_j|^2}{|\bar{c}_j|^2 + |c_j|^2} = -\frac{2\,(x_j \Delta x_j + y_j \Delta y_j)}{x_j^2 + \Delta x_j^2 + y_j^2 + \Delta y_j^2}.$$

- Results: first evidence of direct CPV for $K^{*+}(892)\pi^0$

BaBar preliminary

Decay channel	A_{CP}
$K^0\pi^+\pi^0$	$0.07 \pm 0.05 \pm 0.03 \pm 0.04$
$K^{*0}(892)\pi^+$	$-0.12 \pm 0.21 \pm 0.08 \pm 0.11$
$K^{*+}(892)\pi^0$	$-0.52 \pm 0.14 \pm 0.04 \pm 0.04$ (3.4σ)
$K_0^{*0}(1430)\pi^+$	$0.14 \pm 0.10 \pm 0.04 \pm 0.14$
$K_0^{*+}(1430)\pi^0$	$0.26 \pm 0.12 \pm 0.08 \pm 0.12$
$\rho^+(770)K^0$	$0.21 \pm 0.19 \pm 0.07 \pm 0.30$



Outlook

- First observation of the charmless decay $B^+ \to K_S \pi^+ \pi^0$
- First evidence (3.4σ) of direct CP violation for $B^+ \to K^{*+}(892)\pi^0$
- $\Delta A_{CP}(K^*\pi) = \underbrace{A_{CP}(K^{*+}\pi^0)}_{\text{This new result}} - \underbrace{A_{CP}(K^{*+}\pi^-)}_{\text{HFAG average } -0.23 \pm 0.06} = -0.29 \pm 0.16$

$\to$ To be compared with $\Delta A_{CP}(K\pi) = 0.122 \pm 0.022$

- Results consistent with previous measurements (when available)
- No deviation from Standard Model expectations
- More statistics needed to study further these decays
  $\to$ Belle-2
- BaBar article to be submitted to PRD soon

Belle charm mixing and CPV results at ICHEP 2014

- First observation of D^0-$\bar{D}^0$ mixing in e^+e^- collision in the measurement of time-dependent ratio of WS to RS decay rates

  $x'^2 = (0.09 \pm 0.22) \times 10^{-3}$ $\qquad$ $y' = (4.6 \pm 3.4) \times 10^{-3}$

  $\Rightarrow$ no mixing hypothesis is excluded at 5.1σ level

- Updated measurement of D^0-$\bar{D}^0$ mixing in $D^0 \to K_S^0 \pi^+ \pi^-$

  $x = (0.56 \pm 0.19)\%$ $\qquad$ $y = (0.30 \pm 0.15)\%$

  $\Rightarrow$ significance of mixing is estimated to be 2.5σ

  $\Rightarrow$ No evidence for CP violation in the decay

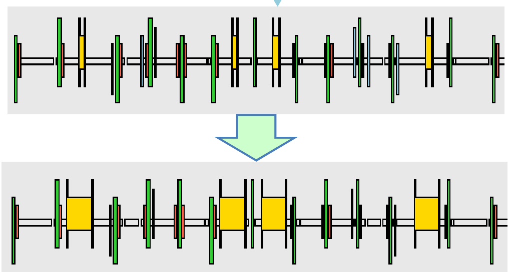
- Significantly improved measurement of time-integrated CP violating asymmetry A_{CP} in $D^0 \to \pi^0 \pi^0$ and the result is consistent with no CPV

  $A_{CP}(\pi^0\pi^0) = (-0.03 \pm 0.64 \pm 0.10)\%$

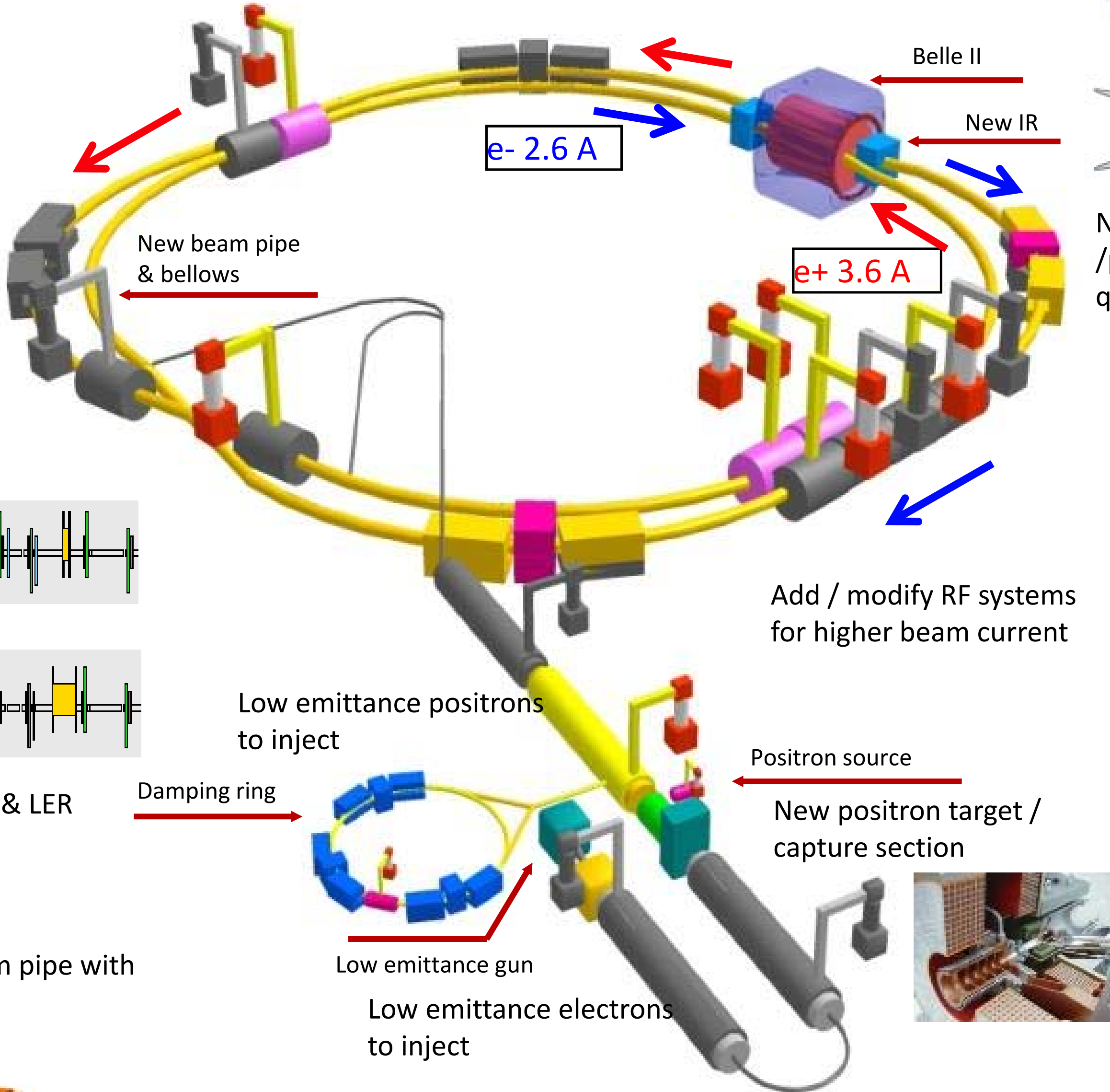
  $\Rightarrow$ updated the existing measurement of CP asymmetry in $D^0 \to K_S^0 \pi^0$

KEKB to SuperKEKB

Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

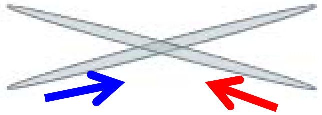


Belle II

New IR

New beam pipe & bellows

Colliding bunches



New superconducting /permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

Low emittance positrons to inject

Positron source

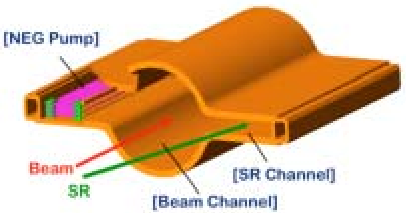
New positron target / capture section

Damping ring

Low emittance gun

Low emittance electrons to inject

TiN-coated beam pipe with antechambers



To obtain x40 higher luminosity