B Physics: New Physics and The Next Generation

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

<u>Excitement in Flavor Physics:</u>

-Connections to the *<u>charged Higgs</u>*

-Rare B Decays + <u>NP</u>

Flavor Physics, The Next Generation:

<u>Belle II and the LHCb upgrade</u>

Apologies: In the limited time, I cannot cover all the recent results from BaBar, Belle, LHCb, CMS, ATLAS, Tevatron …
I have borrowed slides from many excellent physicists and will aim for the "big picture" but skip most details.

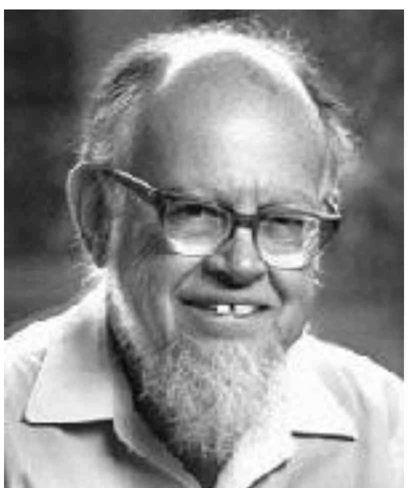
Amplitudes and *Phases* in the Weak Interaction

N. Cabibbo

M.Kobayashi

T.Maskawa

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



L. Wolfenstein (1923-2015)

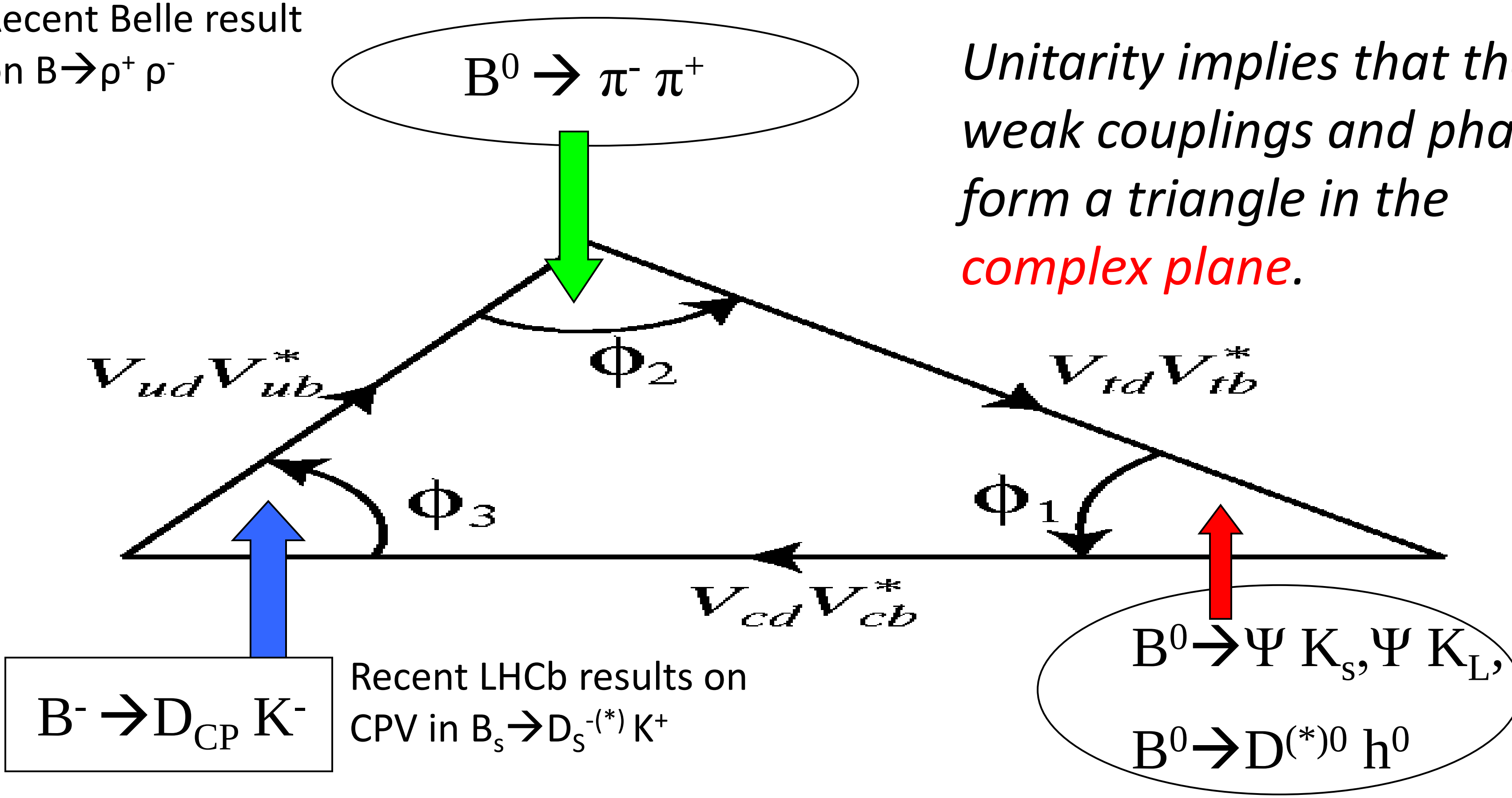
to O(λ^3)

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

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

Recent Belle result on $B \rightarrow \rho^+ \rho^-$

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



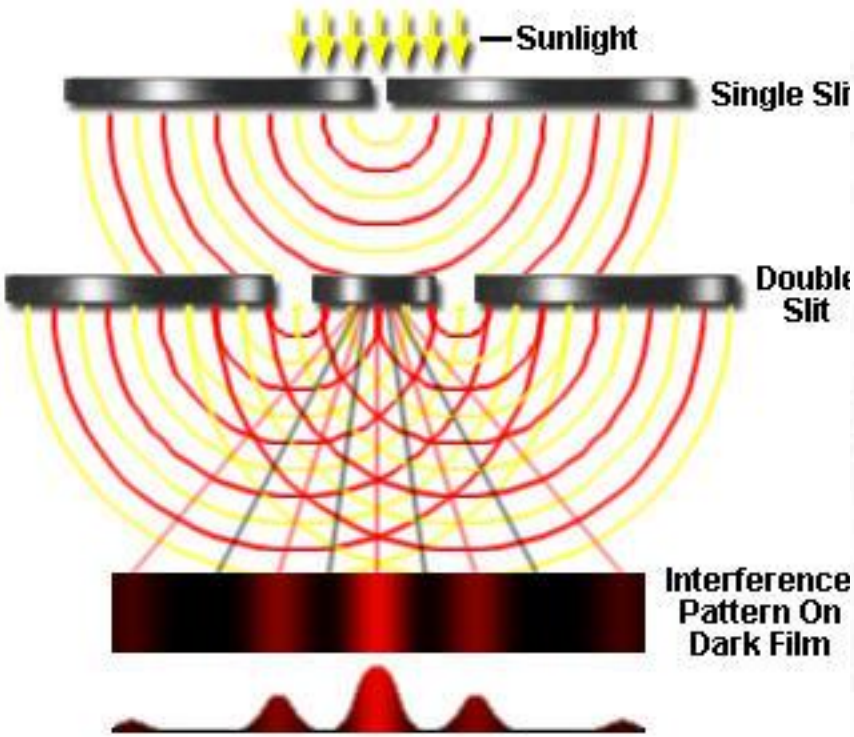
Recent LHCb results on CPV in $B_s \rightarrow D_S^{-(*)} K^+$

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



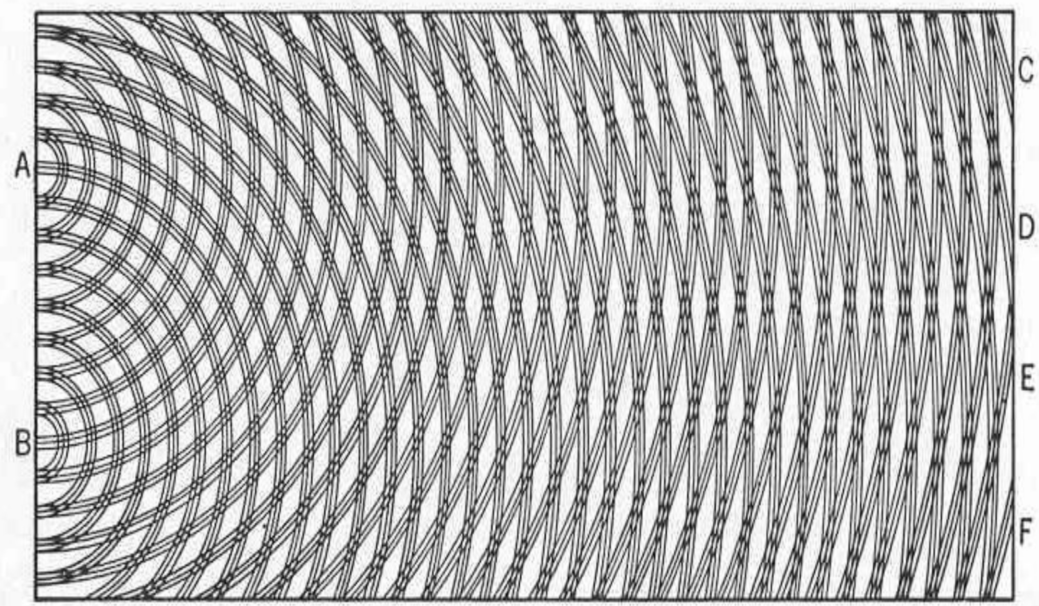
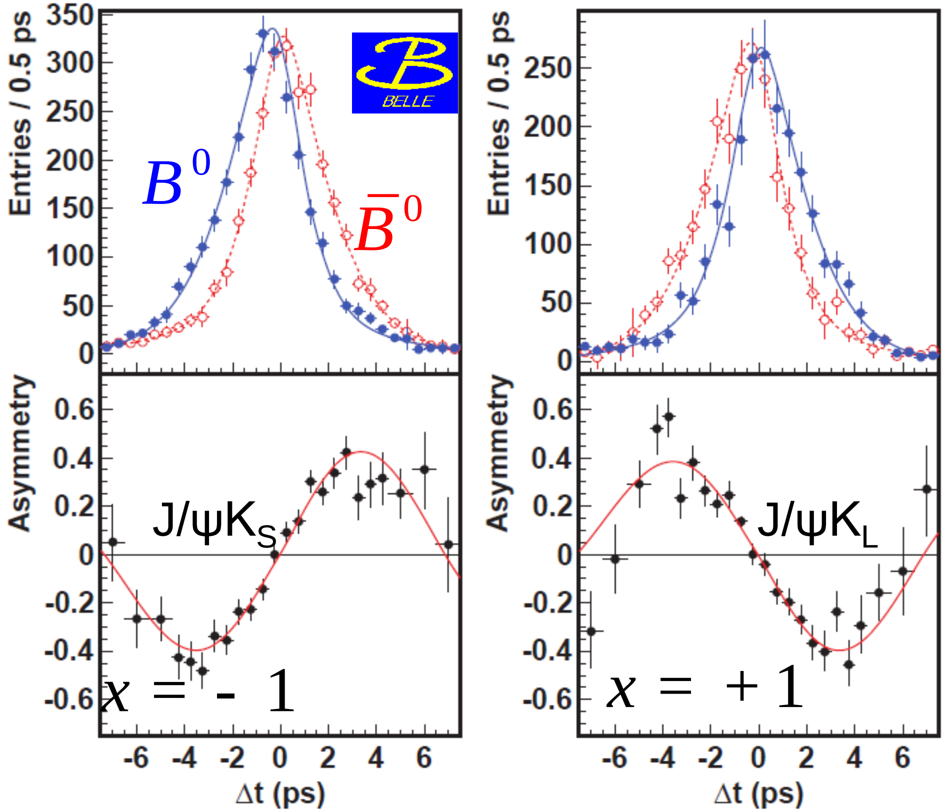
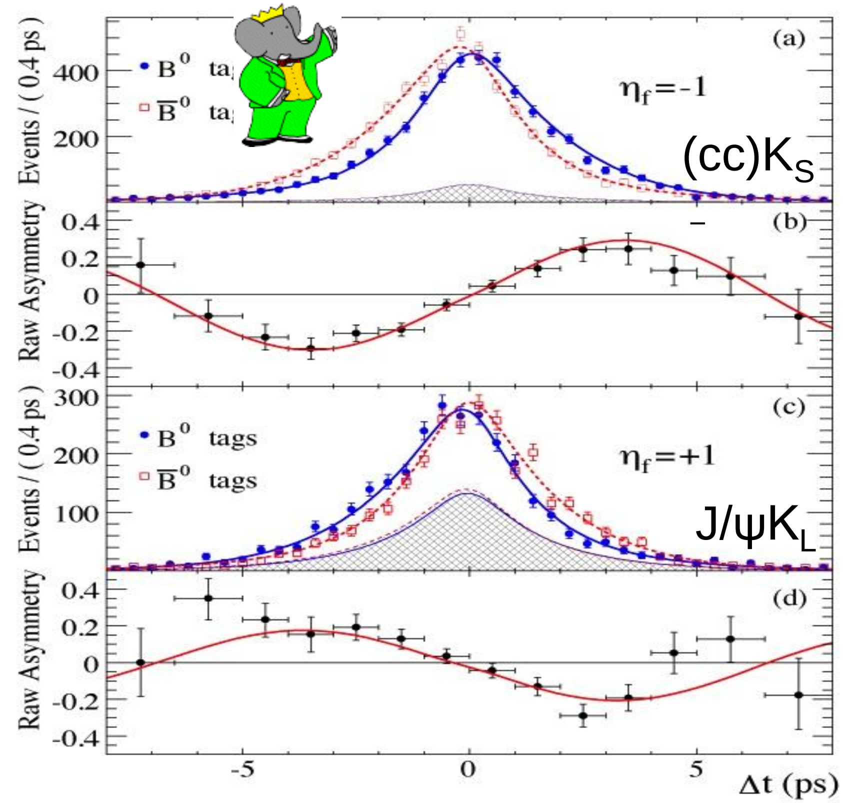


FIG. 1

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 B→Charmonium K^0 modes





$\sin 2\varphi_1 = 0.667 \pm 0.023 \pm 0.012$

$A_f = 0.006 \pm 0.016 \pm 0.012$

PRL108,171802 (2012)

$\sin 2\varphi_1 = 0.687 \pm 0.028 \pm 0.012$

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

PRD79,072009 (2009)

Overpowering evidence for CP violation (matter-antimatter asymmetries). >>>> <u>The phase of V_{td}</u> is in good agreement with Standard Model expectations. *This is the phase of B_d mixing.*

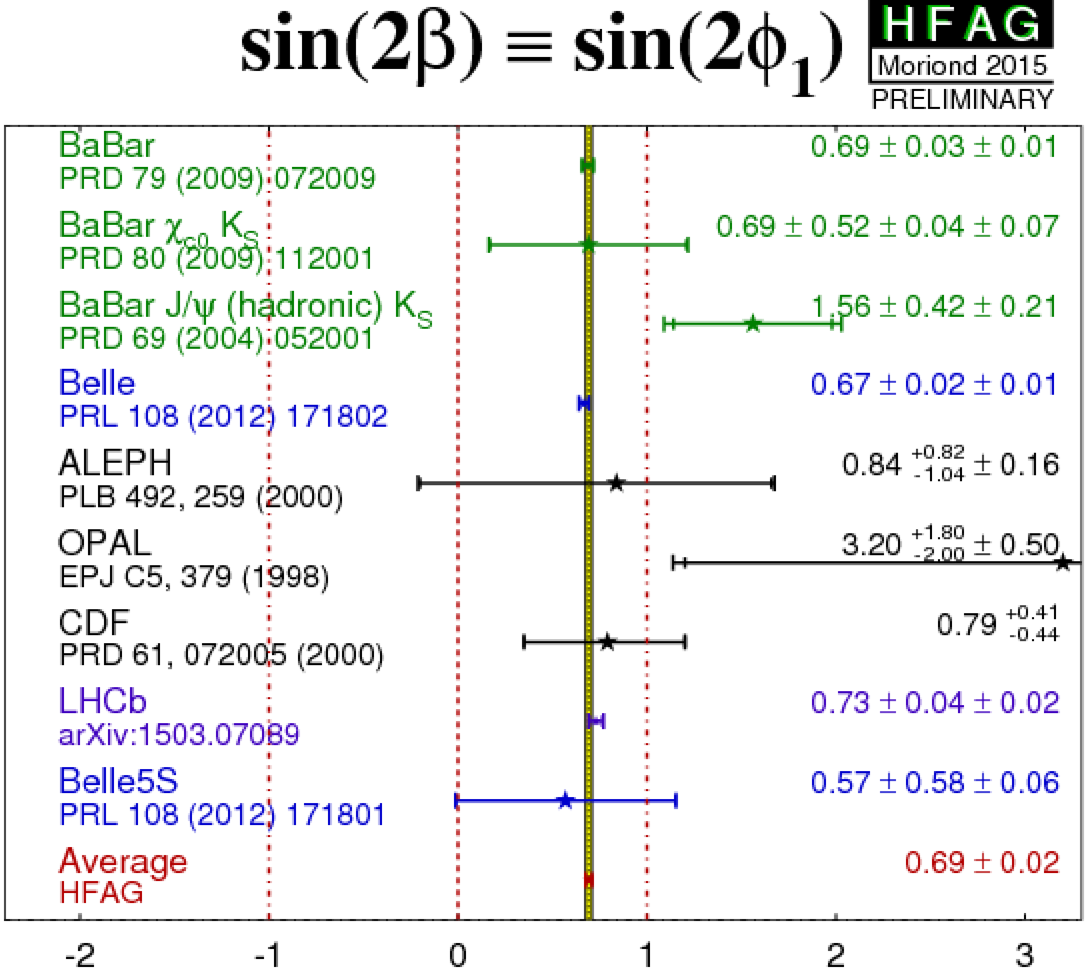
Breaking news: 2016 APS Panofsky Prize for *Experimental Particle Physics* Awarded to

Steve Olsen, Dave Hitlin, Jonathan Dorfan, and Fumihiko Takasaki

A scene in Stockholm, Sweden 2008

Front row 2008 Physics Nobelists: T. Maskawa, M. Kobayashi

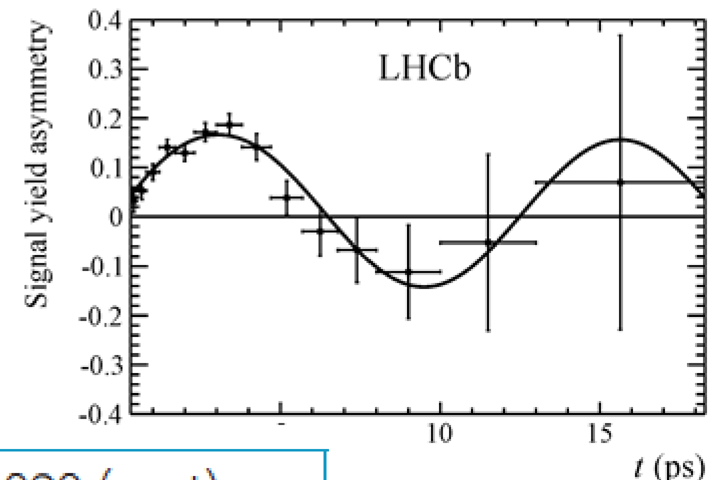
$\sin(2\beta) \equiv \sin(2\phi_1)$



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

2013: LHCb joins the game [±0.07(stat)]

2015: *Latest LHCb measurement is comparable in precision to B factories* (now uses same-side B tagging)



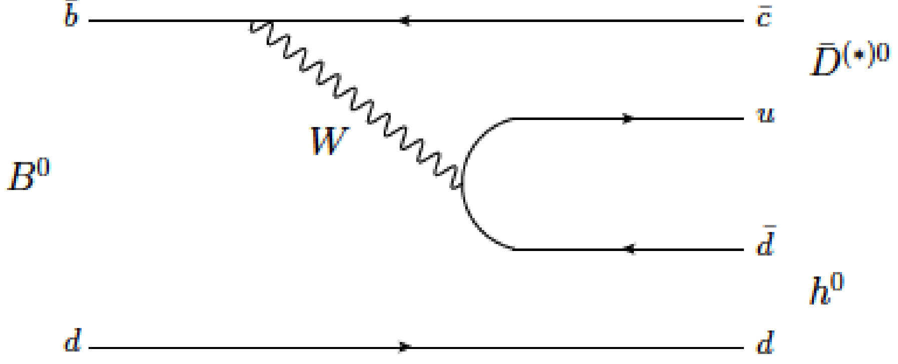
$$S(B^0 \to J/\psi K^0_S) = 0.731 \pm 0.035\,(\text{stat}) \pm 0.020\,(\text{syst}),$$
$$C(B^0 \to J/\psi K^0_S) = -0.038 \pm 0.032\,(\text{stat}) \pm 0.005\,(\text{syst}).$$

B factories: *Check CP violation in b→c [ubar d] processes*

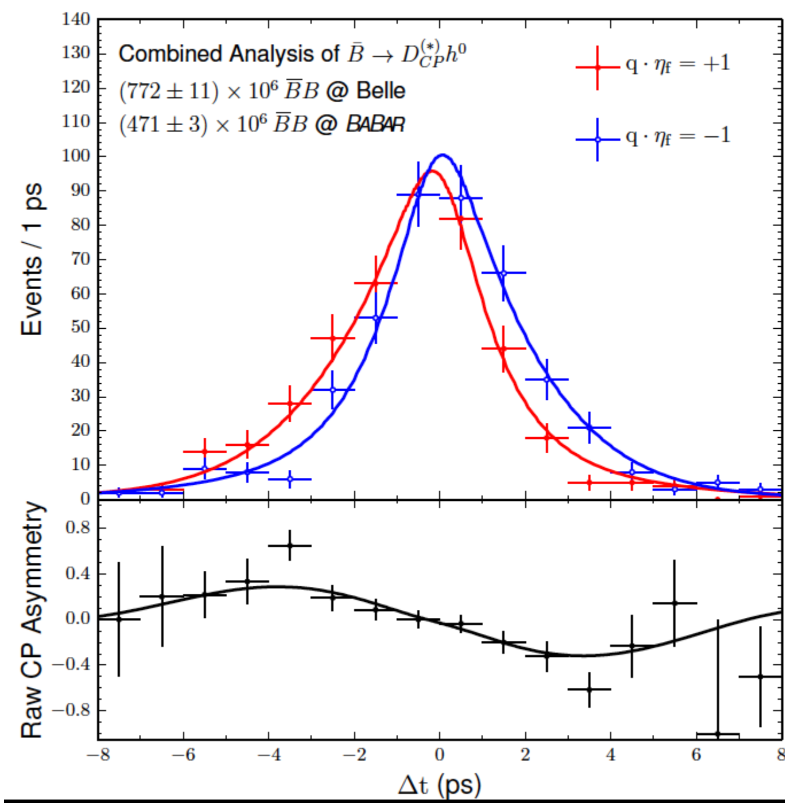
2015: First joint BaBar-Belle data analysis

M. Rohrken et al

"Color-suppressed" B→D h



where D^0 is a CP eigenstate and $h^0=\pi^0, \eta, \omega$



Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4σ CP violation signal→<u>First observation</u>

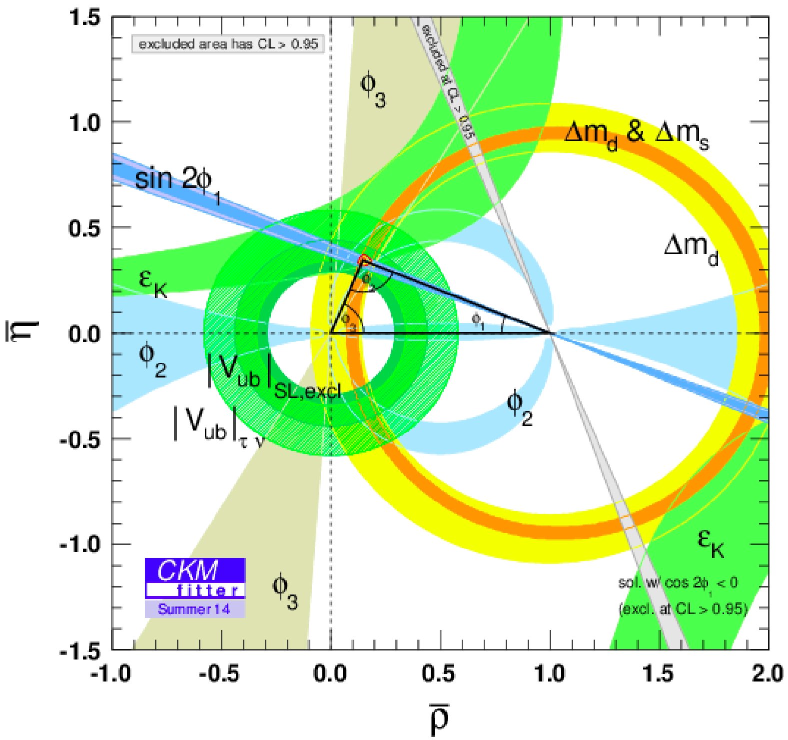
$\sin(2\beta_{eff})=0.66\pm0.10(stat)\pm0.06(sys)$

Phase of V_{td} again

Conclusion: CP violation in b→c ubar d modes is the same as in b→c cbar s modes (e.g. B→J/ψ K_S)

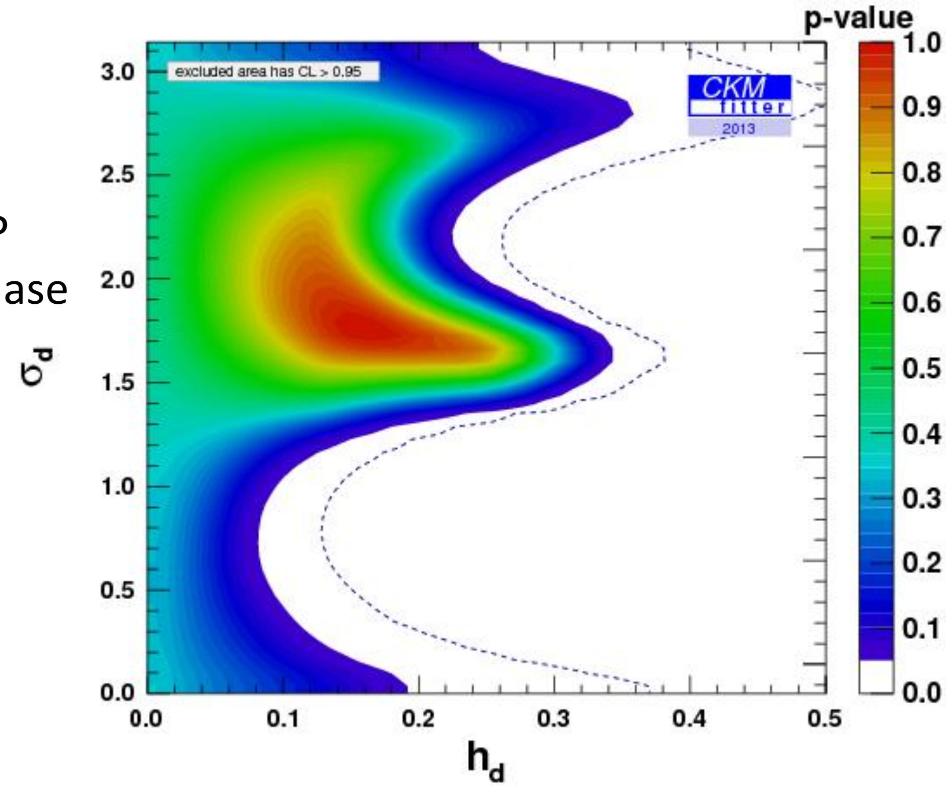
Results from Global Fits to Data (CKMFitter Group)

Great progress on φ_3 or γ (first from B factories and now in the last two years from LHCb). *These measure the phase of V_{ub}* [CKM2014, K. Trabelsi's review: $\pm 7^0$]



Similar results from UTFIT as well from G. Eigen et al.

NP Phase

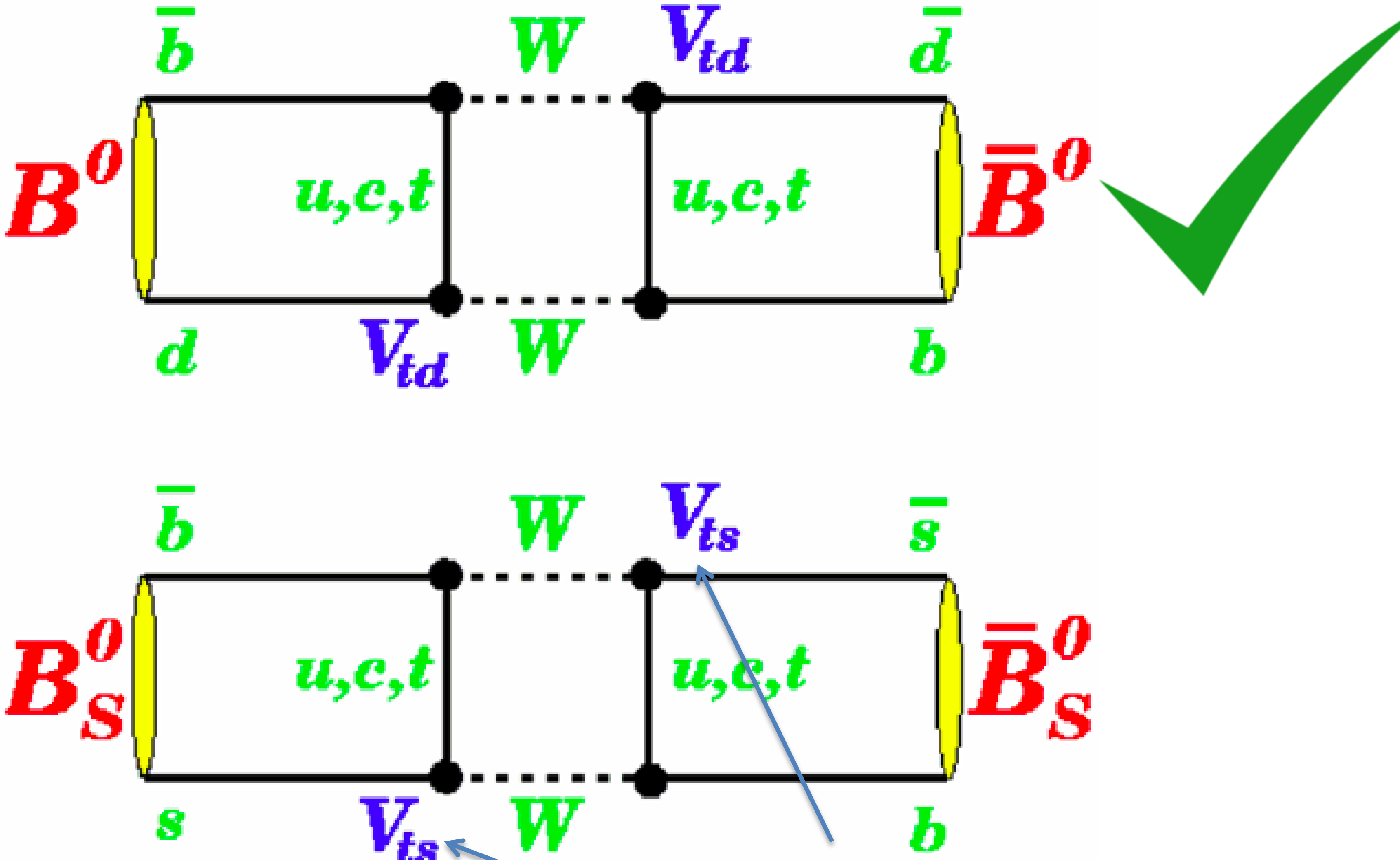


NP/SM amplitude ratio

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

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

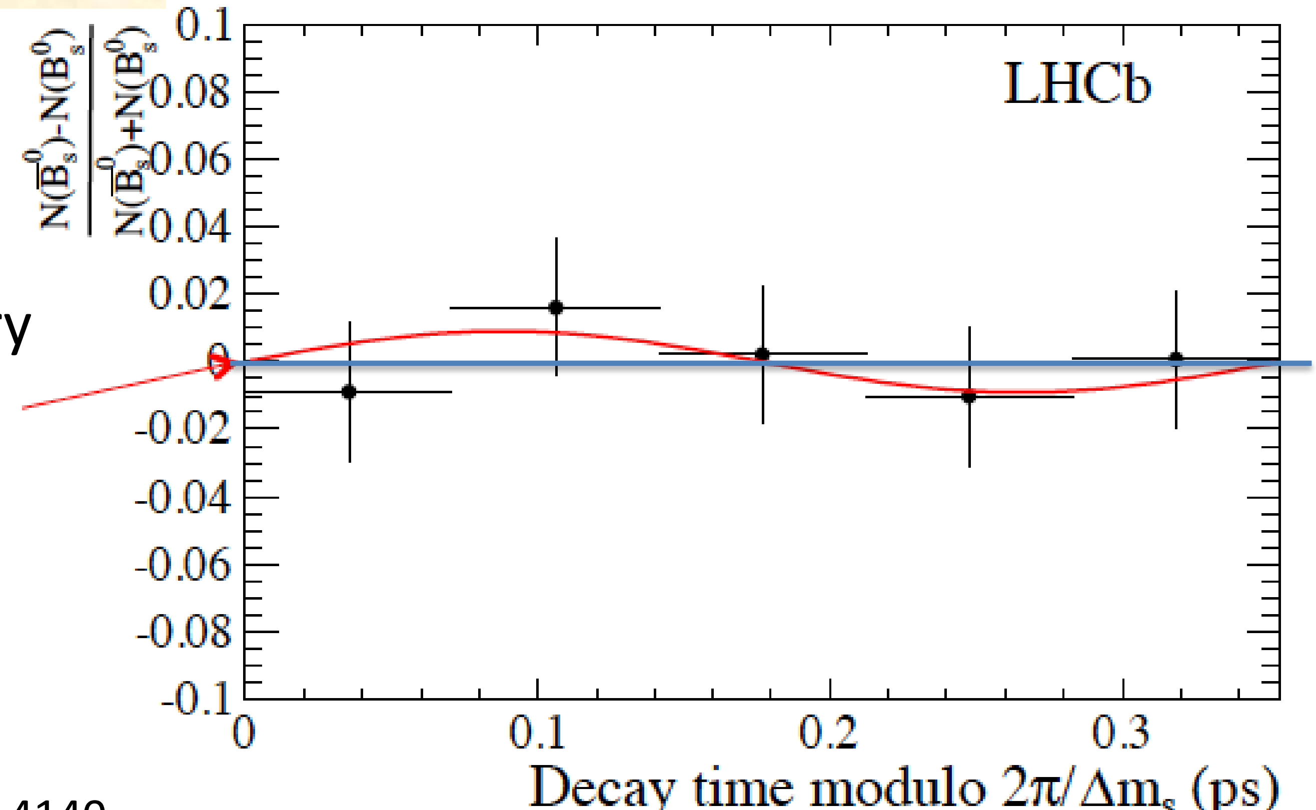
$B_s \rightarrow J/\psi\varphi$, a pseudoscalar to vector-vector mode, is usually used. However, $B_s \rightarrow J/\psi\ f_0(980)$ is a pure CP eigenstate since the f_0 (980) is a scalar.

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

$\Phi_s=(70\pm68\pm8)$ mrad

Red curve: expectation for Φ_s = 70 mrad

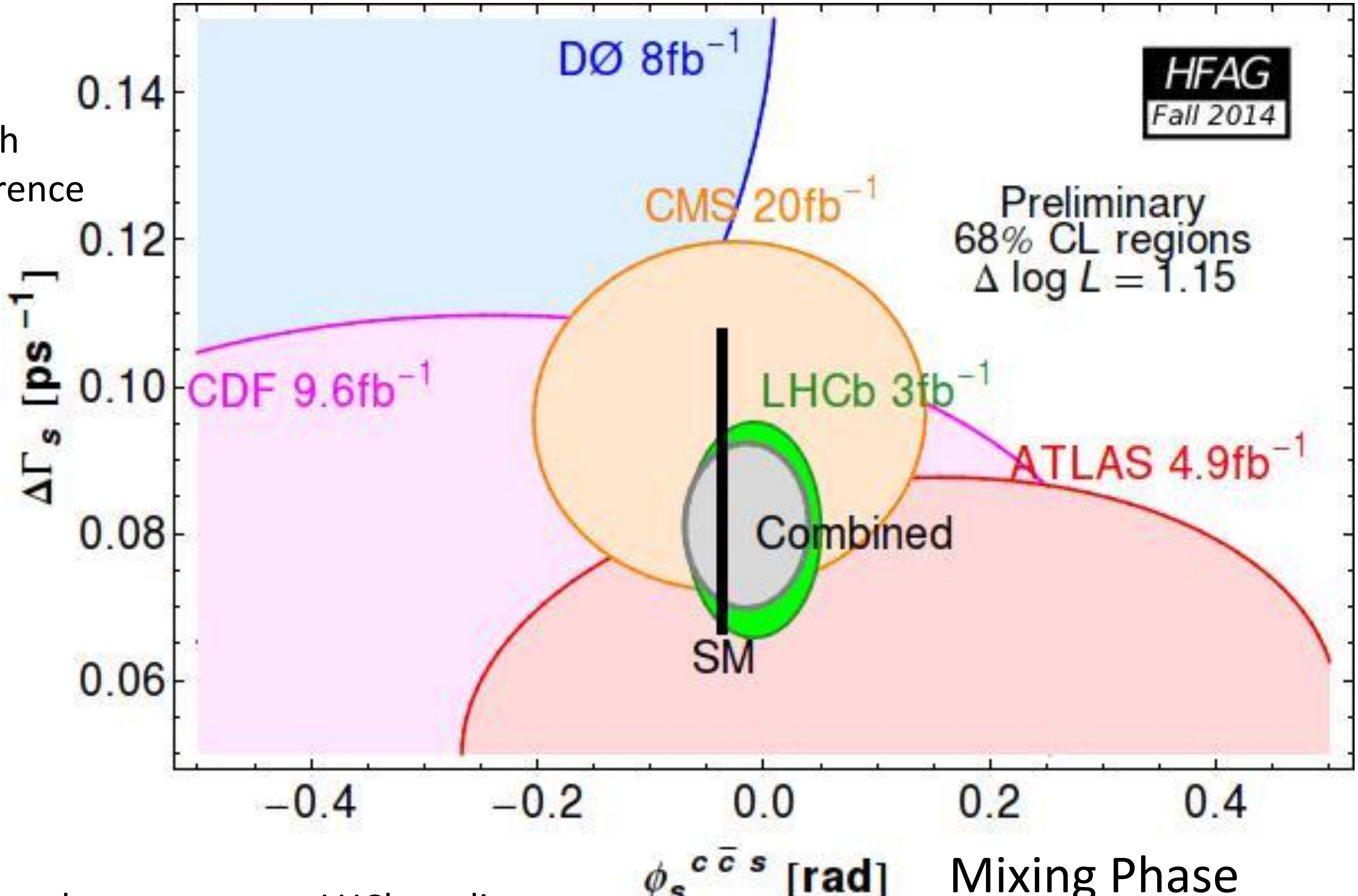
Asymmetry



arXiv: 1405.4140

Results on the phase of B_s-anti B_s mixing (i.e. phase of V_{ts}) [use $B_s \rightarrow J/\psi\varphi$; $J/\psi\pi\pi$ modes]

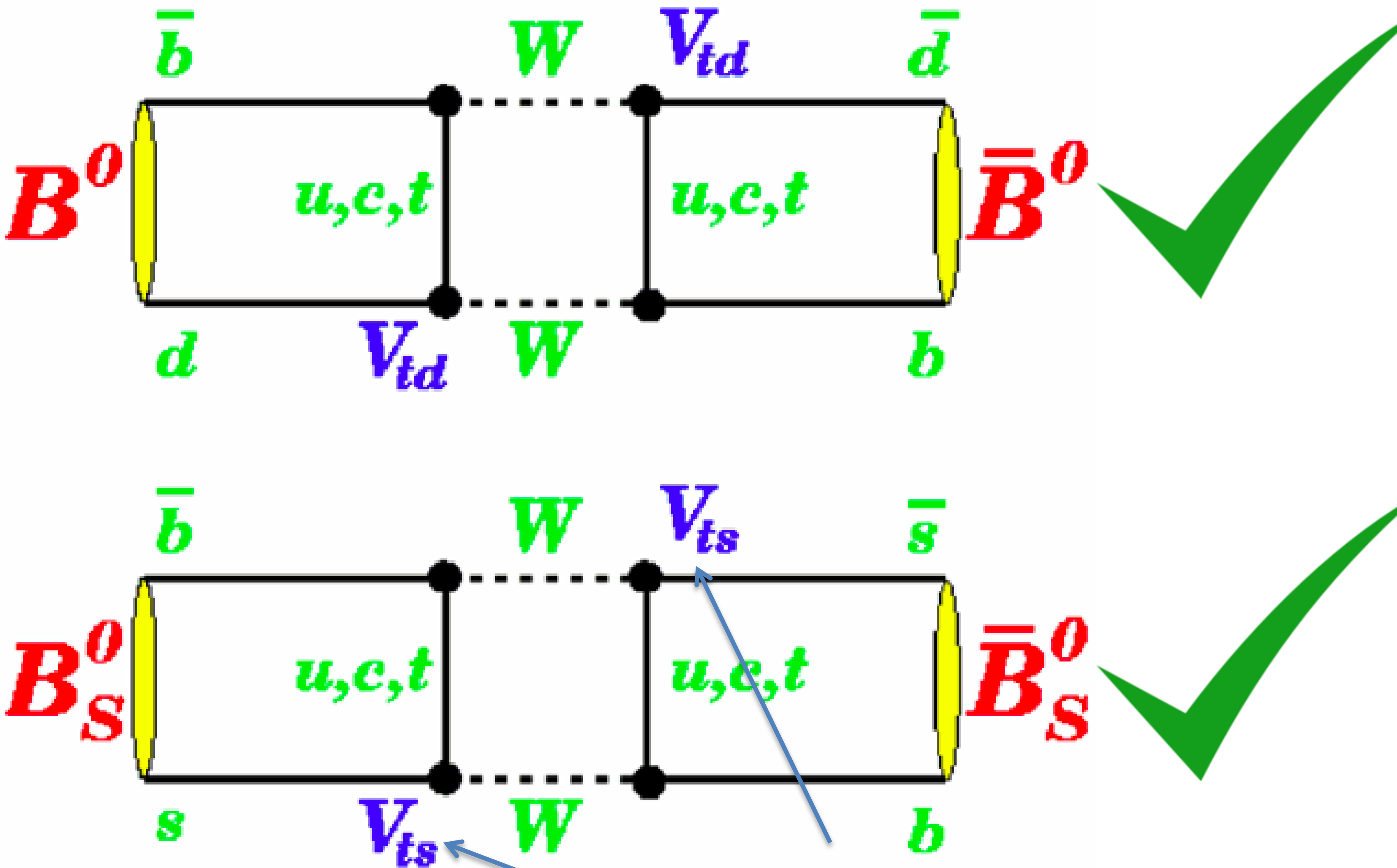
Width difference



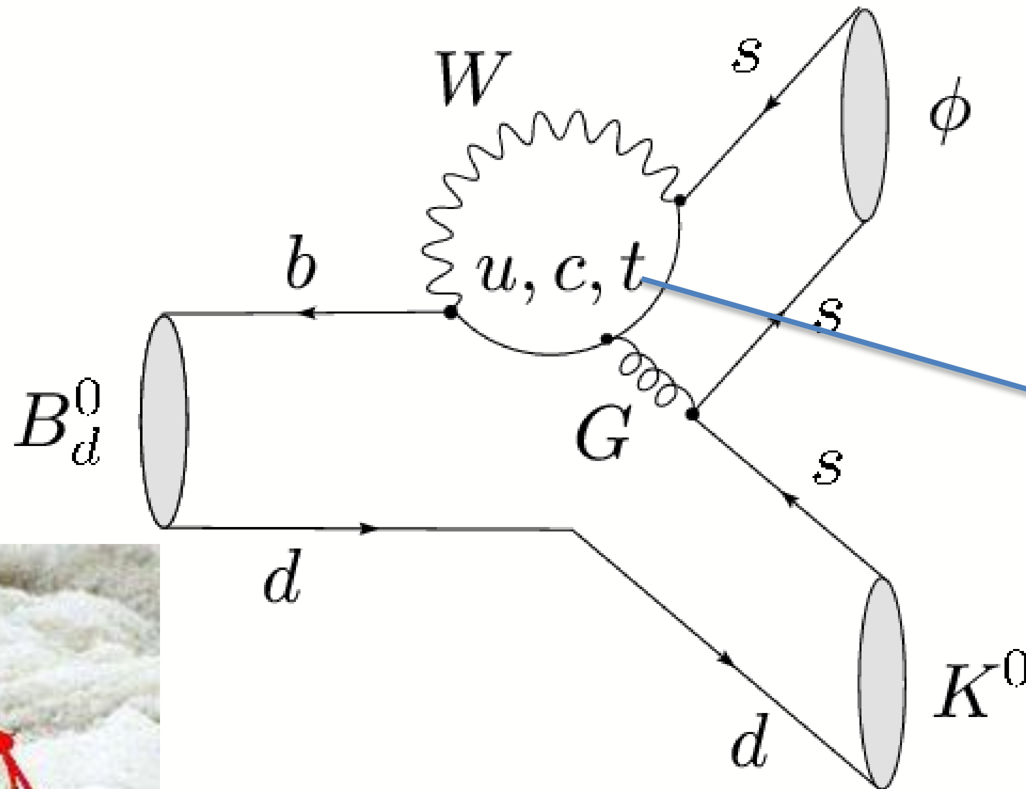
Mixing Phase

(Includes the most recent LHCb prelim result, gives WA of -36 ±13 mrad)

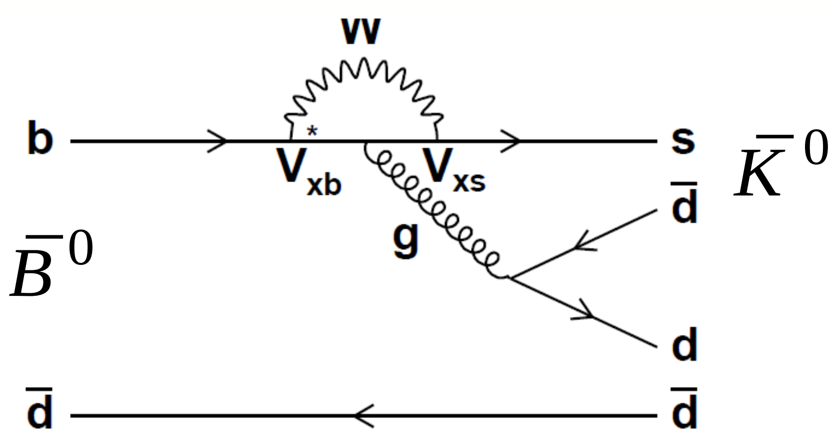
Boxes



No phase expected from SM but possible from NP particles

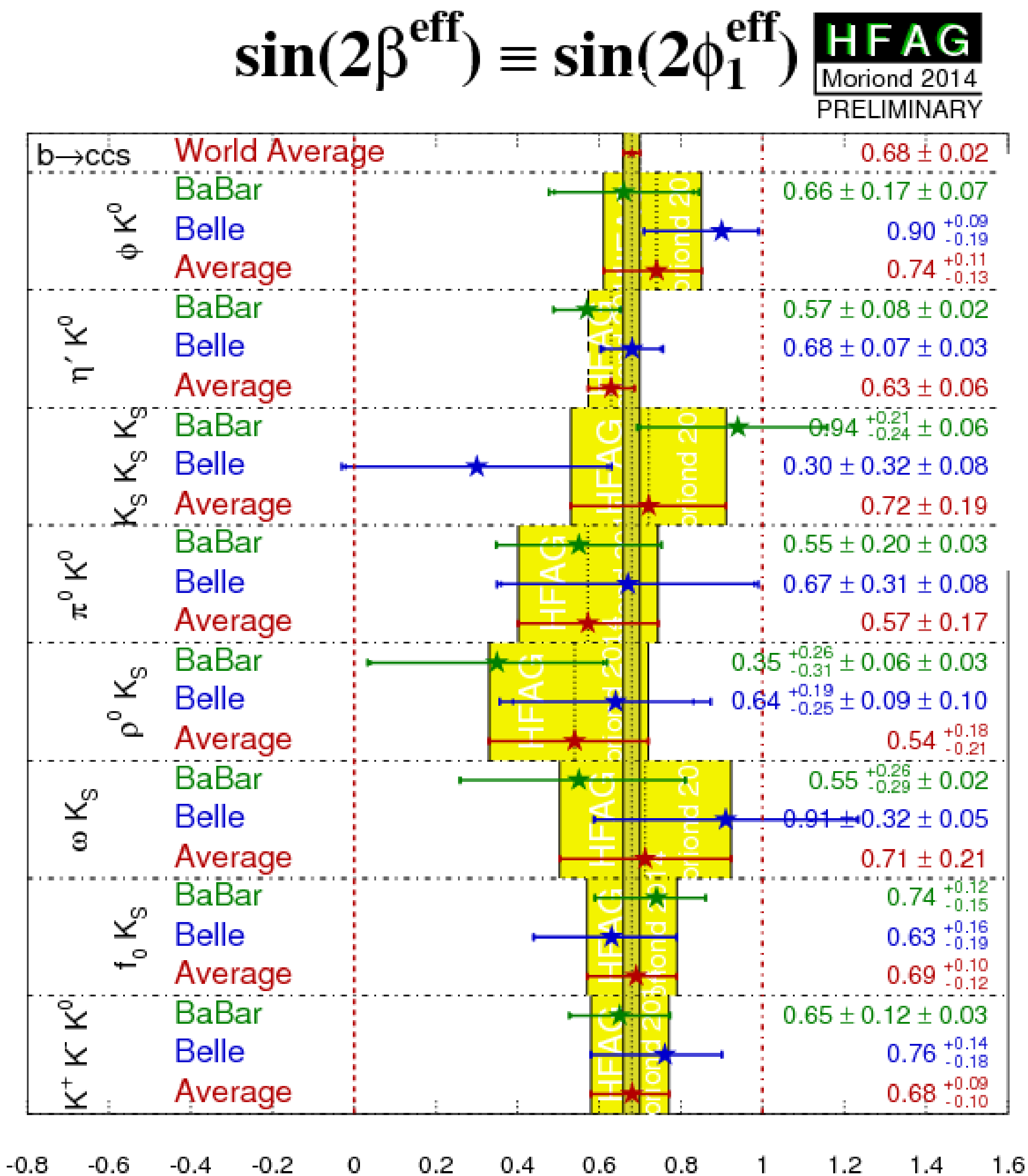


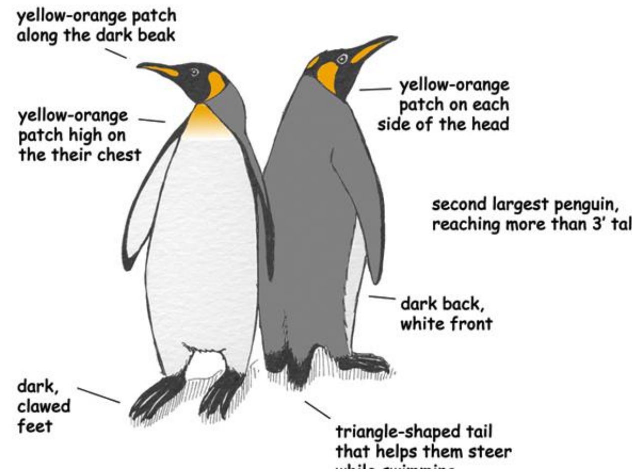
Phase of V_{ts}



Recent Belle results on $B \rightarrow \omega K_S$, $B \rightarrow \eta' K_S$

New Physics Phases in Penguin b→s decays





No evidence for NP at current level of sensitivity

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

"Missing Energy" Decays

Tsutentaku tower, Osaka

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2 Accelerators Find Particles That May Break Known Laws of Physics

The LHC and the Belle experiment have found particle decay patterns that violate the Standard Model of particle physics, confirming earlier observations at the BaBar facility

By Clara Moskowitz | September 9, 2015 | Véalo en español

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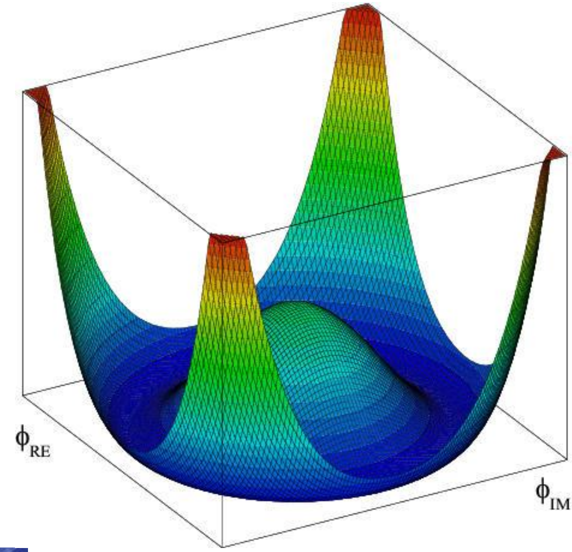
Democracy suffers a blow—in particle physics

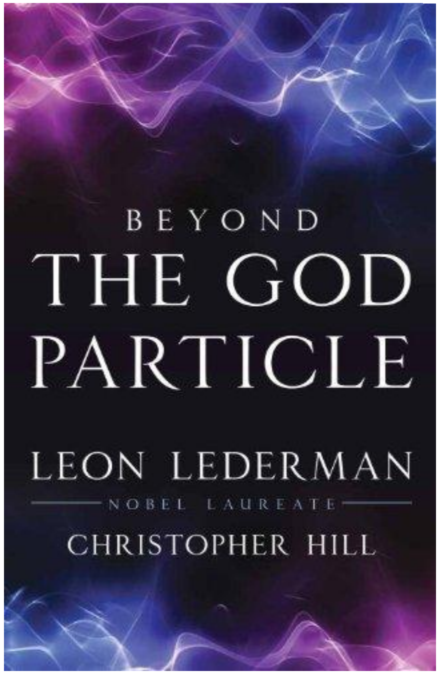
Three independent B-meson experiments suggest that the charged leptons may not be so equal after all.

Steven K. Blau 17 September 2015

The BEH boson is now firmly established by experimental results from ATLAS and CMS. *Now planning for Higgs flavor factory facilities (e.g ILC, FCC, CEPC, H-LHC).*



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



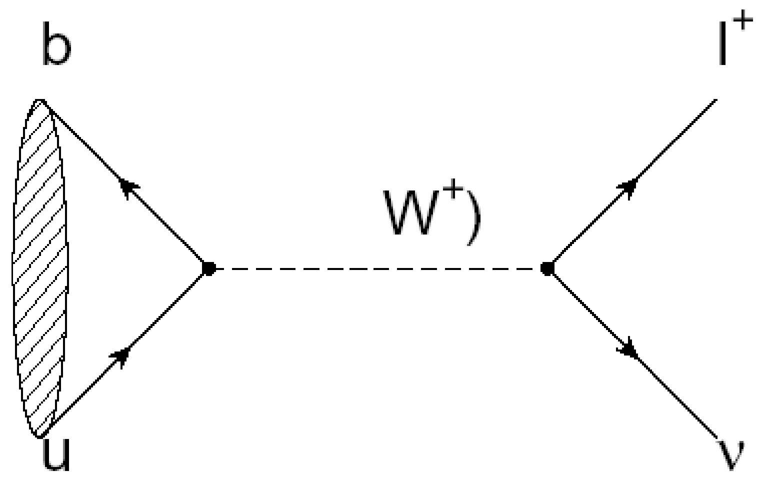
Y. Nambu, 1921-2015

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

B→τ ν

(Decay with *Large* Missing Energy)

Sensitivity to new physics from a ***charged Higgs***



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

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

W.S.Hou,. PRD 48, 2342 (*1993*)

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

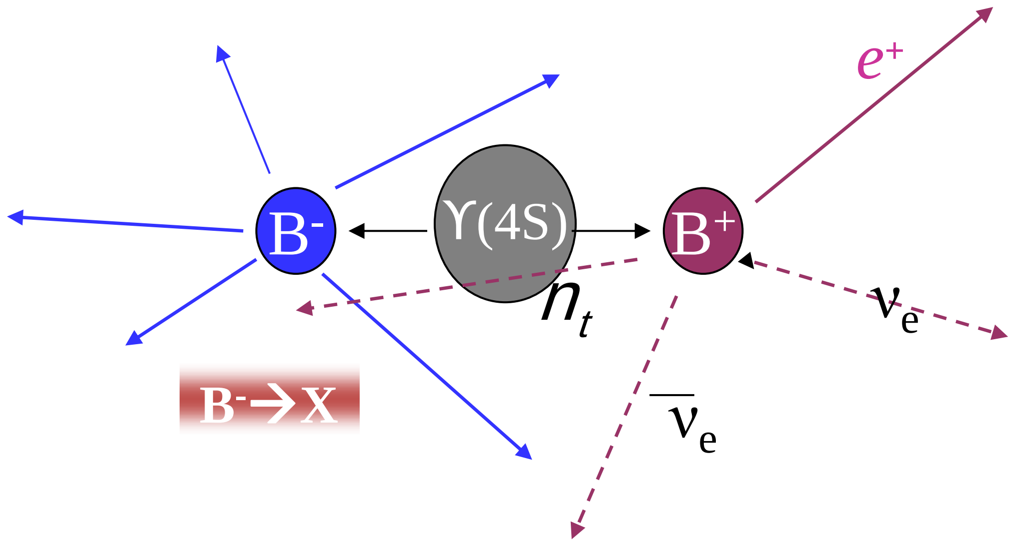
- *Higgs doublet of type I* (ϕ_1 couples to upper (u-type) and lower (d-type) generations. No fermions couple to ϕ_2)

- *Higgs doublet of type II* (ϕ_u couples to u type quarks, ϕ_d couples to d-type quarks, u and d couplings are different; $\tan(\beta) = v_u/v_d$) [favored NP scenario e.g. MSSM, generic SUSY]

- *Higgs doublet of type III* (not type I or type II; anything goes. "FCNC hell"→many FCNC signatures)

Thanks to Xerxes Tata

Why measuring $B^+ \rightarrow \tau^+ \nu$ is non-trivial



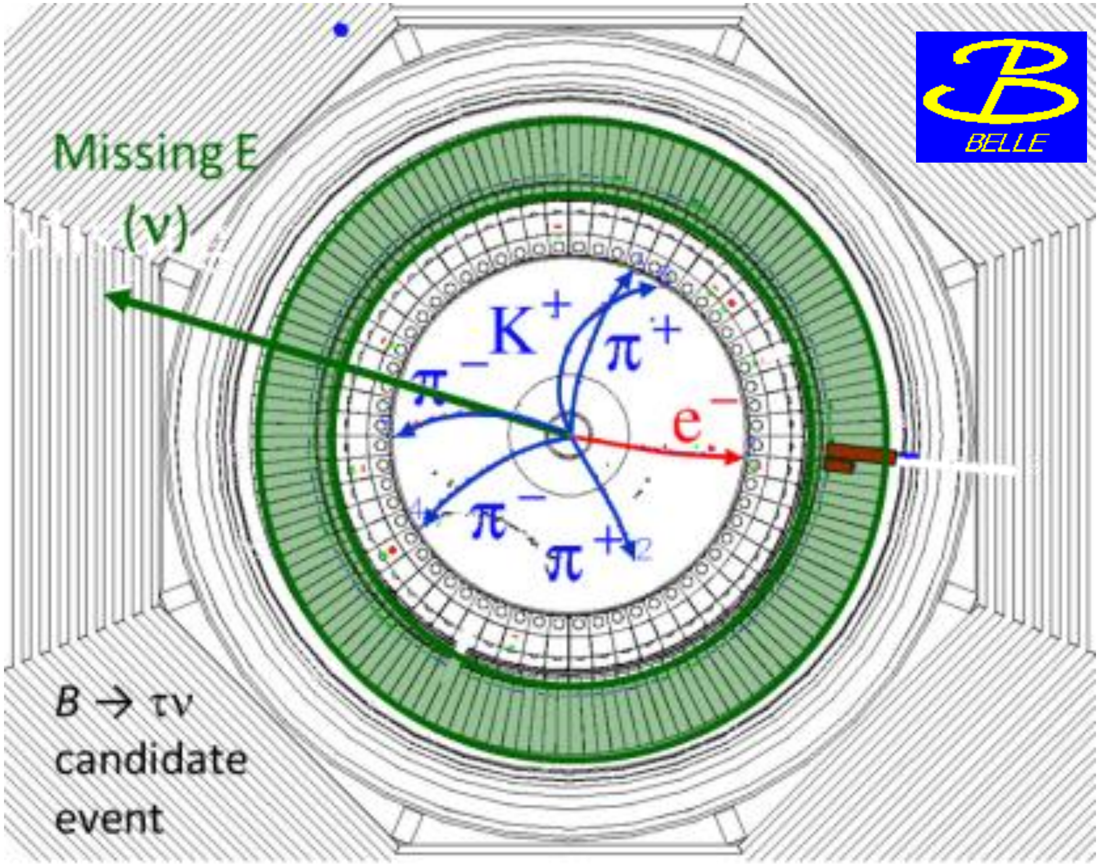
Most of the sensitivity is from tau modes with 1-prongs.

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

(This may be hard at a hadron collider)

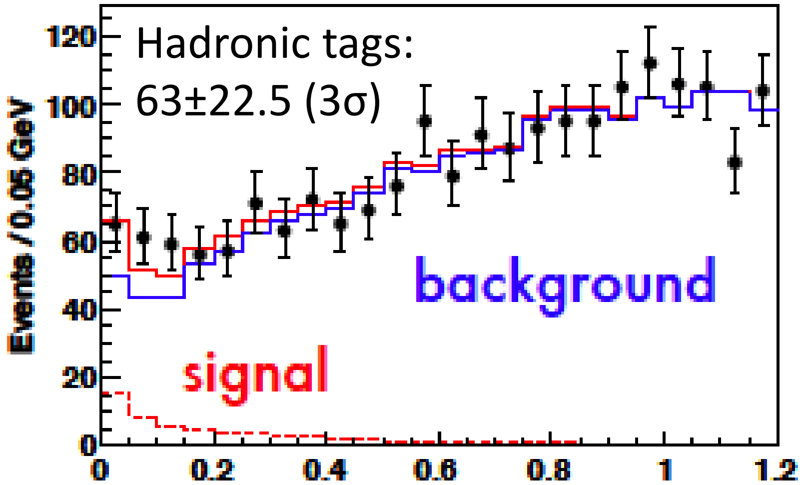
Example of a Missing Energy Decay (B→τν) *in* <u>*Data*</u>

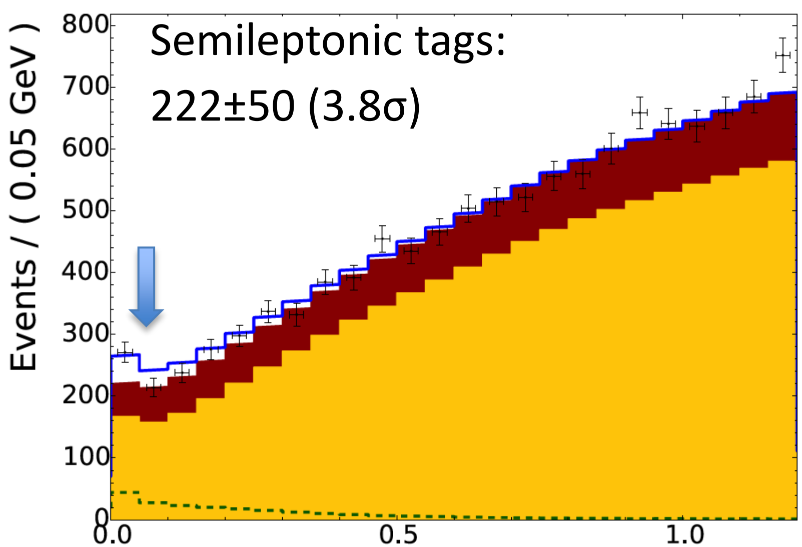
$$B^+ \rightarrow D^0\pi^+$$
$$(\rightarrow K\pi^-\pi^+\pi^-)$$
$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$

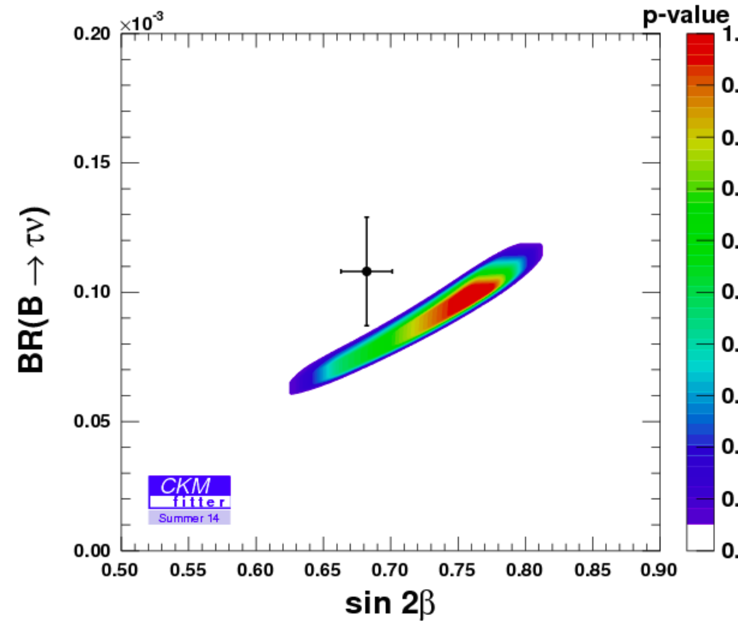


The clean e+e- environment makes this possible

Example: Belle B→τν results with full *reprocessed* data sample and either hadronic or semileptonic tags (arXiv: 1409.5269→PRD)







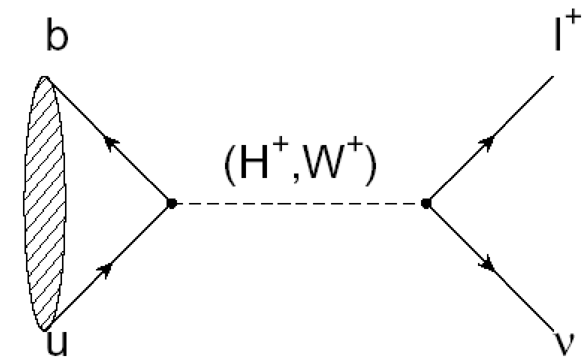
With the full B factory statistics only “evidence”. No single observation from either Belle or BaBar.

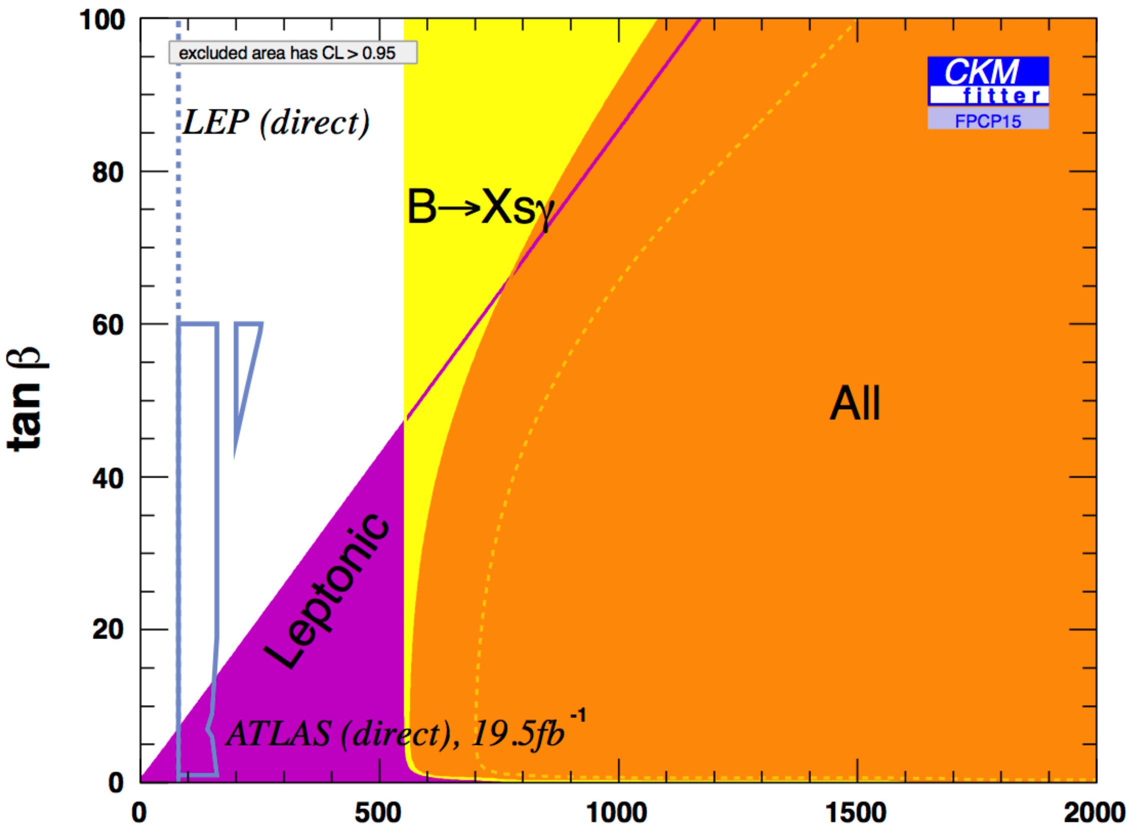
The horizontal axis is the “Extra Calorimeter Energy”

Complementarity of e+ e- factories and LHC

(Slide adapted from A. Bevan)

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

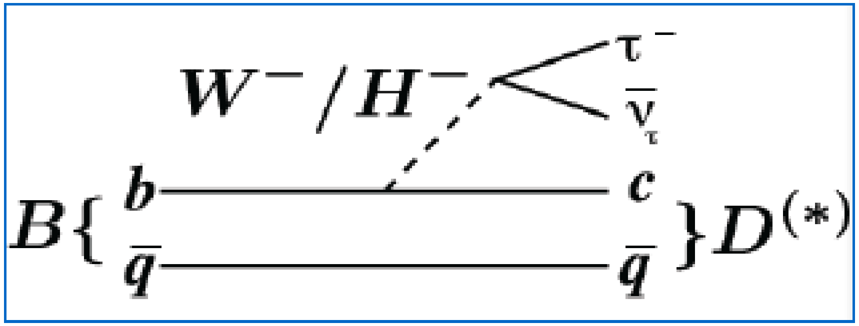


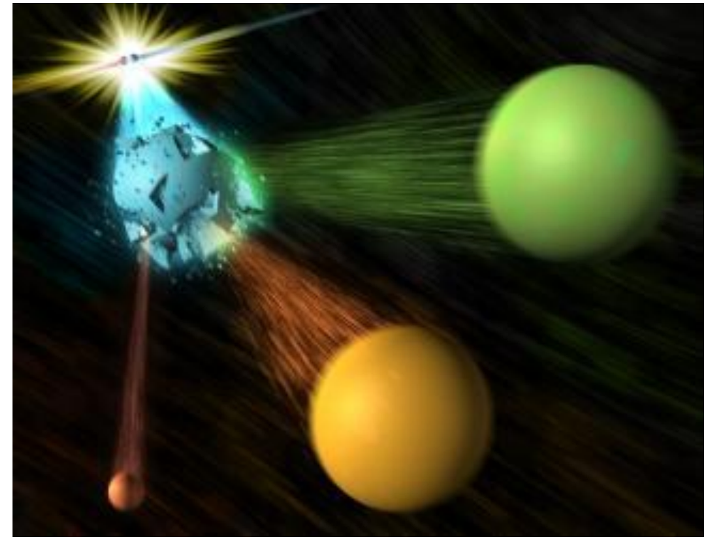


$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

Currently inclusive b to sγ rules out m_{H+} below ~480 GeV/c^2 range at 95% CL (independent of tanβ), M. Misiak et al.

http://arxiv.org/abs/1503.01789





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

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

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

$\longrightarrow$ Signal

$\longrightarrow$ Normalization ($l = e$ or μ)

Slide adapted from A. Soffer

Example from a BaBar paper

<u>Signals in B→D$^{(*)}$ τν (489±63, 888±63)</u>

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

But wait !!! Now *possible* at LHCb.

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

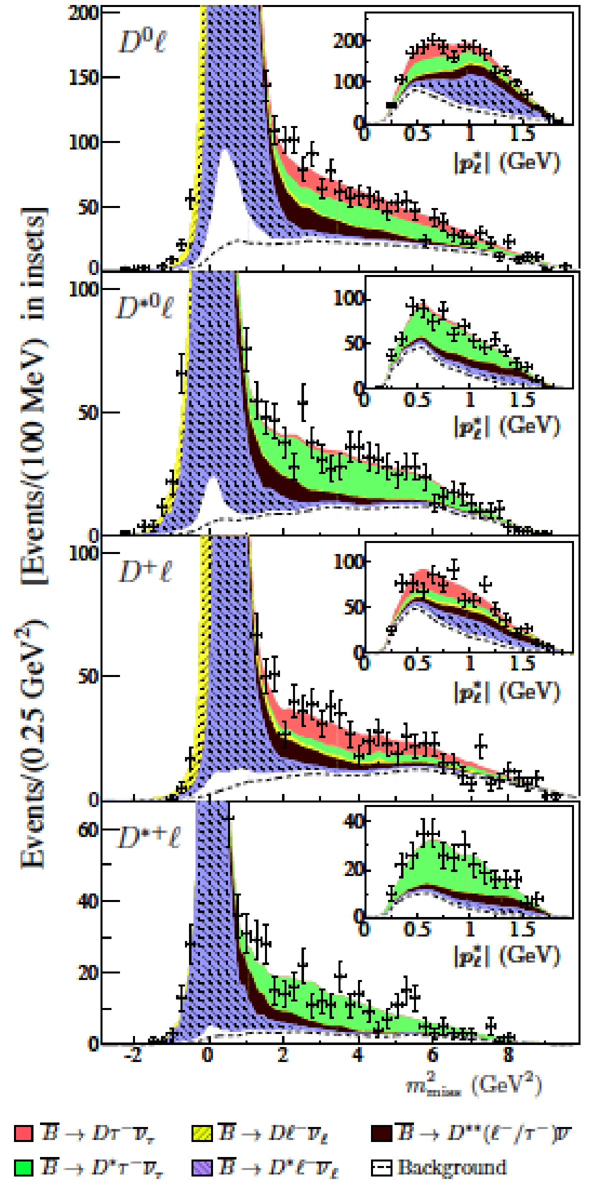
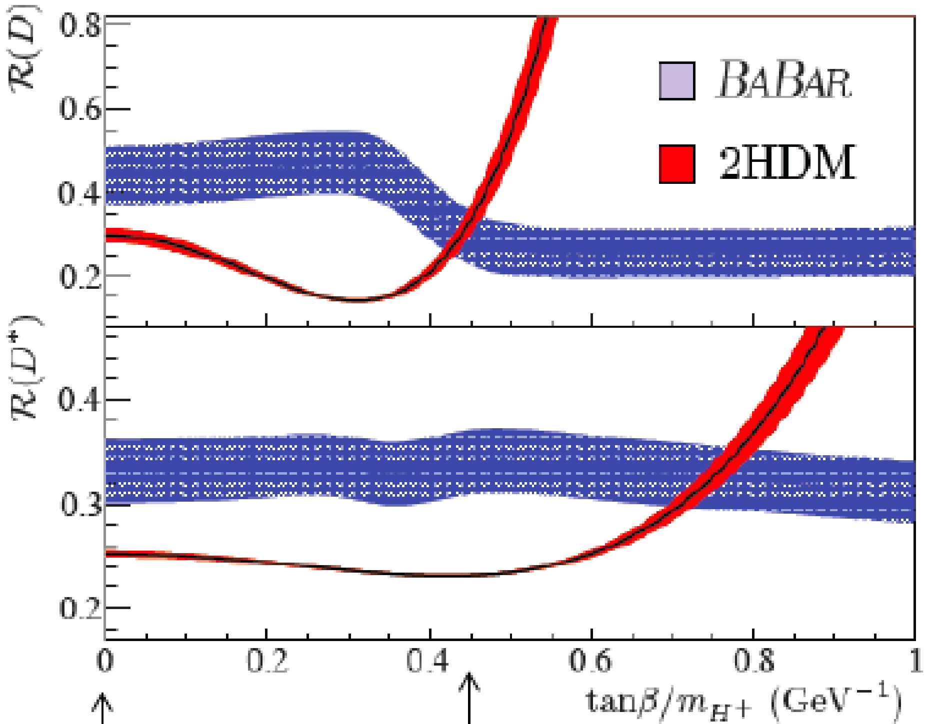


FIG. 1. (Color online) Comparison of the data and the fit projections for the four $D^{(*)}\ell$ samples. The insets show the $|p^*_\ell|$ projections for $m^2_{miss} > 1\,GeV^2$, which excludes most of the normalization modes. In the background component, the region above the dashed line corresponds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

Limits on type-II 2HDM

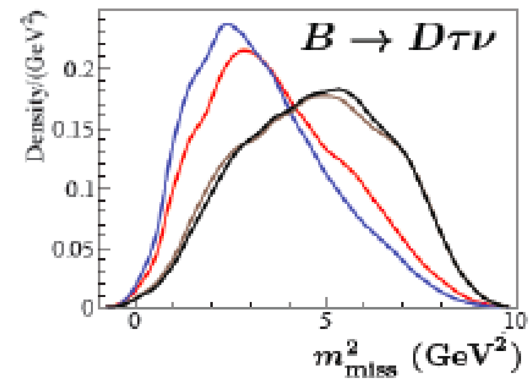


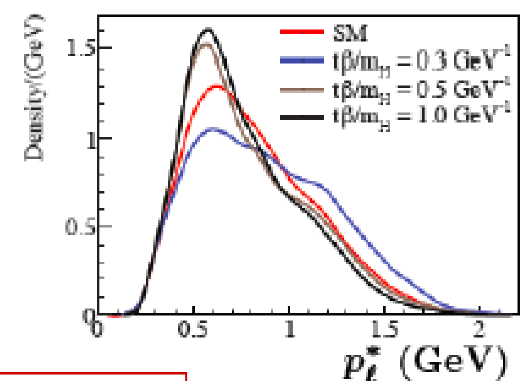
$\tan\beta/m_{H^+} =$
0.44 ± 0.02 GeV^{-1}

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

SM

2HDM modifies fit-variable distribution and hence the efficiency

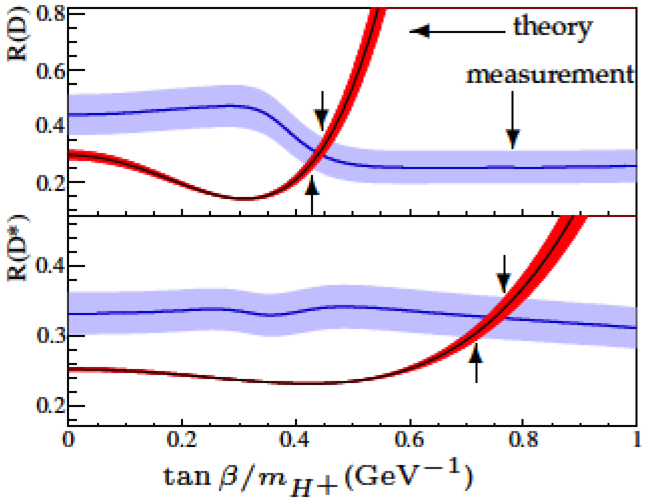




Best point is $\tan\beta/m_{H+}$ = 0.45 GeV^{-1}, excluded at 99.8% CL (3.1 σ).
All other values (with m_{H+} > 15 GeV) are worse.

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 $\tan(\beta)/m_{H+}$"



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

New Belle result with hadronic tags

May 25 2015, Nagoya FPCP

T. Kuhr

http://xxx.lanl.gov/abs/1507.03233; to appear in Phys Rev D

Warning: color-coding different from BaBar

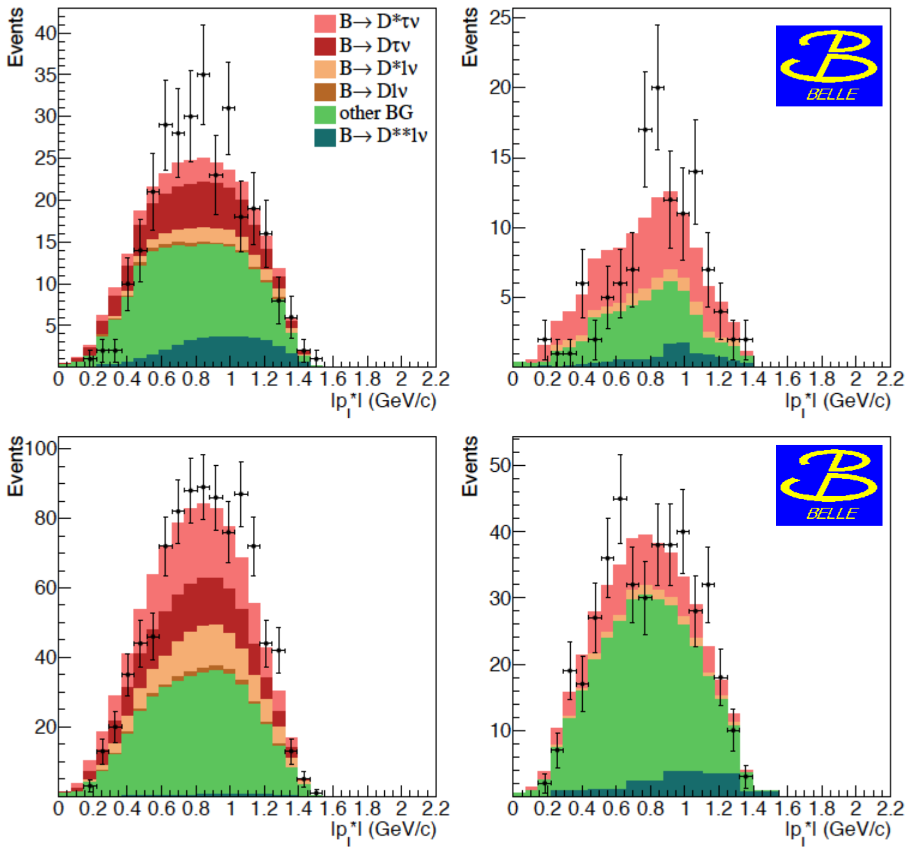


FIG. 6. Projections of the fit results and data points with statistical uncertainties in a signal enhanced region of $M^2_{\rm miss} > 2.0\,{\rm GeV}^2/c^4$ in the p^*_ℓ dimension. Top left: $D^+\ell^-$; top right: $D^{*+}\ell^-$; bottom left: $D^0\ell^-$; bottom right: $D^{*0}\ell^-$.

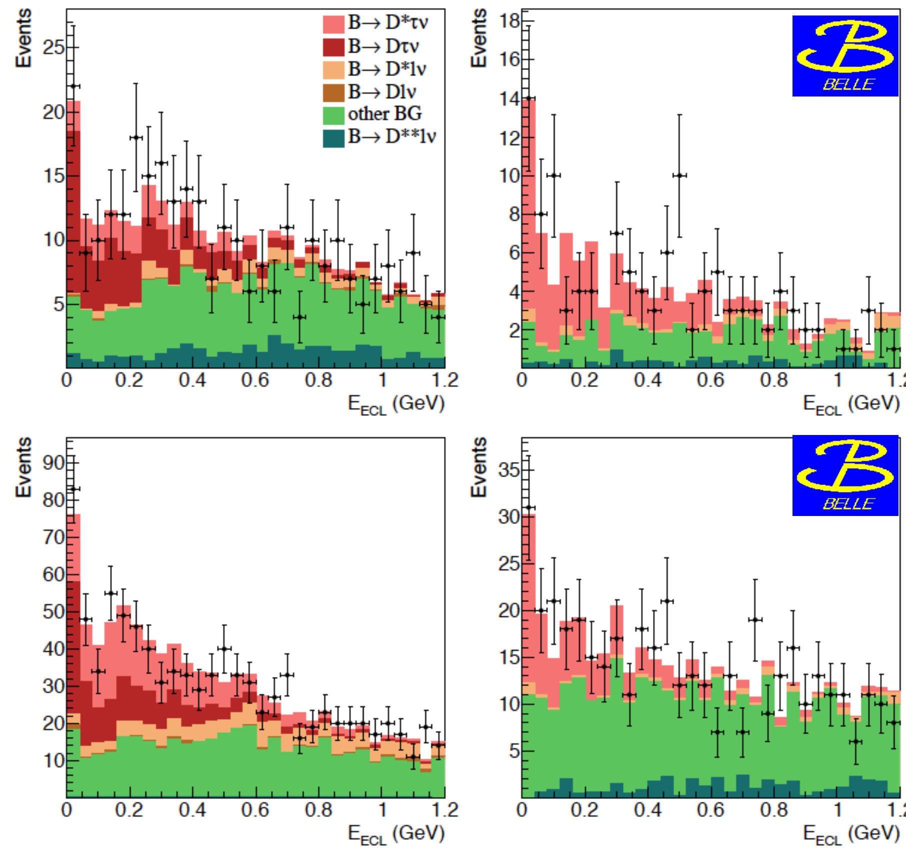


FIG. 5. Projections of the fit results and data points with statistical uncertainties in a signal enhanced region of $M^2_{\rm miss} > 2.0\,{\rm GeV}^2/c^4$ in the $E_{\rm ECL}$ dimension. Top left: $D^+\ell^-$; top right: $D^{*+}\ell^-$; bottom left: $D^0\ell^-$; bottom right: $D^{*0}\ell^-$.

Signal enhanced projections of lepton momenta in the high M^2_{miss} region

Signal enhanced projections of extra calorimeter energy in the high M^2_{miss} region

New Belle result with hadronic tags

May 25 2015, Nagoya FPCP

http://xxx.lanl.gov/abs/1507.03233; to appear in Phys Rev D

Compatible with both BaBar and the 2HDM model (and SM !).

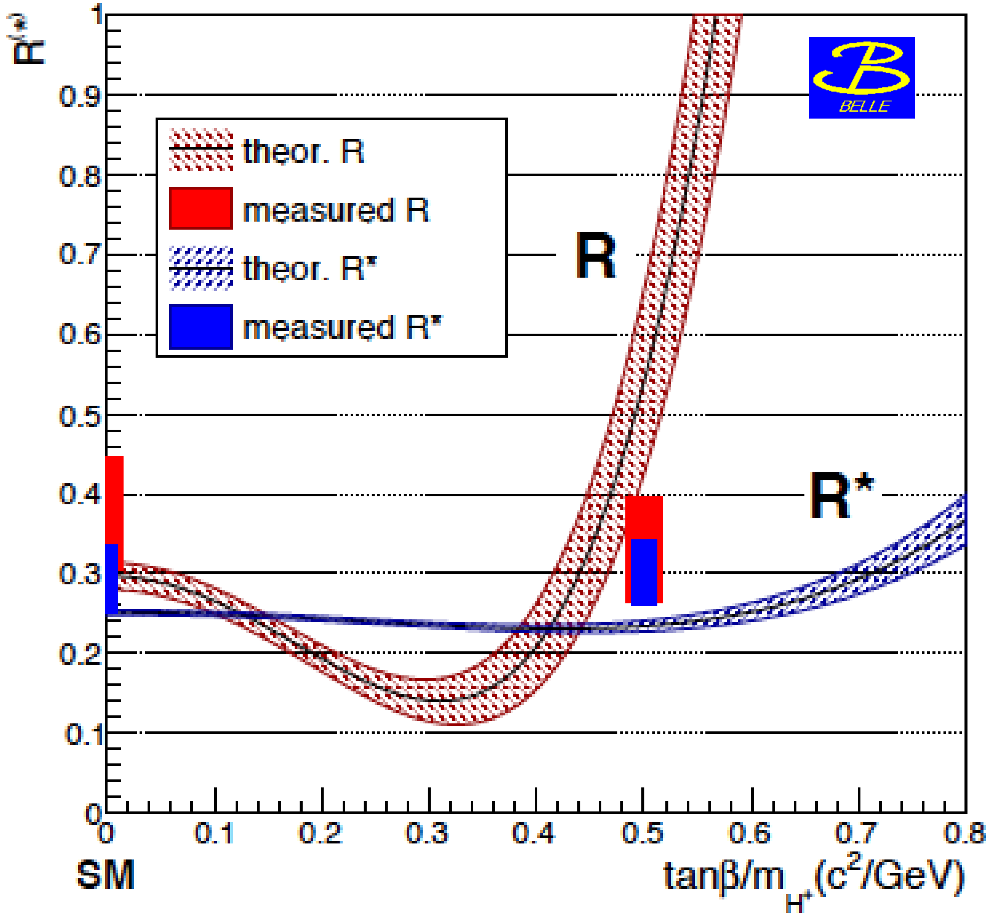


FIG. 8. Theoretical predictions with $1\,\sigma$ error ranges for R (red) and R^* (blue) for different values of $\tan\beta/m_{H^+}$ in the 2HDM of type II. This analysis' fit results for $\tan\beta/m_{H^+} = 0.5\,c^2/\mathrm{GeV}$ and SM are shown with their $1\,\sigma$ ranges as red and blue bars with arbitrary width for better visibility.

Need more data and more Belle analyses to resolve the issue.

New LHCb result

Compatible with BaBar $D^*\tau\upsilon$ BF ($B \rightarrow D\tau\upsilon$ in the pipeline)

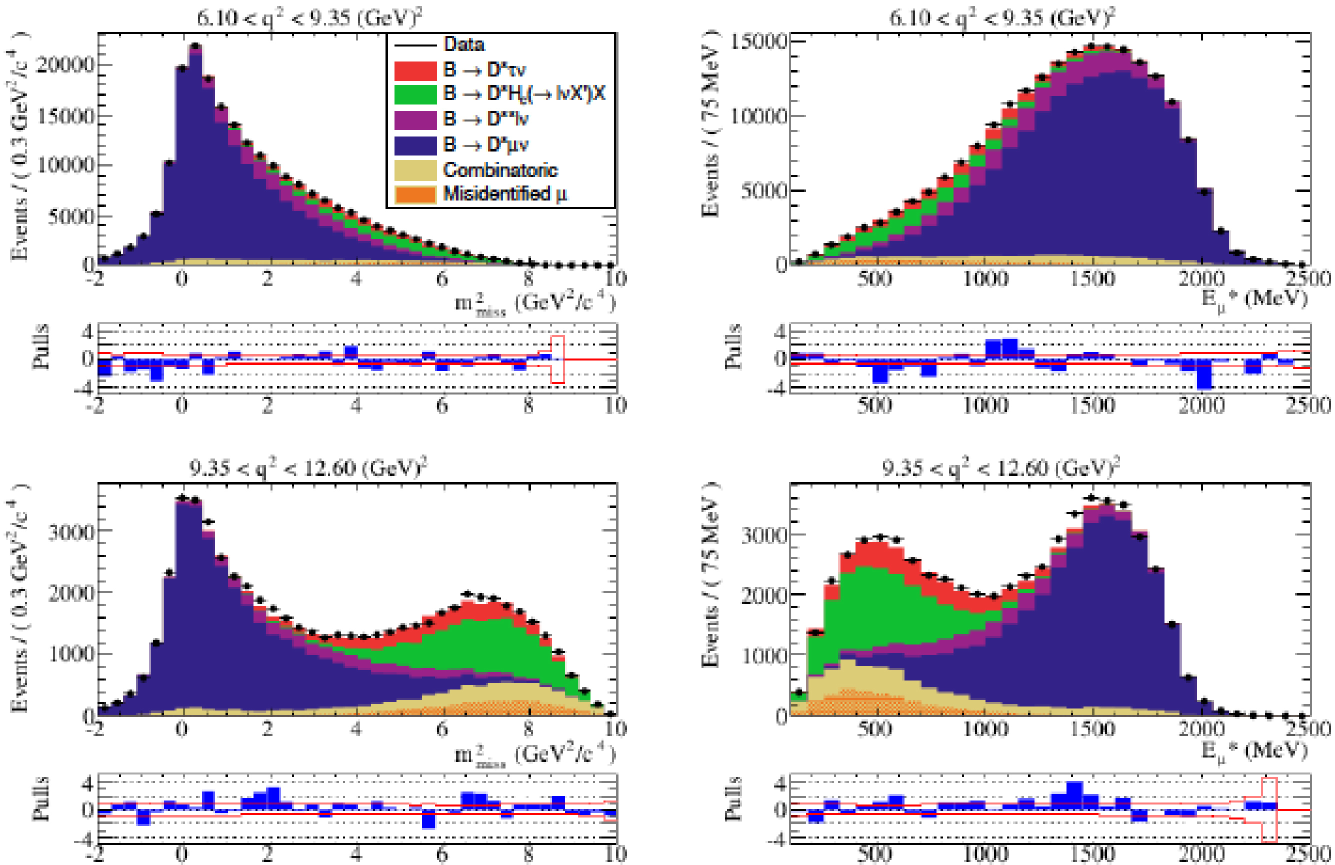
May 25 2015, Nagoya FPCP

Published in **Phys. Rev. Lett. 115, 111803** (2015)

3. $B \to D^* \tau \nu$ (LHCB-PAPER-2015-025)

Signal fit

Mass resolution is poor but vertex isolation is very powerful

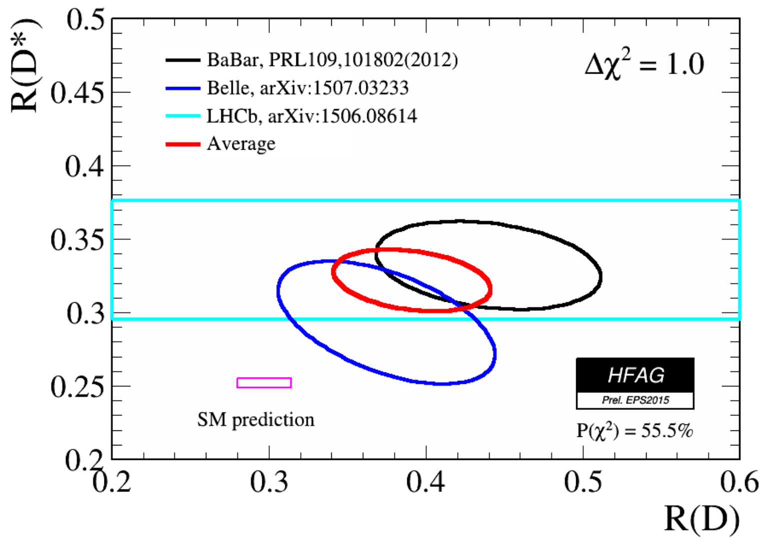


Oui, c'est possible !

G. Ciezarek

Apres Nagoya: *New World Averages* for R(D) and R(D*)

July 23, 2015



Now 3.9σ from SM

	$R(D)$	$R(D^*)$
BaBar	$0.440 \pm 0.058 \pm 0.042$	$0.332 \pm 0.024 \pm 0.018$
Belle	$0.375^{+0.064}_{-0.063} \pm 0.026$	$0.293^{+0.039}_{-0.037} \pm 0.015$
LHCb		$0.336 \pm 0.027 \pm 0.030$
Average	0.388 ± 0.047	0.321 ± 0.021
SM expectation	0.300 ± 0.010	0.252 ± 0.005
Belle II, 50/ab	± 0.010	± 0.005

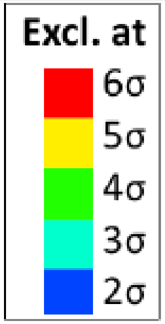
It is *obvious* that we need two orders of magnitude of data to solve these issues related to the *charged Higgs*.

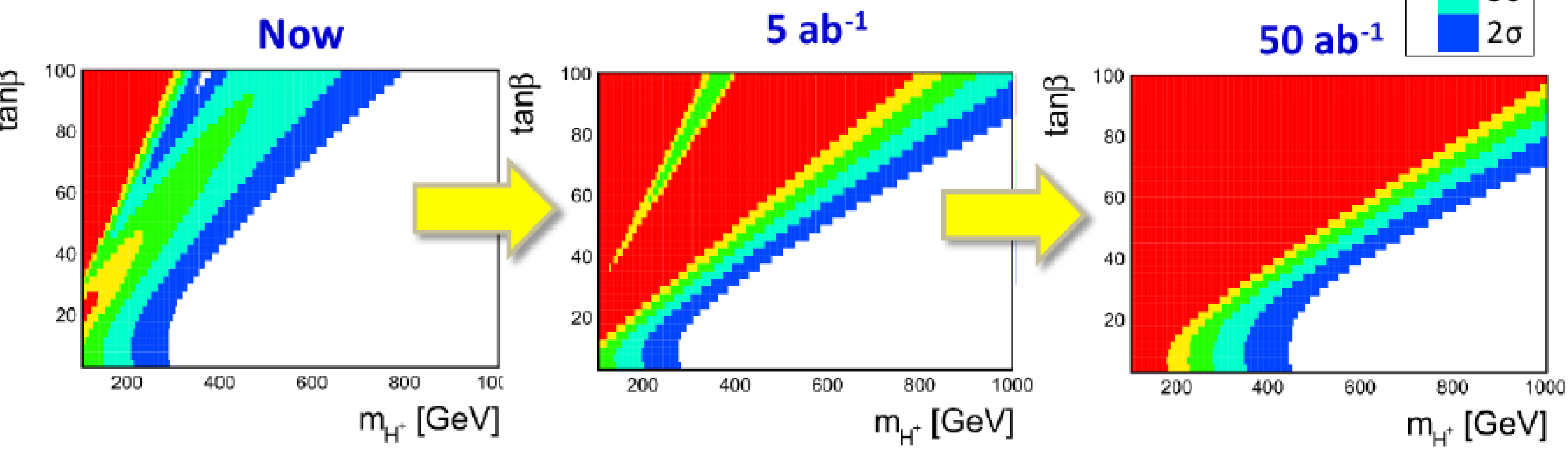
Initial Belle II projections for charged Higgs sensitivity

	Exp.			Th.
	Now	5 ab^{-1}	50 ab^{-1}	Now
$B \to \tau\nu$	25%	10%	3%	-7+14%
$B \to D\tau\nu$	30%	11%	4%	4%
$B \to D^{*}\tau\nu$	19%	7%	2%	2%
$B \to X_s\gamma$	7%	5%	4%	7%

Will improved by precise V_{ub} measurements.
My naive estimation assuming σ_{fB} ~1% :
~5% @Belle II era

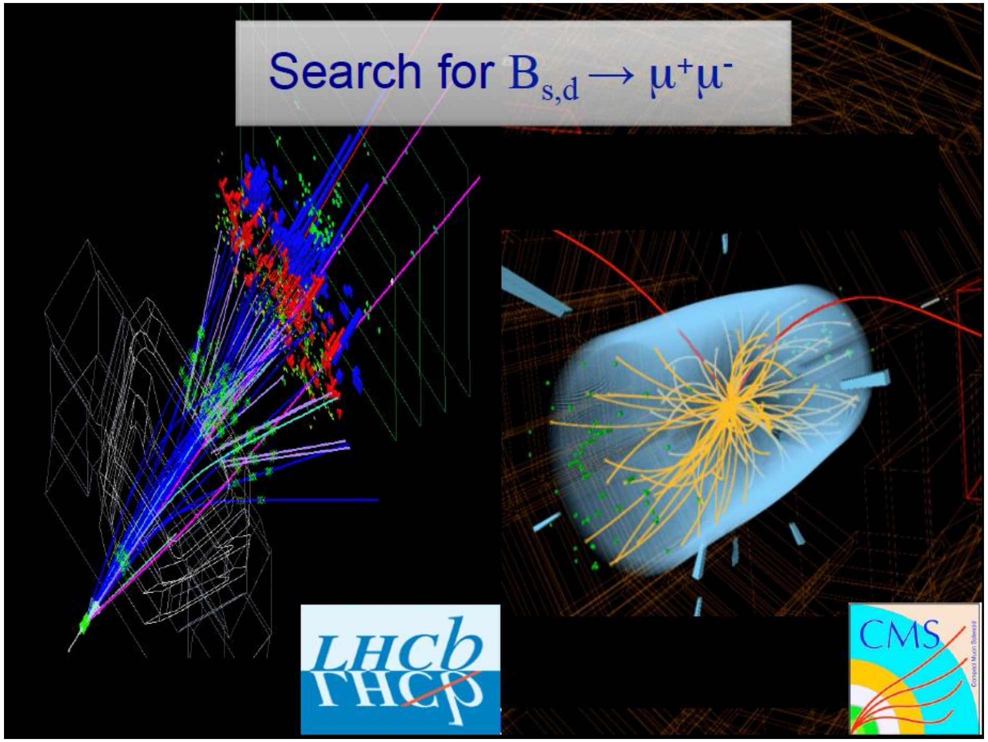
My naive estimation





Rare B Decays

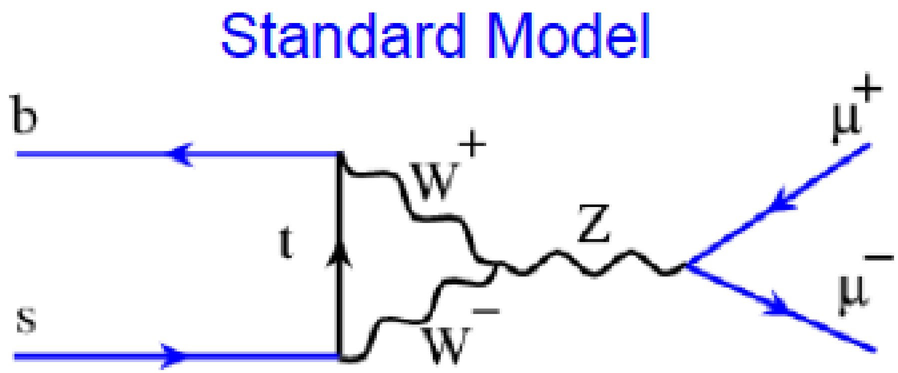
Two event displays



J. Albrecht

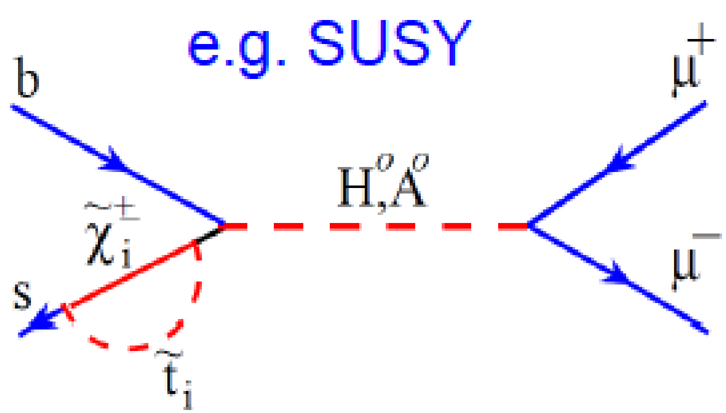
Goa, India

LHC found the rarest B decay; $B_s \rightarrow \mu^+ \mu^-$



BF ~O(10^{-9})

Left handed couplings
→ helicity suppressed

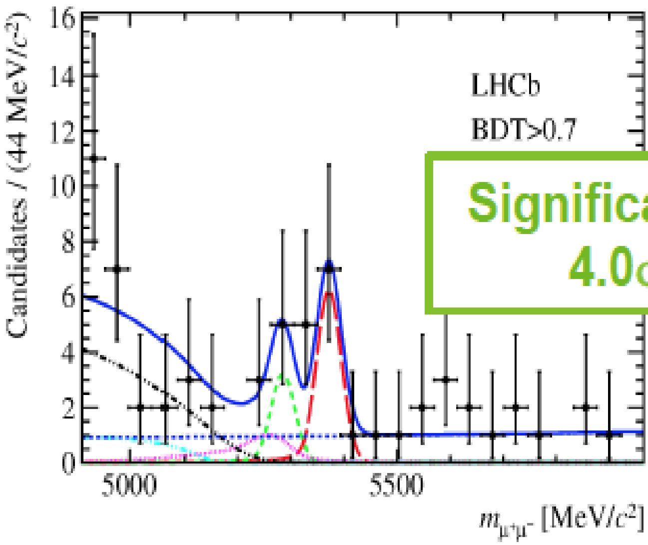


N. B. Here and in $b \rightarrow s\, l^+ l^-$ all the heavy particles of the SM enter as virtual particles in the Feynman diagrams

LHCb

- Update: full dataset: 3fb^{-1}
  - Improved BDT
  - Expected sensitivity: **5.0σ**

PRL 111 (2013) 101805



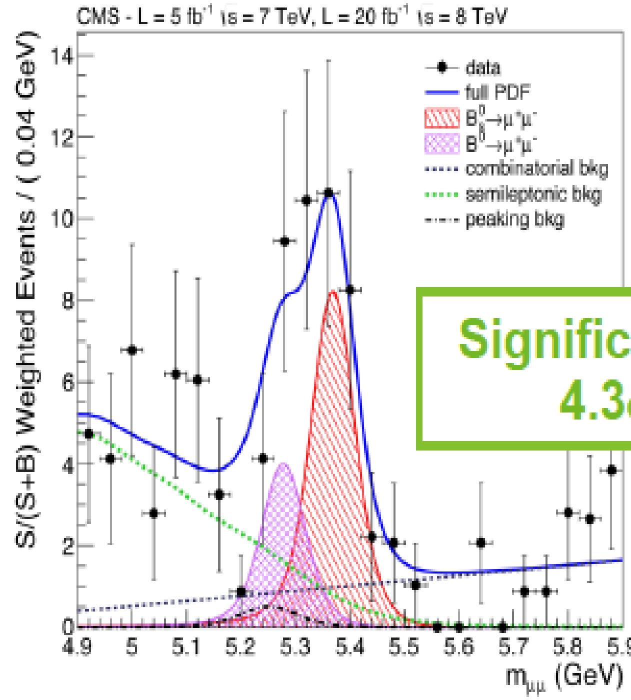
Significance: 4.0σ

$$BR(B_s \to \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}) \times 10^{-9}$$

$$BR(B^0 \to \mu^+\mu^-) = (3.7^{+2.4}_{-2.1}) \times 10^{-10}$$

$$BR(B^0 \to \mu^+\mu^-) < 7 \times 10^{-10} @95\%CL$$

CMS



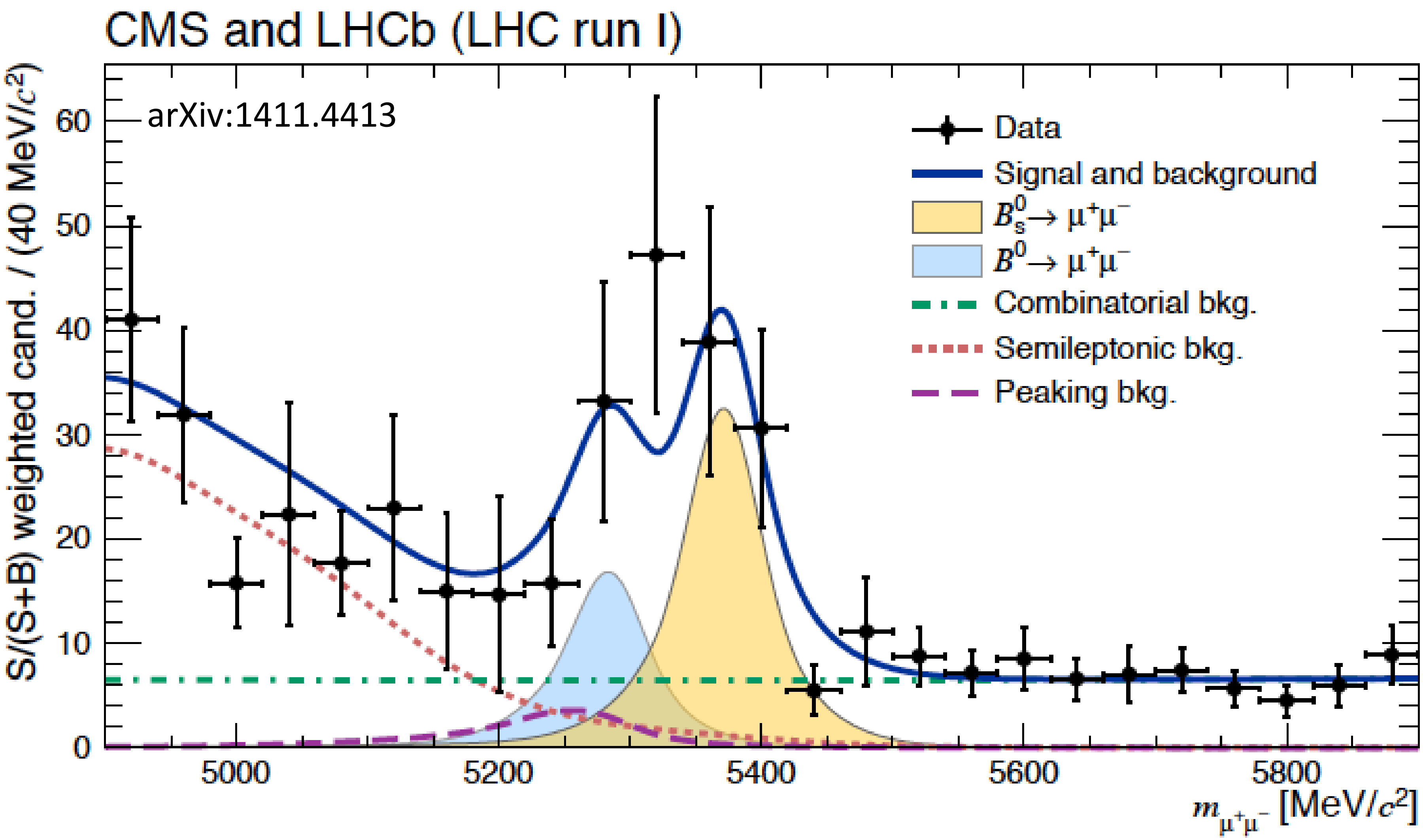
Significance: 4.3σ

$$BR(B_s \to \mu^+\mu^-) = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$$

$$BR(B^0 \to \mu^+\mu^-) = (3.5^{+2.1}_{-1.8}) \times 10^{-10}$$

$$BR(B^0 \to \mu^+\mu^-) < 11 \times 10^{-10} @95\%CL$$

PRL 111 (2013) 101804



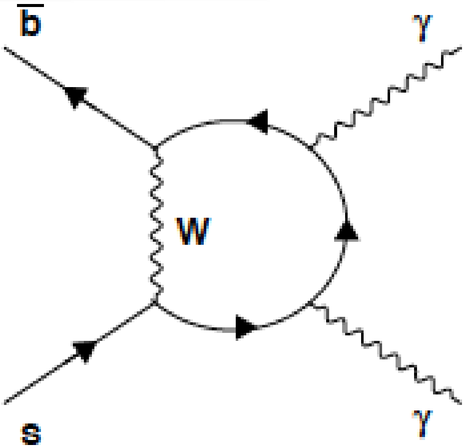
Published in Nature: June 4, 2015

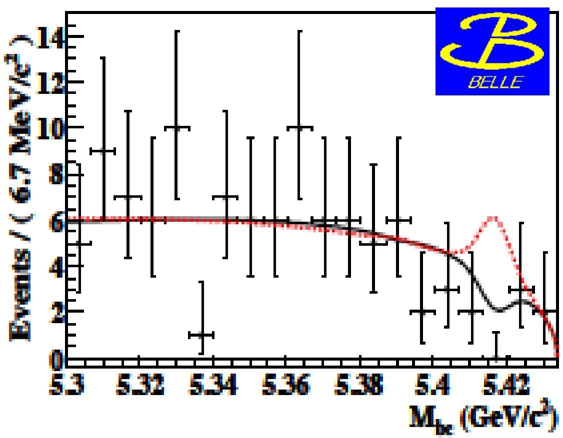
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$

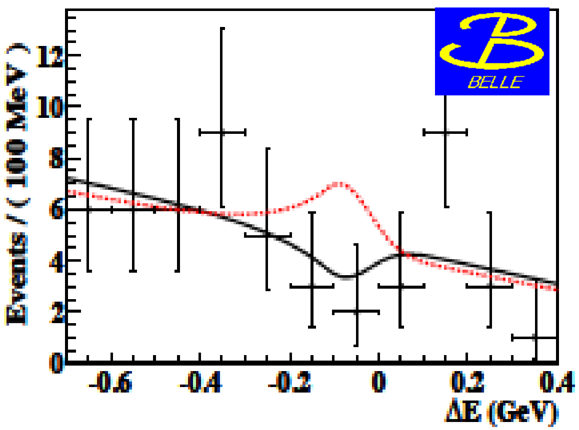
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (3.6\ ^{+1.6}_{-1.4}) \times 10^{-10} \quad ?$$

SM: $BR(B_s) = (3.65 \pm 0.23)\ 10^{-9}$
$BR(B^0) = (1.1 \pm 0.1)\ 10^{-10}$
PRL 112 101801 (2014)

Combining evidence from two LHC experiments (LHCb and CMS), $B_s \rightarrow \mu^+ \mu^-$ is *observed* with 6.2σ significance. The corresponding B_d decay is not clearly seen yet.







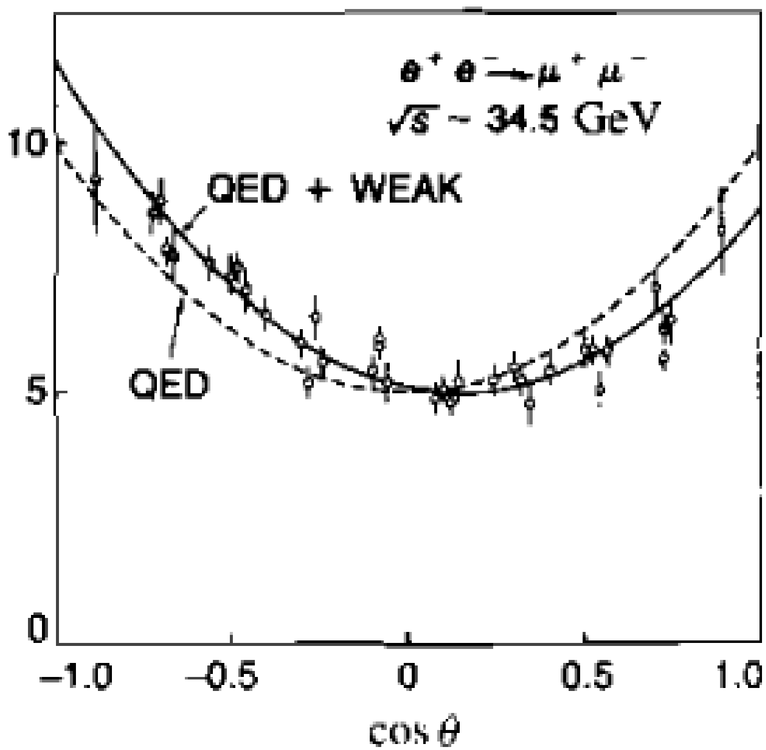
BF ($B_s \rightarrow \gamma\gamma$) $<3.1 \times 10^{-6}$

D. Dutta et al (Belle)
Phys. Rev. D 91, 011101(R)

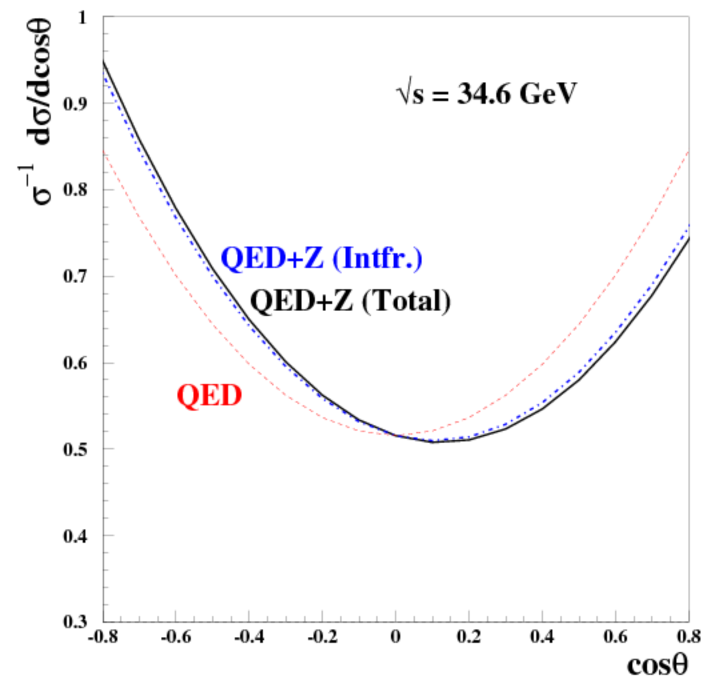
Complementarity [*uses and requires Upsilon(5S) data*]

Red Hot Flavor Physics

High Energy Physics History: finding NP in A_{FB} (using interference)



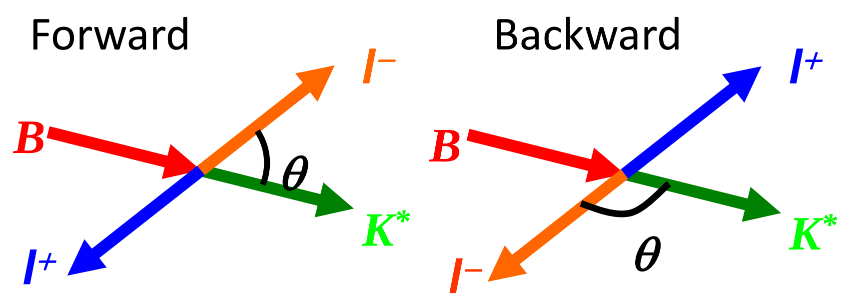
a fit including the weak interaction (solid line).



Conclusion: There is a Z boson at higher energy even though colliders of the time did not have enough $\sqrt{s}$ to produce it

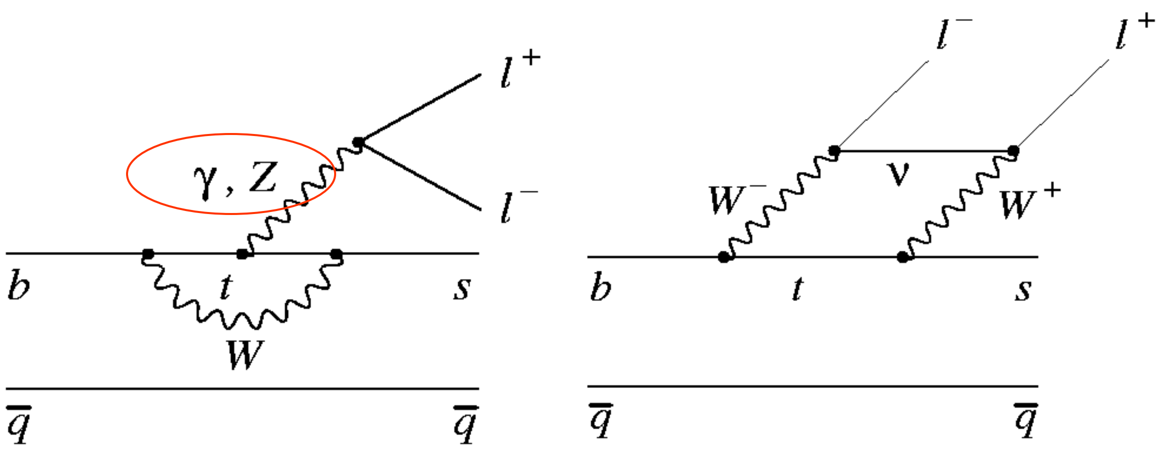
$A_{FB}(B \to K^* l^+ l^-)(q^2)$

*The SM forward-backward asymmetry in $b \to s\ l^+\ l^-$ arises from the **interference** between γ and Z^0 contributions.*



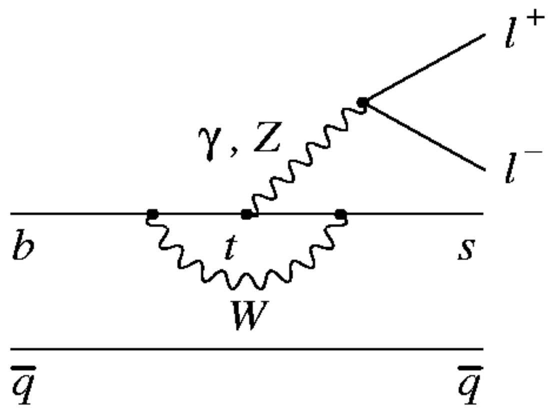
$$A_{FB}(B \to K^* \ell^+ \ell^-) = -C_{10}\xi(q^2)\left[Re(C_9)F_1 + \frac{1}{q^2}C_7F_2\right]$$

Ali, Mannel, Morozumi, PLB273, 505 (1991)



Note that all the heavy particles of the SM (W, Z, top) enter in this decay.

More on $A_{FB}(B \rightarrow K^{*}l^{+}l^{-})(q^{2})$



Can in effect vary √s for NP

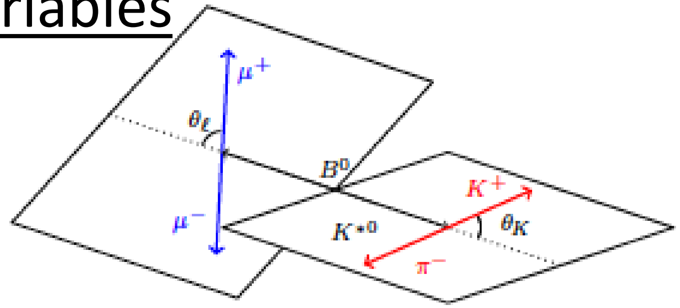
A_{FB} depends on $q^2 = M^2(l^+l^-)$

$$A_{FB}(B \to K^{*}\ell^{+}\ell^{-}) = -C_{10}\xi(q^{2})\left[Re(C_{9})F_{1} + \frac{1}{q^{2}}C_{7}F_{2}\right]$$

Ali, Mannel, Morozumi, PLB273, 505 (1991)

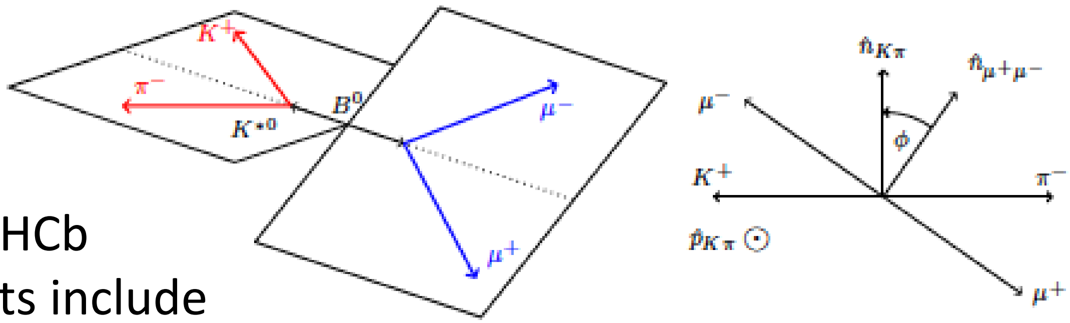
The “zero-crossing” of A_{FB} depends only on a ratio of form factors and is a *clean* observable.

B→K* l l angular variables



(a) θ_K and θ_ℓ definitions for the B^0 decay

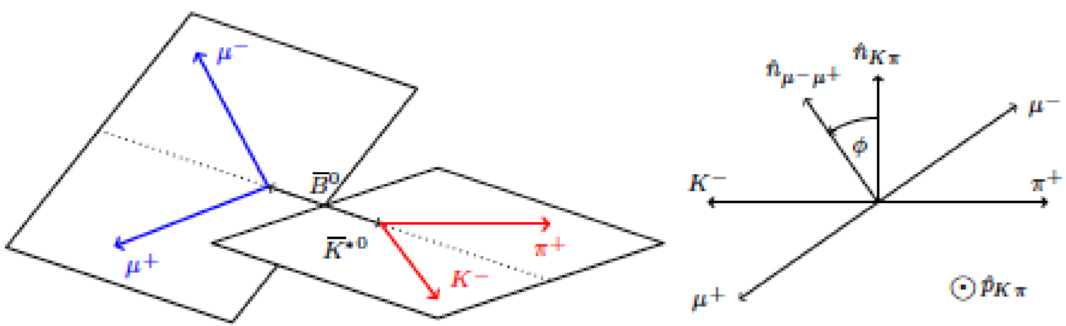
K^* and l^+ l^- helicity angles



(b) ϕ definition for the B^0 decay

N.B. Recent LHCb measurements include ϕ angle data

Angle between *the normals* to the two decay planes.



(c) ϕ definition for the $\overline{B}^0$ decay

From the 2013 LHCb paper

$B \rightarrow K^{*} l^{+} l^{-} (q^2)$ bootcamp

Angular dependence

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^3(\Gamma \pm \bar{\Gamma})}{d\vec{\Omega}} =$$

F_L is the longitudinal polarization fraction.

$$\frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\vartheta_K + F_L\cos^2\vartheta_K$$
$$+\frac{1}{4}(1-F_L)\sin^2\vartheta_K\cos 2\vartheta_L$$
$$-F_L\cos^2\vartheta_K\cos 2\vartheta_L + S_3\sin^2\vartheta_K\sin^2\vartheta_L\cos 2\phi$$
$$+S_4\sin 2\vartheta_K\sin 2\vartheta_L\cos\phi +$$
$$+ \quad + S_7\sin 2\vartheta_K\sin\vartheta_L\sin\phi$$
$$+ \quad \Big]$$

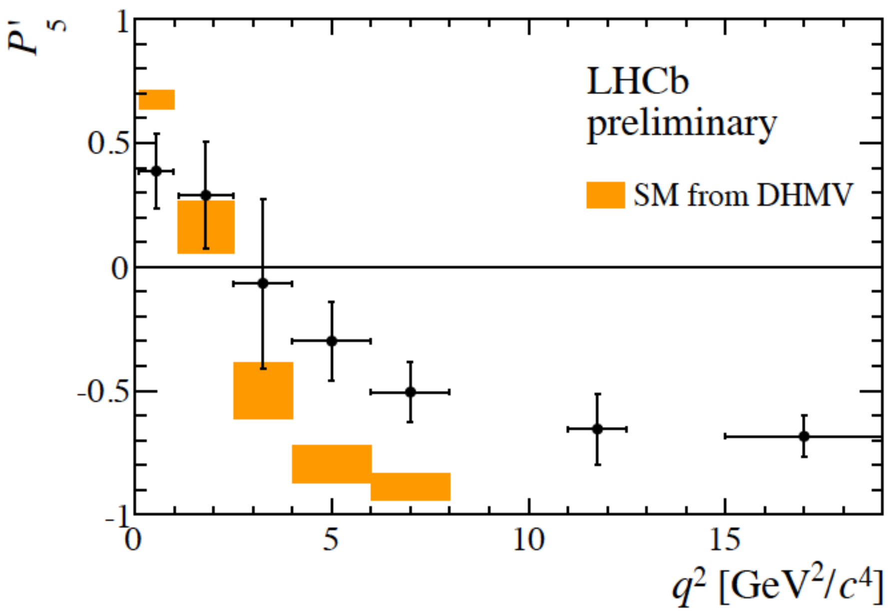
(-) means the term is only in $G - \bar{G}$

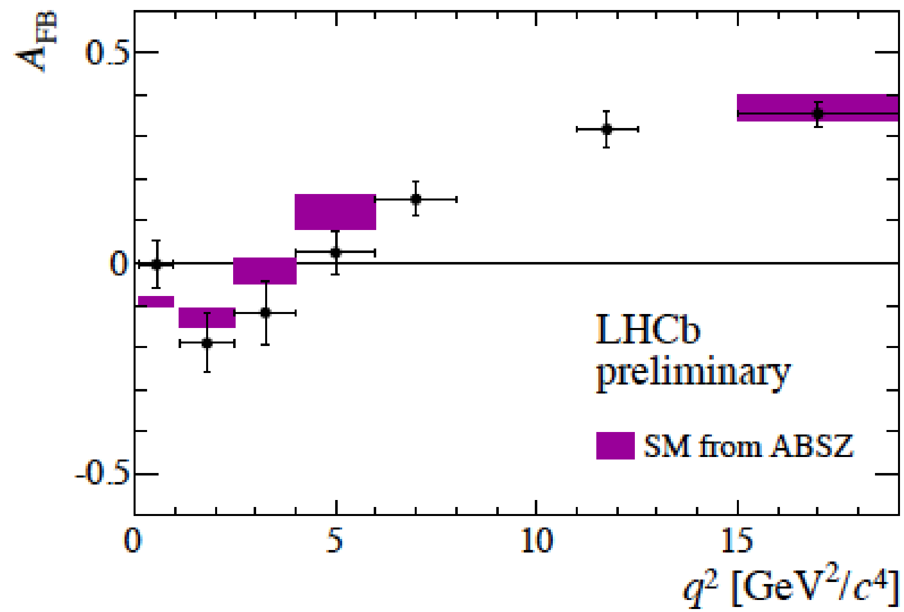
Introduce $P_{4,5}' = S_{4,5}/\mathrm{sqrt}[F_L(1-F_L)]$ to reduce dependence on form factors

Thanks to Rahul Sinha

New LHCb 3fb^{-1} results on $B \rightarrow K^* \mu^+\mu^-$ (q^2)

Angular Asymmetries based on 2398±57 signal events





"The P_5' measurements are only compatible with the SM prediction at a level of 3.7σ…..A mild tension can also be seen in the A_{FB} distribution, where the measurements are systematically <=1σ below the SM prediction in the region $1.1 < q^2 < 6.0$ GeV^2"

Blank regions are the J/ψ and ψ′ vetos

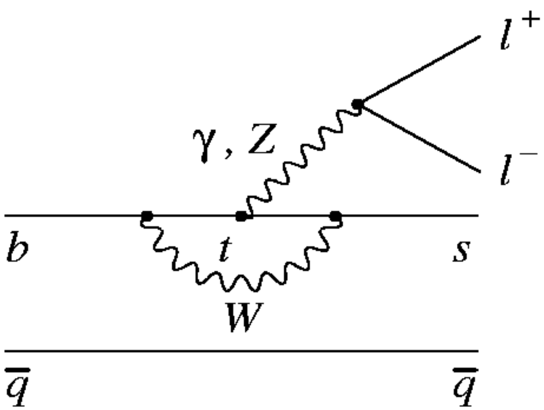
Theory from http://arxiv.org/abs/1407.8526

Experiment from LHCb-CONF-2015-002

New LHCb results on $B \rightarrow K^* \mu^+\mu^- (q^2)$

Is HEP History repeating itself ? [*Make sure this is not a tricky SM form factor effect.]*

Why does NP appear first in this mode (and not others) ?



Possible answer: All the heavy particles of the SM (t, W, Z) and maybe NP (except the Higgs) appear here. Sensitive to NP via interference (linear effects).

Theory issues on $B \to K^{*}\,\mu^{+}\mu^{-}\,(q^{2})$

"To better understand the compatibility of the data with the SM a global analysis of the data, taking into account correlations between observables is necessary"-LHCb conference paper.

➔Check dependence on light-cone form factors (some checks already done by Lattice QCD group, or *fit form factors from data a la Mandal and Sinha and check for consistency*)

➔Check binning effects (do an unbinned analysis of NP)

➔Can tails of large B→K* [c-cbar] produce the anomalies found in the angular distributions ?

B→K* $l^+ l^-$ form factor ratios determined from *data* disagree with theory

SKIP TODAY

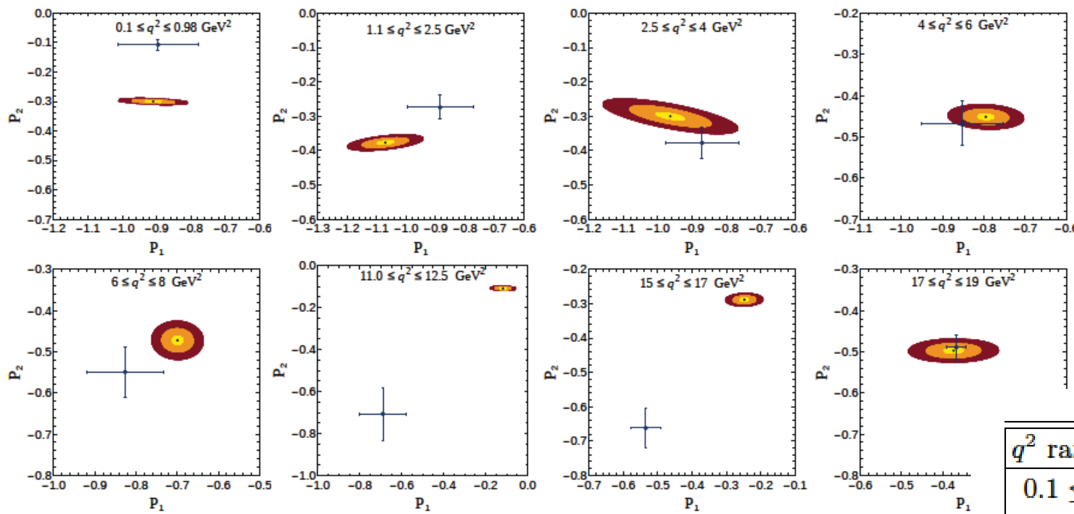


FIG. 1. (color online). The allowed region for P_1 versus P_2 plane. The innermost yellow (lightest), the middle c and outer most red (dark) contours represent 1σ, 3σ and 5σ regions, respectively. The theoretically estima Ref. [7] for $q^2 \leq 8$ GeV^2 and Ref. [10] for $q^2 \geq 11$ GeV^2 are shown as points with error bars. In most cases, th agreement between the theoretical values and those obtained from data. However, for the ranges 0.1 ≤ $11.0 \leq q^2 \leq 12.5$ GeV^2 and $15 \leq q^2 \leq 17$ GeV^2 there are significant disagreements.

It is convenient to define P_1 and P_2 as,

$$P_1 = \frac{\mathcal{F}_\perp}{\mathcal{F}_\parallel}, \qquad P_2 = \frac{\mathcal{F}_\perp}{\mathcal{F}_0}. \tag{8}$$

The observables $F_\perp$, F_L, A_{FB}, A_5 and A_4 can be written [2] as

$$F_\perp = u_\perp^2 + 2\zeta \tag{9}$$

$$F_L P_2^2 = u_0^2 + 2\zeta \tag{10}$$

$$A_{FB}^2 = \frac{9\zeta}{2P_1^2}\left(u_\parallel \pm u_\perp\right)^2 \tag{11}$$

$$A_5^2 = \frac{9\zeta}{4P_2^2}\left(u_0 \pm u_\perp\right)^2 \tag{12}$$

$$A_4 = \frac{\sqrt{2}}{\pi P_1 P_2}\left(2\zeta \pm u_0 u_\parallel\right) \tag{13}$$

Three form factors here

q^2 range in GeV^2	$V(q^2)$	$A_1(q^2)$	$A_{12}(q^2)$
$0.1 \leq q^2 \leq 0.98$	0.704 ± 0.404 (0.81σ)	0.538 ± 0.309 (0.79σ)	0.246 ± 0.141 (1.27σ)
$1.1 \leq q^2 \leq 2.5$	0.624 ± 0.081 (2.48σ)	0.384 ± 0.051 (1.42σ)	0.331 ± 0.052 (0.72σ)
$2.5 \leq q^2 \leq 4.0$	0.318 ± 0.185 (0.70σ)	0.204 ± 0.119 (0.89σ)	0.270 ± 0.177 (1.56σ)
$4.0 \leq q^2 \leq 6.0$	0.556 ± 0.026 (1.42σ)	0.398 ± 0.020 (2.02σ)	0.359 ± 0.032 (1.28σ)
$6.0 \leq q^2 \leq 8.0$	0.597 ± 0.017 (0.83σ)	0.437 ± 0.014 (2.74σ)	0.394 ± 0.022 (2.18σ)
$11.0 \leq q^2 \leq 12.5$	0.172 ± 0.006 (5.65σ)	0.539 ± 0.027 (2.43σ)	0.462 ± 0.028 (2.82σ)
$15.0 \leq q^2 \leq 17.0$	0.713 ± 0.004 (6.25σ)	0.638 ± 0.026 (3.36σ)	0.505 ± 0.016 (4.64σ)
$17.0 \leq q^2 \leq 19.0$	1.936 ± 0.007 (4.38σ)	0.678 ± 0.025 (3.82σ)	0.498 ± 0.014 (4.64σ)

TABLE I. The form factor values obtained from fit to 3 fb^{-1} of LHC*b* data [4]. Round brackets indicate the standard deviation between fitted values and theoretical estimates [7, 10]. We find significant discrepancies for several values, especially for the large q^2 region.

R. Mandal, R.Sinha, arXiv 1506:04535

$B \to K^* l^+ l^-$ form factor ratios determined from data are inconsistent: violate HQET equalities at q^2_{max}

q^2 range in GeV^2	u_0	u
$15 \le q^2 \le 17$	0.001 ± 0.015	$0.013 \pm$
$17 \le q^2 \le 19$	0.137 ± 0.013	0.002
$15 \le q^2 \le 19$	0.068 ± 0.005	$0.002 \pm$

TABLE II. The values of u_0, $u_\parallel$ and
to 3 fb^{-1} of LHCb data [4]. In large
equality $u_0 = u_\parallel = u_\perp$ is expected to h
charm loop contributions with negligib
value of $u_\parallel$ for the larger q^2 bin is unex
any conclusions. Significant discrepanci
to be solely due to non-factorizable c
are observed between the values of $u_\perp$

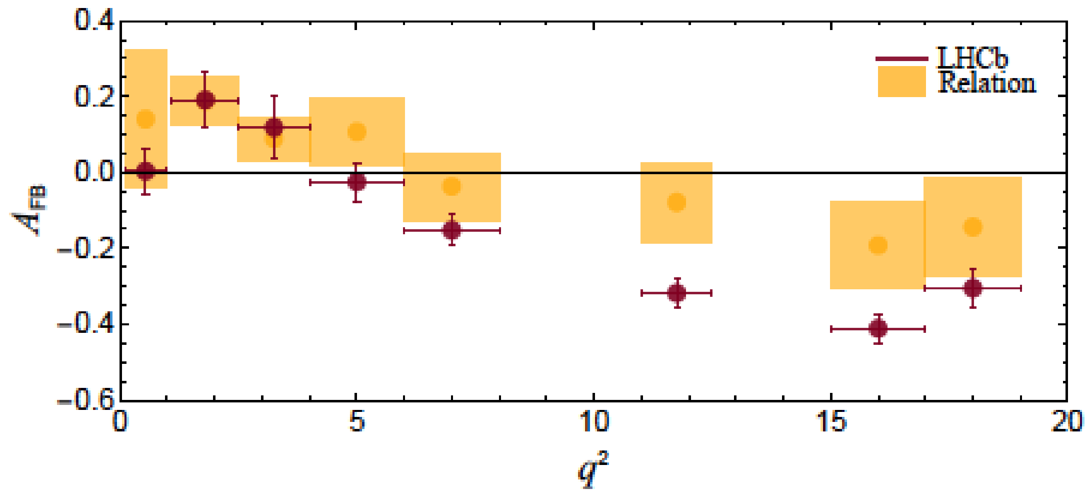


FIG. 3. (color online). The mean values and 1σ uncertainties for A_{FB} calculated using the 'Relation' (Eq. (17)) are shown by yellow (light) bands. We emphasize that these bands are derived using only experimentally measured observables and do not depend on any theoretical input. The error bars in red (dark) correspond to the experimentally measured central values and errors in A_{FB} for the respective q^2 bins. See text for details.

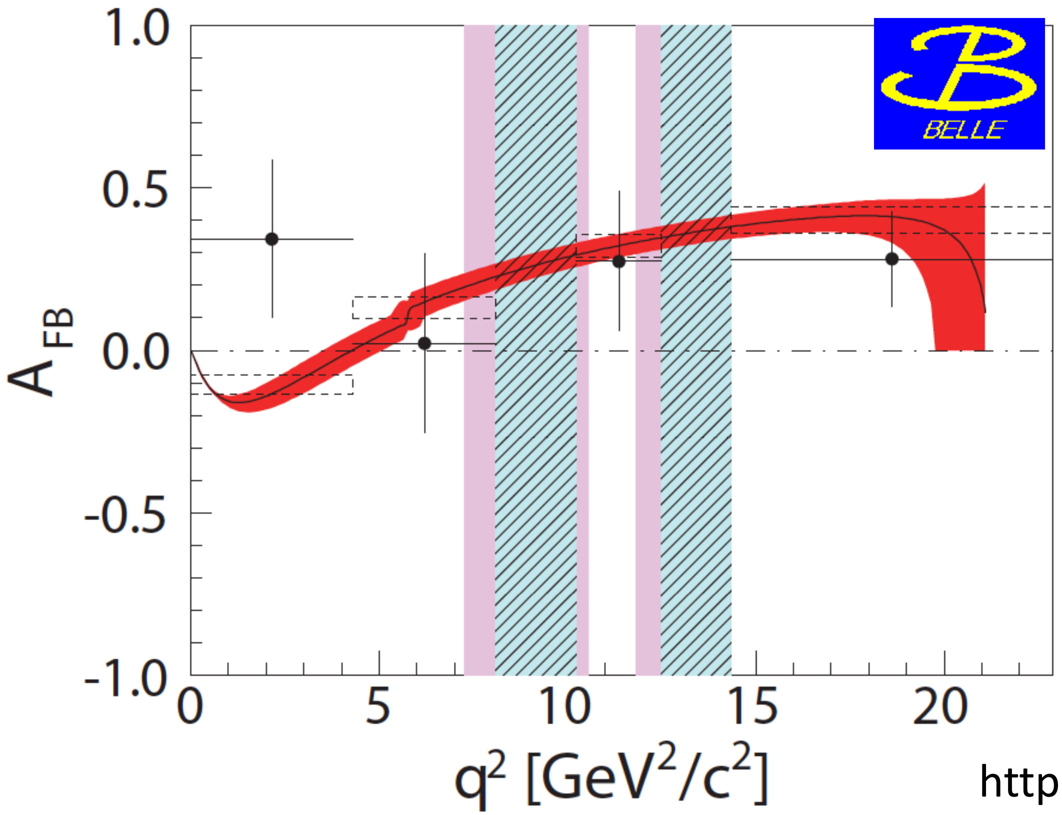
Cannot recover by adding resonances or large non-perturbative effects. But NP works.

<u>Still confirmation and more data is needed to close the case</u>

R. Mandal, R.Sinha, arXiv 1506:04535

$A_{FB}(q^2)$ for <u>Inclusive</u> $b \to s\, l^+ l^-$

~301 $b \to s\, l^+ l^-$ signal events



No form factors

Where is the zero crossing ?

Precise result useful for NP diagnosis

http://arxiv.org/abs/1402.7134

TABLE II. Fit results for the four q^2 bins. For $\mathcal{A}_{\rm FB}$, the first uncertainty is statistical and the second uncertainty is systematic. $\mathcal{A}_{\rm FB}$ values predicted by the SM [4, 7] are also shown with systematic uncertainties. For the signal yields, only statistical uncertainties are shown. The uncertainties of α and β are due to the statistical uncertainties of the MC.

		1st bin	2nd bin	3rd bin	4th bin
q^2 range [GeV$^2/c^2$]	$(B \to X_s e^+ e^-)$	[0.2,4.3]	[4.3,7.3]	[10.5,11.8]	[14.3, 25.0]
	$(B \to X_s \mu^+ \mu^-)$		[4.3,8.1]	[10.2,12.5]	
$\mathcal{A}_{\rm FB}$		$0.34 \pm 0.24 \pm 0.02$	$0.04 \pm 0.31 \pm 0.05$	$0.28 \pm 0.21 \pm 0.01$	$0.28 \pm 0.15 \pm 0.01$
$\mathcal{A}_{\rm FB}$ (theory)		-0.11 ± 0.03	0.13 ± 0.03	0.32 ± 0.04	0.40 ± 0.04
$N^{ee}_{\rm sig}$		45.6 ± 10.9	30.0 ± 9.2	25.0 ± 7.0	39.2 ± 9.6
$N^{\mu\mu}_{\rm sig}$		43.4 ± 9.2	23.9 ± 10.4	30.7 ± 9.9	62.8 ± 10.4
α^{ee}		1.289 ± 0.004	1.139 ± 0.003	1.063 ± 0.003	1.121 ± 0.003
$\alpha^{\mu\mu}$		2.082 ± 0.010	1.375 ± 0.003	1.033 ± 0.003	1.082 ± 0.003
β		1.000	1.019 ± 0.003	1.003 ± 0.000	1.000

TABLE I: Projections for the statistical uncertainties on the $B \to K^{(*)} \nu\bar{\nu}$ branching fractions.

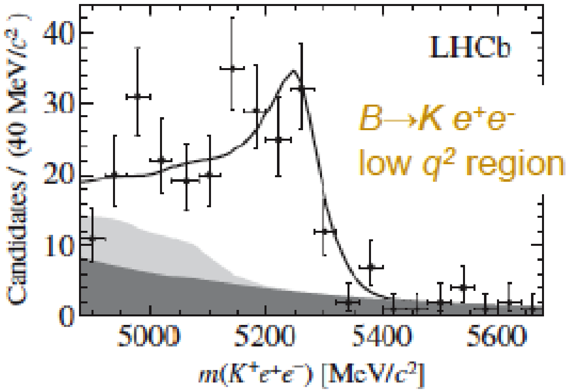
Mode	$\mathcal{B}$ $[10^{-6}]$	Efficiency Belle $[10^{-4}]$	$N_{\text{Backg.}}$ 711 fb^{-1} Belle	$N_{\text{Sig-exp.}}$ 711 fb^{-1} Belle	$N_{\text{Backg.}}$ 50 ab^{-1} Belle II	$N_{\text{Sig-exp.}}$ 50 ab^{-1} Belle II	Statistical error 50 ab^{-1}	Total Error
$B^+ \to K^+ \nu\bar{\nu}$	3.98	5.68	21	3.5	2960	245	23%	24%
$B^0 \to K^0_S \nu\bar{\nu}$	1.85	0.84	4	0.24	560	22	110%	110%
$B^+ \to K^{*+} \nu\bar{\nu}$	9.91	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0} \nu\bar{\nu}$	9.19	1.44	5	2.0	704	143	20%	22%
$B \to K^* \nu\bar{\nu}$ combined							15%	17%

Ans: Verify hint of lepton universality breakdown at Belle II (good electron eff)

Control region gives R_K consistent with unity.
Interesting, low q^2 region gives:

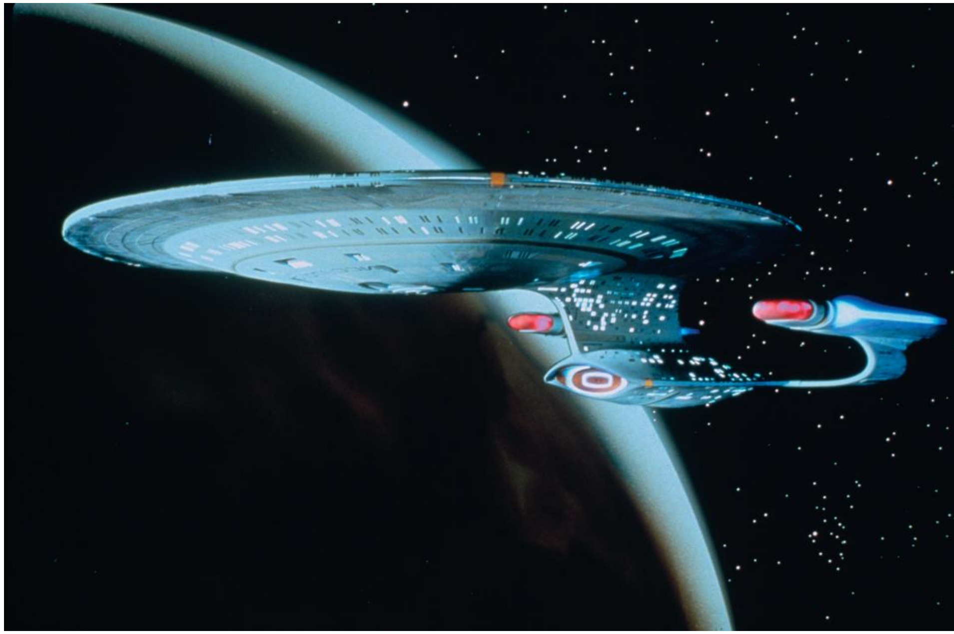
$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

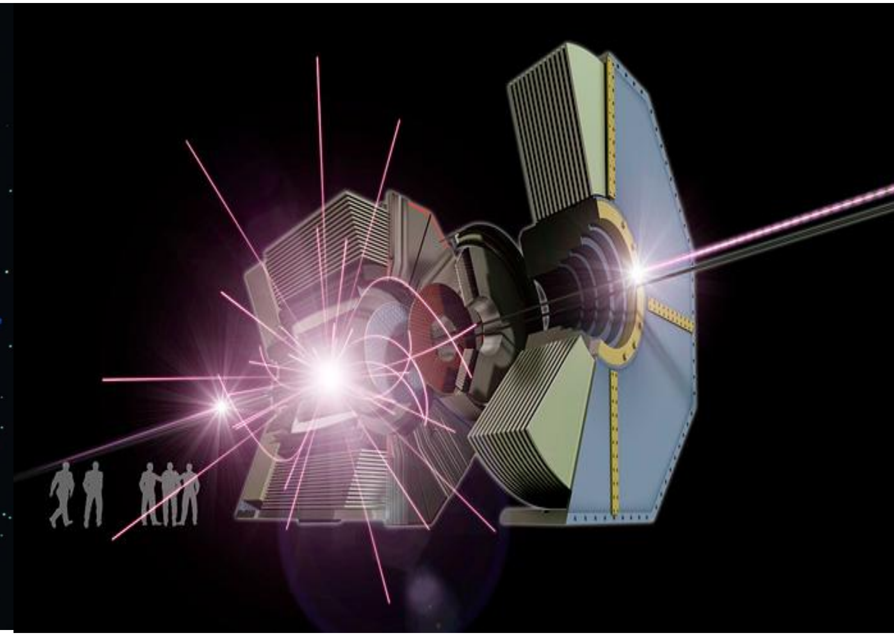
which is 2.6σ from unity, 3σ if BaBar included.



R. Aaij et al. (LHCb collab); PRL 113, 151601 (2014)

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





The Next Generation

Belle II and the LHCb upgrade

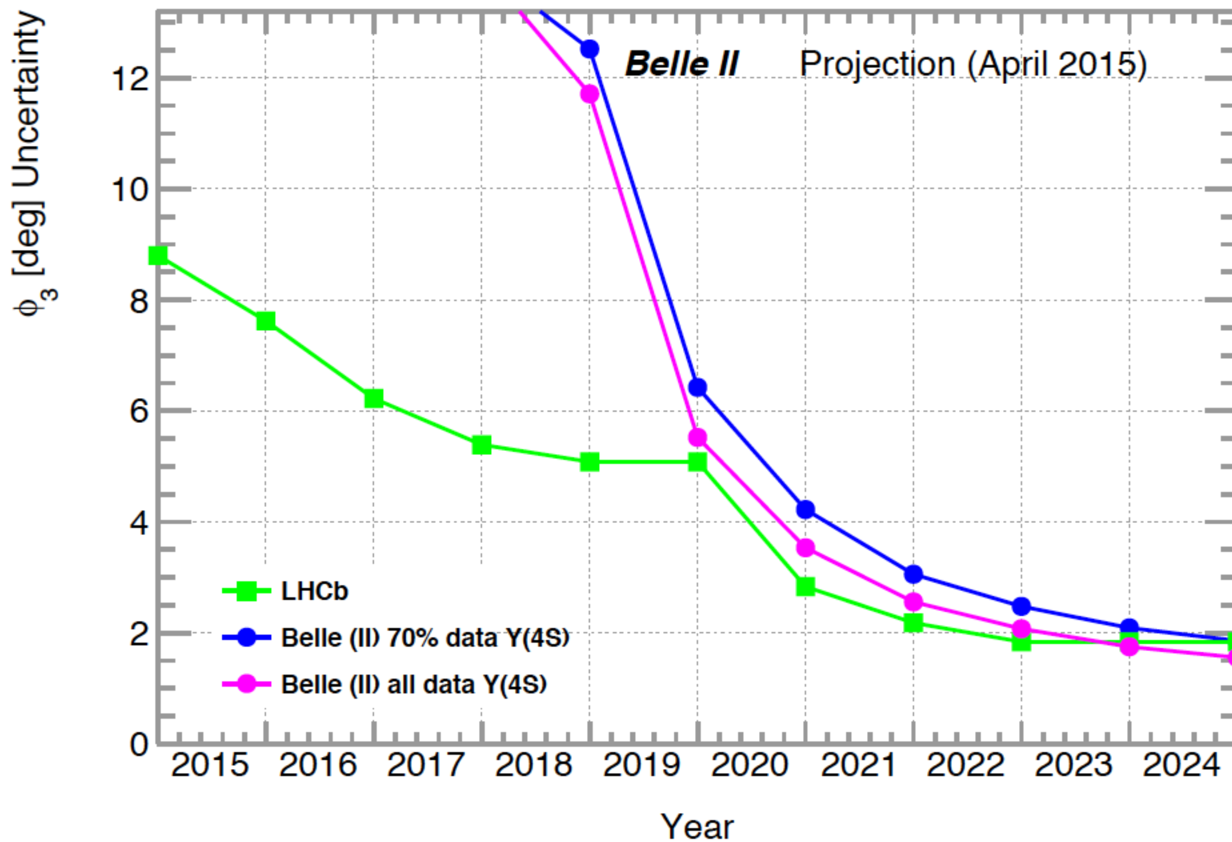
US P5 report (p. v): “Explore the unknown: new particles, interactions, and physical principles”

Physics Reach of Belle II and the LHCb upgrade

Competition and complementarity

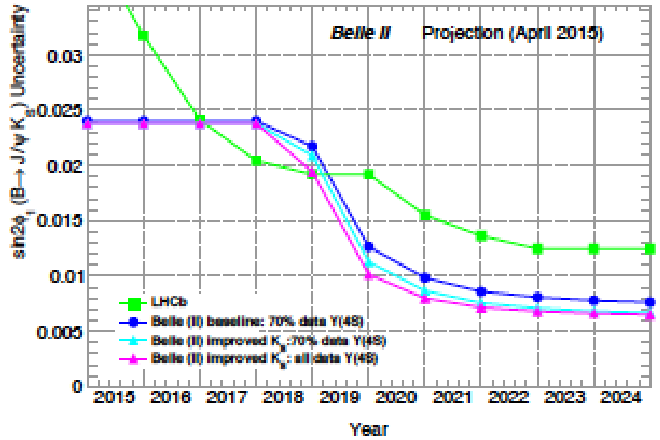
Tofu Gelato ?

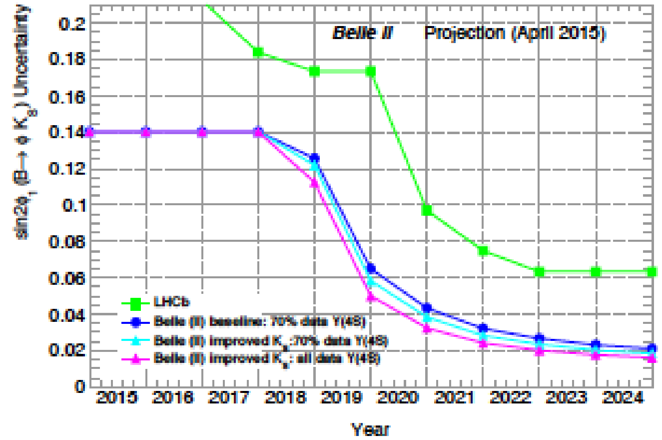
Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\lvert V_{us}\rvert$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\lvert V_{cb}\rvert$ $[B \to X_c \ell \nu]$	**	1%	Belle II



$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\lvert q/p\rvert_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

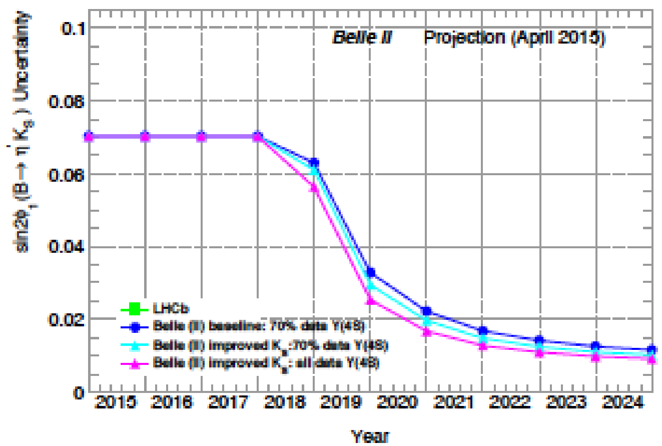
Tight race



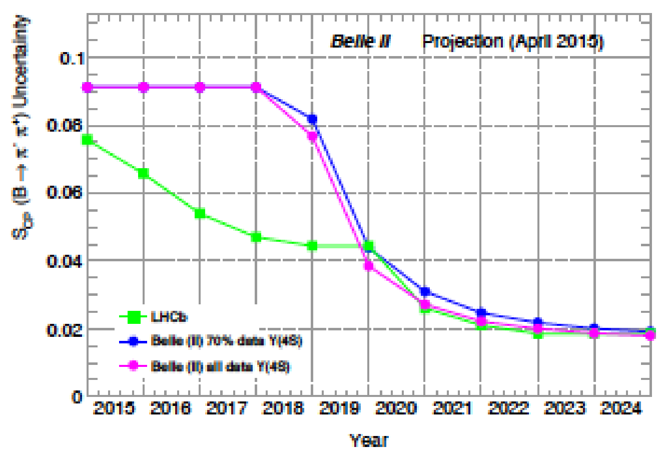


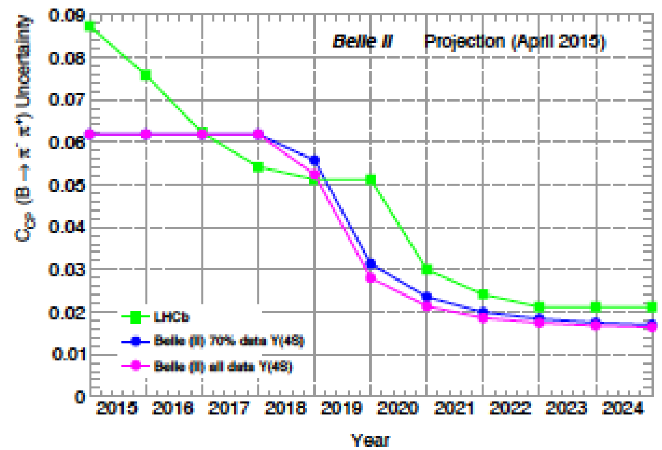
Belle II ahead

Belle II dominates here

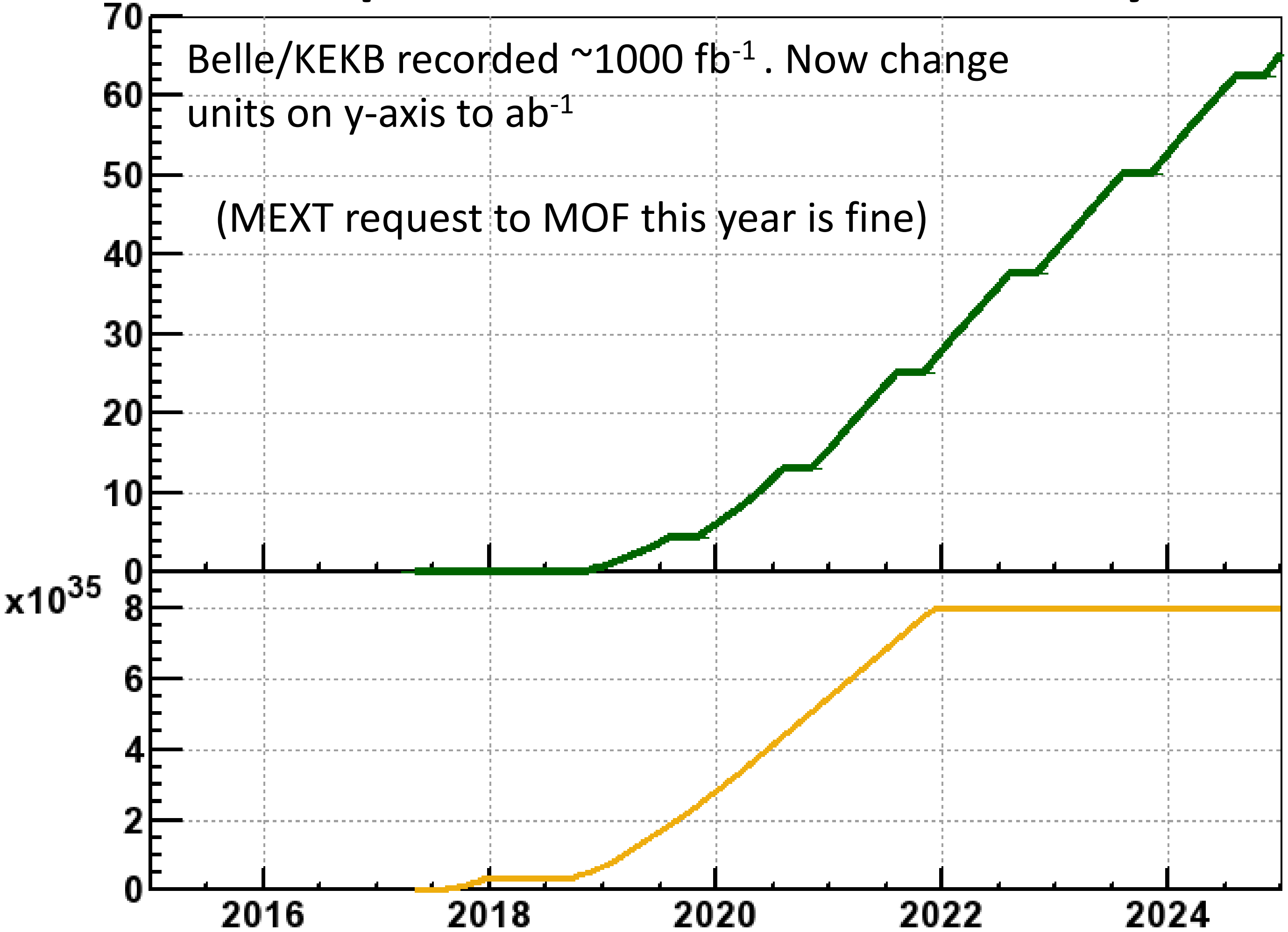


Tight race





Latest SuperKEKB Luminosity Profile



N.B. To realize this steep turn-on, requires close cooperation between Belle II and SuperKEKB [and *international collaboration* on the accelerator].

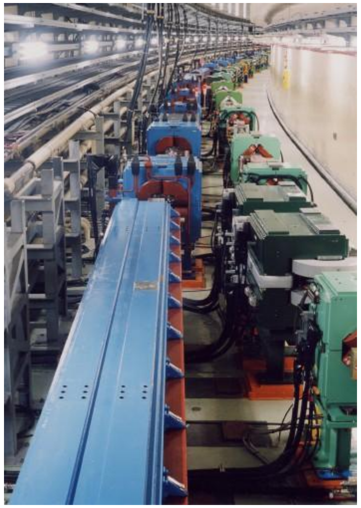
Also assumes *full* and *stable* operation funding profile.

Compare the Parameters for KEKB and SuperKEKB

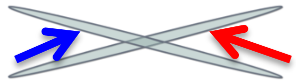
	KEKB Design	**KEKB Achieved : with crab**	**SuperKEKB Nano-Beam**
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
$\beta_y{}^*$ (mm)	10/10	5.9/5.9	0.27/0.30
$\beta_x{}^*$ (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y / \varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(mm)	1.9	0.94	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

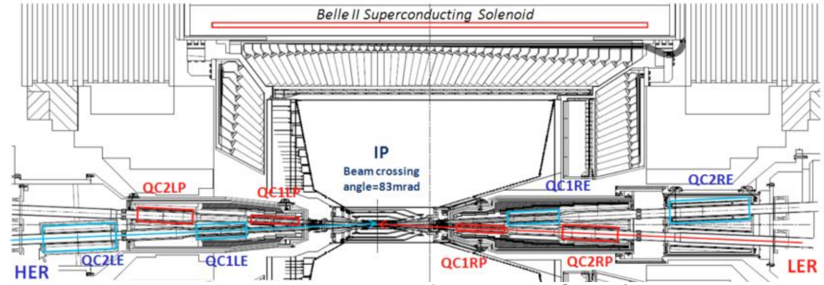
Nano-beams are the key (vertical spot size is ~50nm !!)

This is not a typo



2015: Basic hardware (except final focus) now in place





New superconducting final focusing magnets near the IP

e+ 3.6A

e- 2.6A

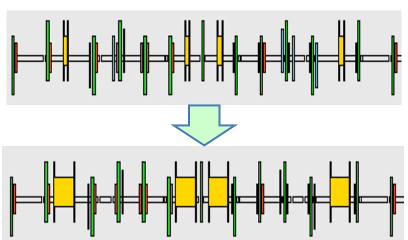
KEKB to SuperKEKB

- 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
$2.1\times10^{34} \rightarrow 8\times10^{35}$ cm^{-2}s^{-1}

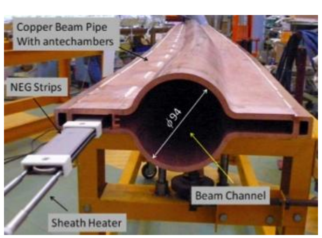
Redesign the lattice to reduce the emittance (replace short dipoles with longer ones, increase wiggler cycles) (*all magnets installed 8/2014*)



Reinforce RF systems for higher beam currents

Improve monitors and control system

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

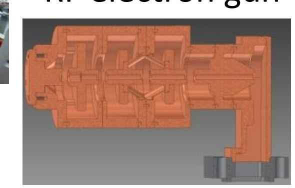


New e+ Damping Ring constructed

Injector Linac upgrade

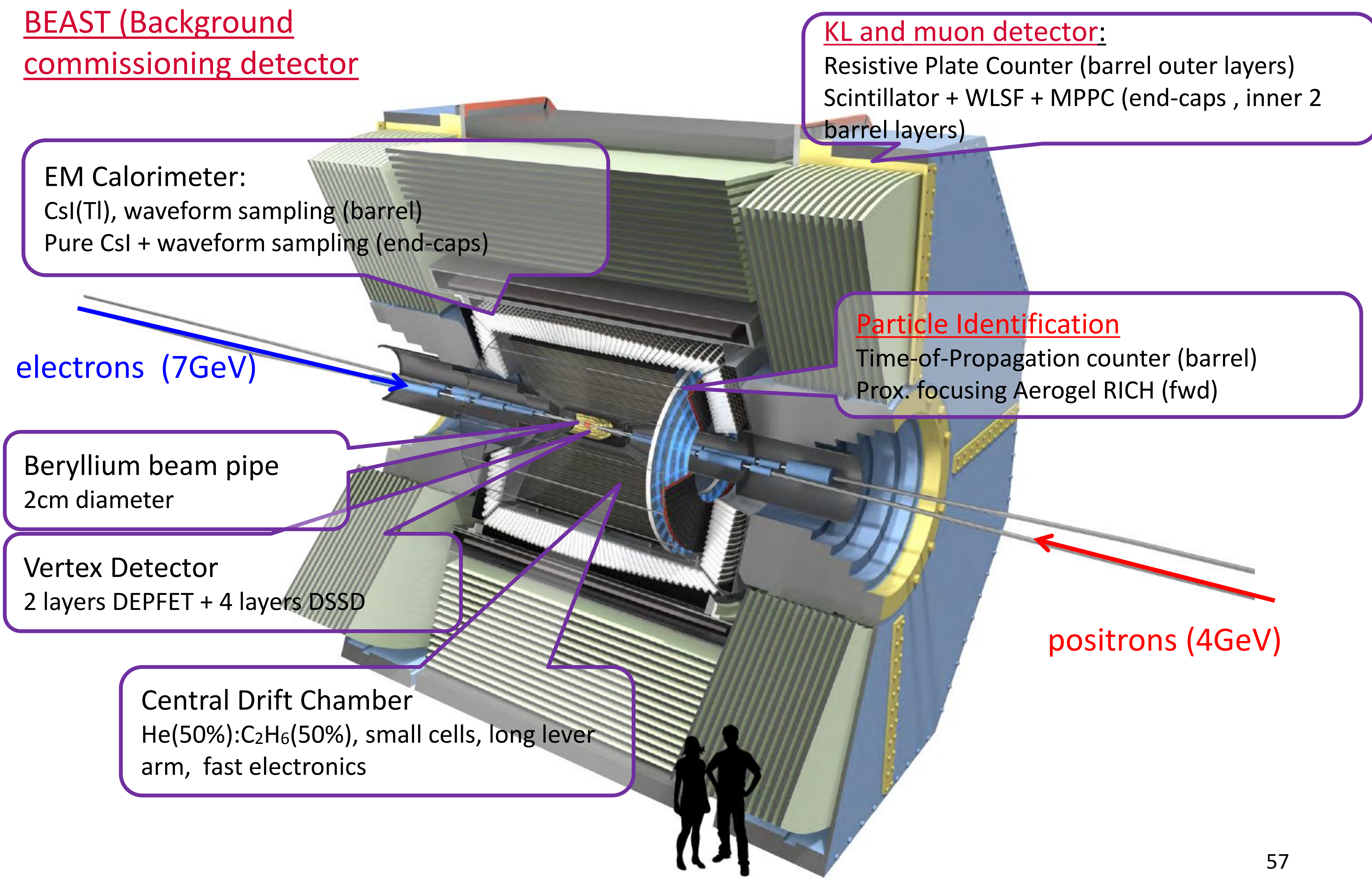
Upgrade positron capture section

Low emittance RF electron gun



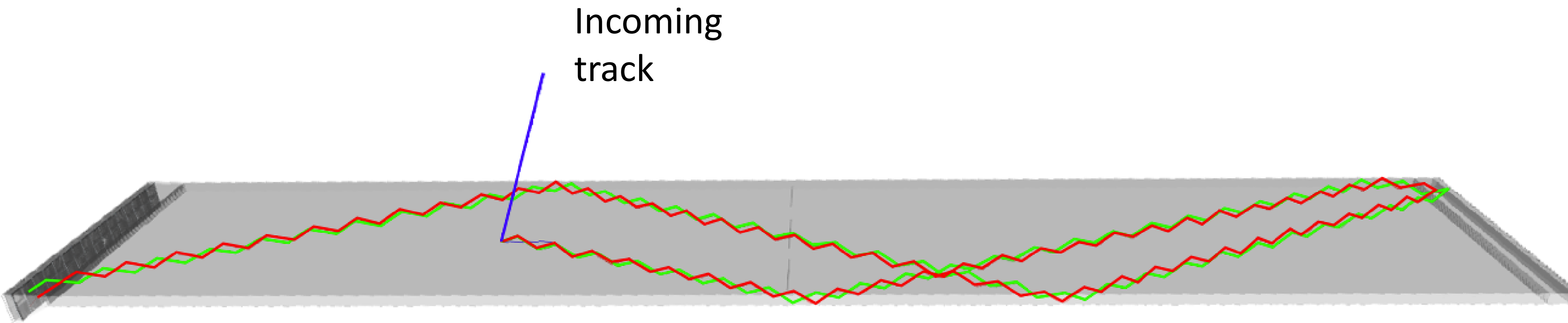
Hawaii in underlined red

Belle II Detector

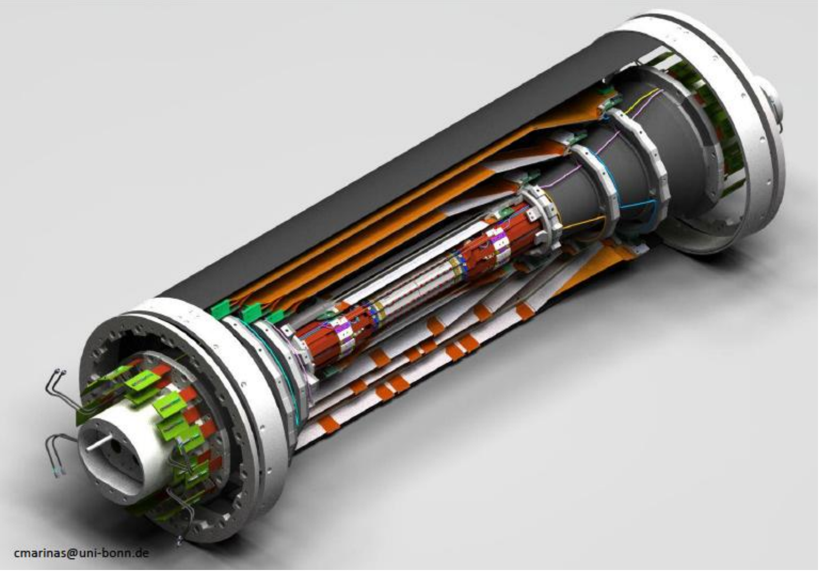


Barrel Particle Identification

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, Spain…)

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

DSSD (double sided silicon detectors)

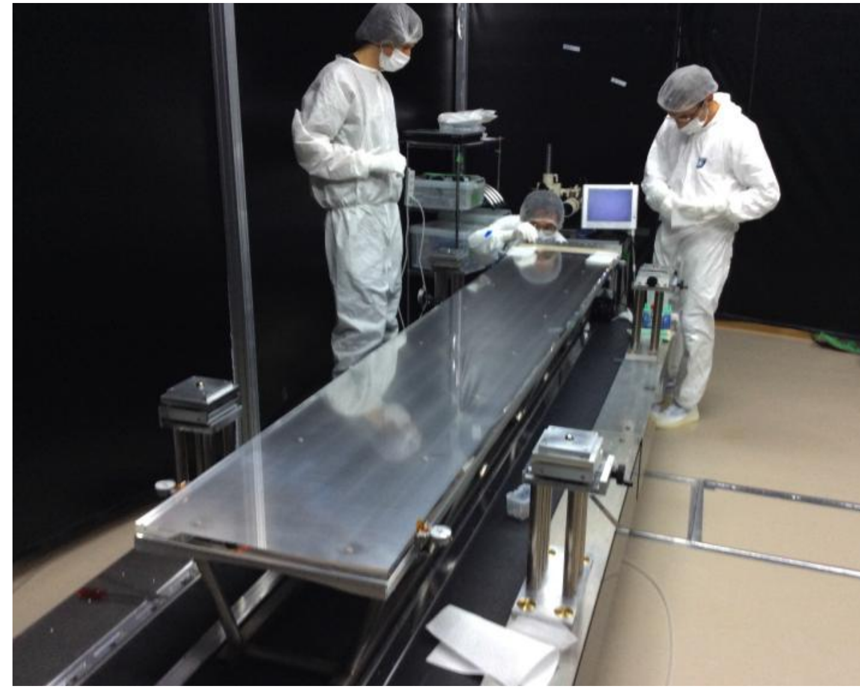
- Layer 3 r=38 mm (Australia)
- Layer 4 r=80 mm (India)
- Layer 5 r=115 mm (Austria)
- Layer 6 r=140 mm (Japan)

FWD/BWD Italy

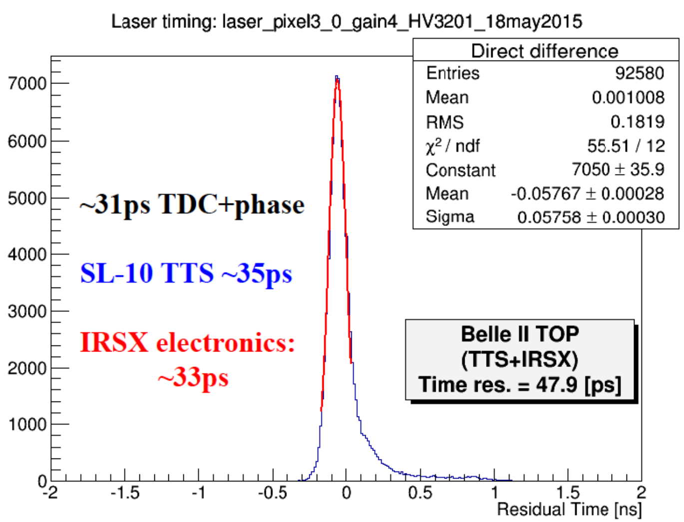
+Poland, Korea

Belle II iTOP at Fuji Hall/Hawaii

Module 01 assembly at Fuji Hall



Module 04 assembly at Fuji Hall

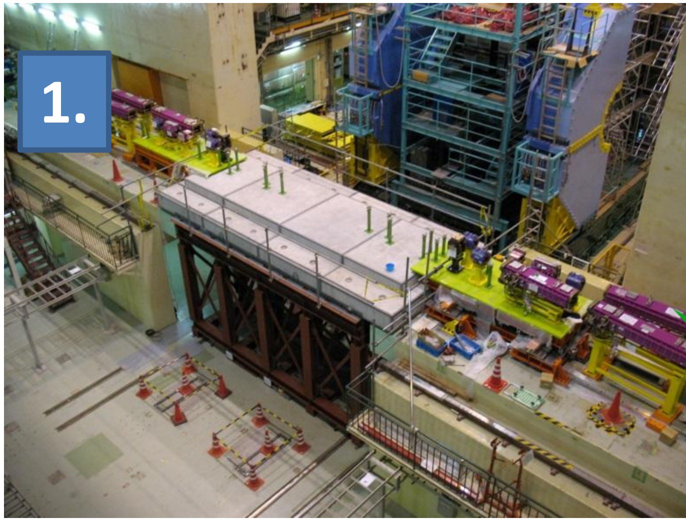


Production testing of readout with single photo-electron laser pulses in Hawaii; electronics resolution ~35ps

All quartz and electronics in hand; now testing and assembling.

BEAST Phase 1 Installation Sequence

1.



Install IP bridge: **Completed**

2. Install 6km cables: **Completed** June 25-28

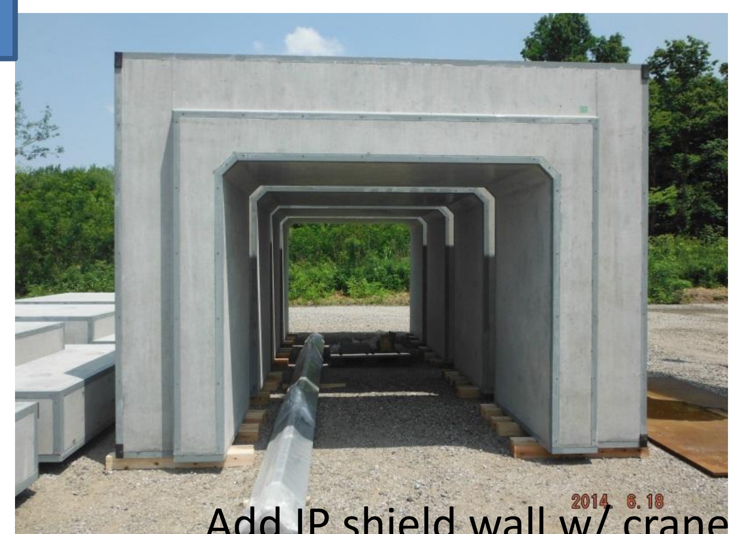
3. Install IP chamber: **Completed** June 29th

4.

M. Hedges (Univ. Hawai`i) - B2IM

Install support structure and sensors: Aug 17- Sep 22

5.

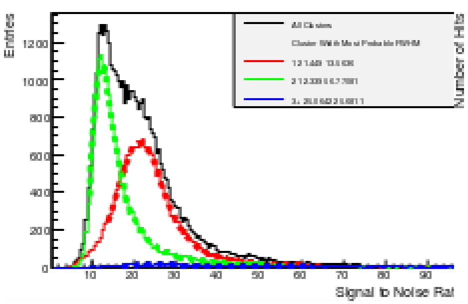


Add IP shield wall w/ crane

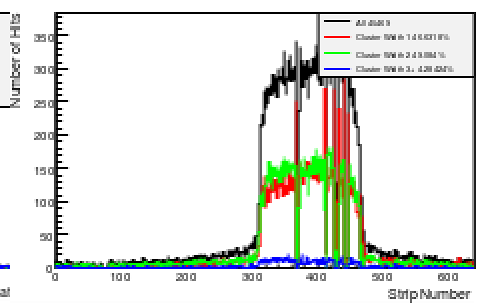
Highlights of Belle II construction

SuperKEKB hardware is being finalized.

BEAST PHASE I beampipe installed

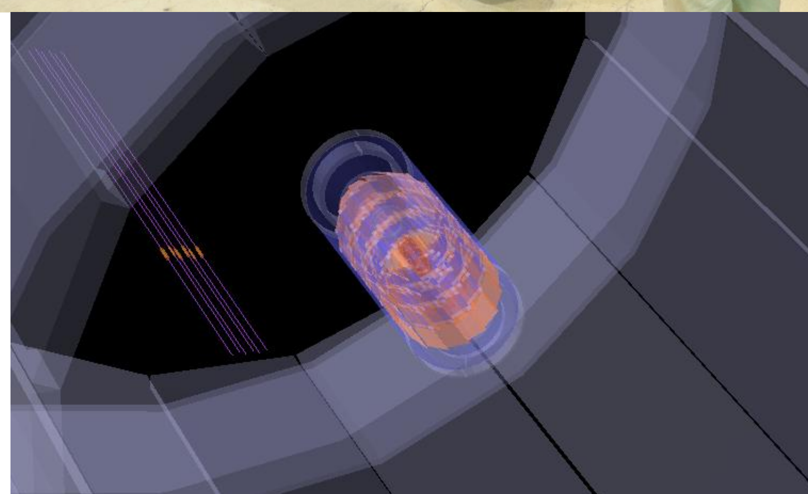


S/N



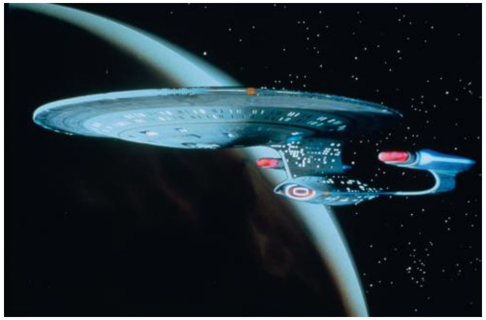
Hits

Final Belle II SVD ladder in CERN beam in June (working well !)



(a) CDC arriving at Tsukuba Hall; (b) first cosmics with partly instrumented electronics (6 layers)

Innovative Technologies in Belle II



Pixelated photo-sensors play a central role

MCP-PMTs in the iTOP

HAPDs in the ARICH

SiPMs in the KLM

Waveform sampling with precise timing is "saving our butts".

Front-end custom ASICs (Application Specific Integrated Circuits) for all subsystems ➔ a 21st century HEP experiment.

KL/muon detector (TARGETX ASIC)

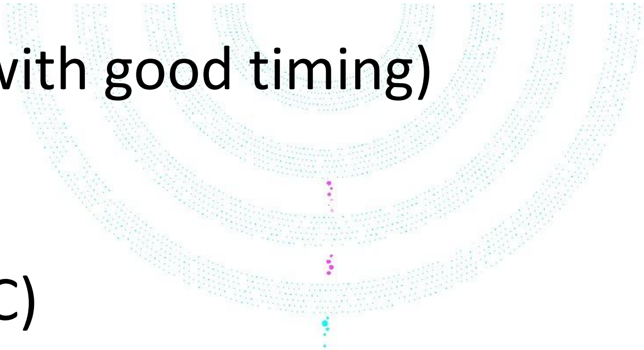
Electromagnetic calorimeter

(New waveform sampling backend with good timing)

iTOP particle identification (IRSX ASIC)

Aerogel RICH (KEK custom ASIC)

Central Drift Chamber (KEK custom ASIC)



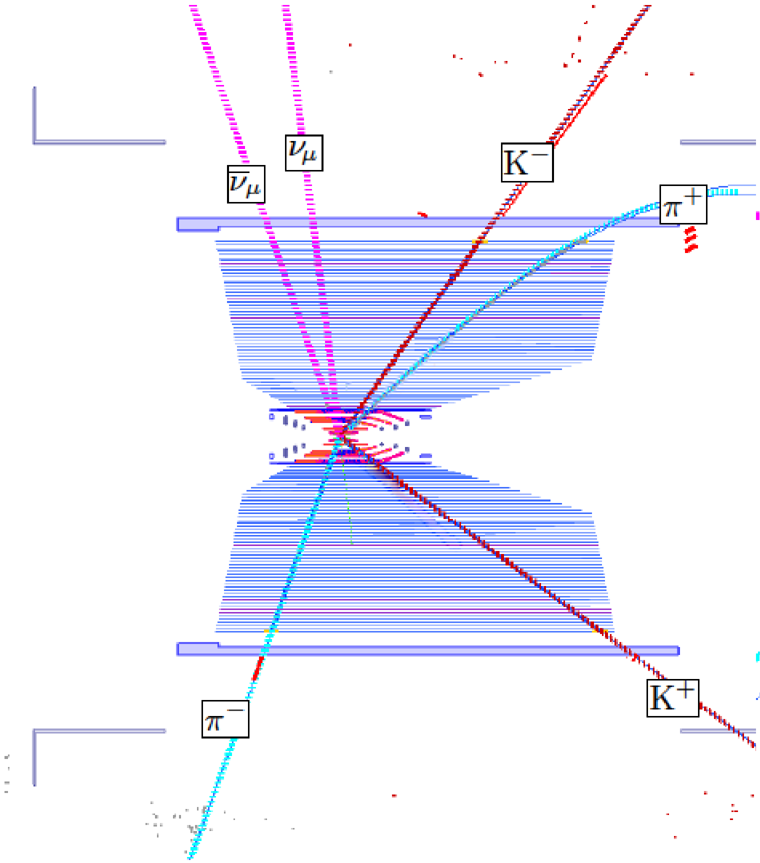
SVD (APV2.5 readout chip adapted from CMS)

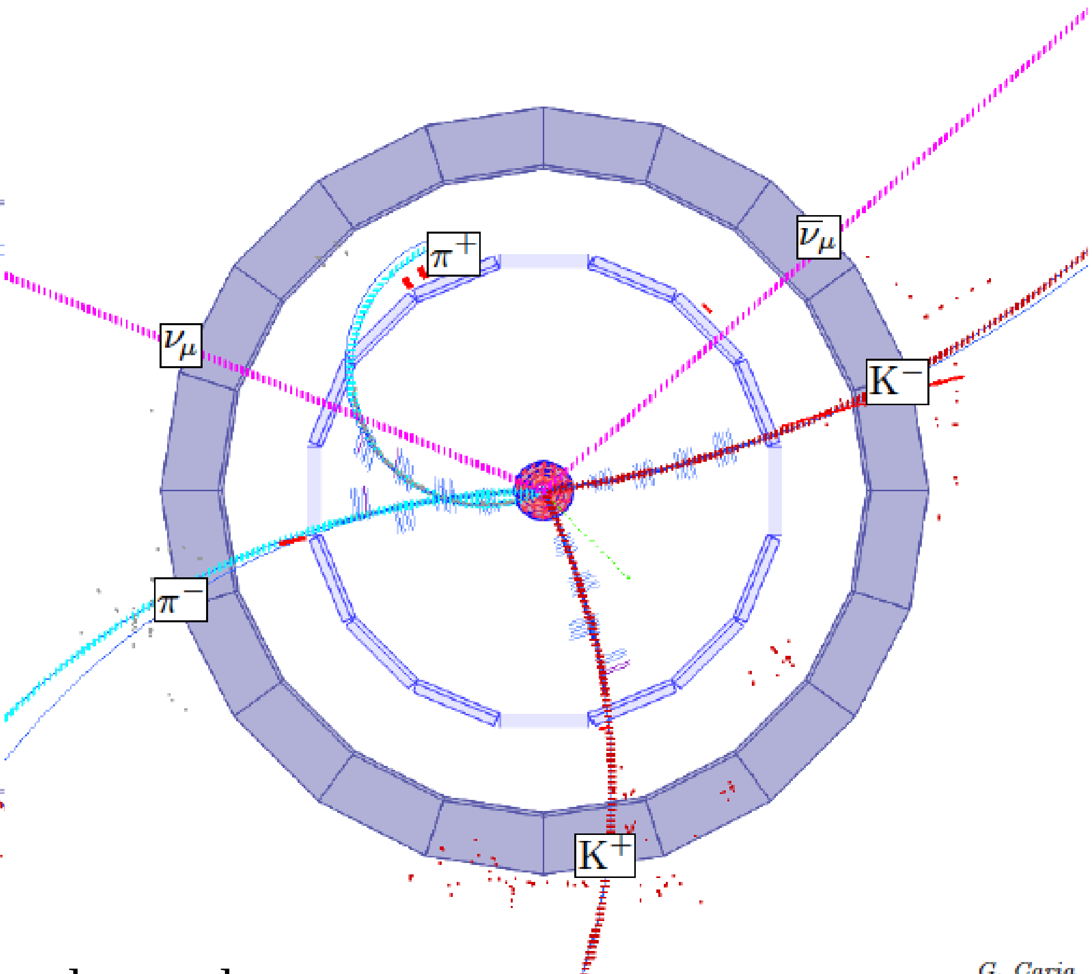
"Missing Energy Decay" in a Belle II GEANT4 MC simulation

Signal B→K ν ν   tag mode: B→Dπ; D→Kπ

Zoomed view of the vertex region in r--phi

View in r-z

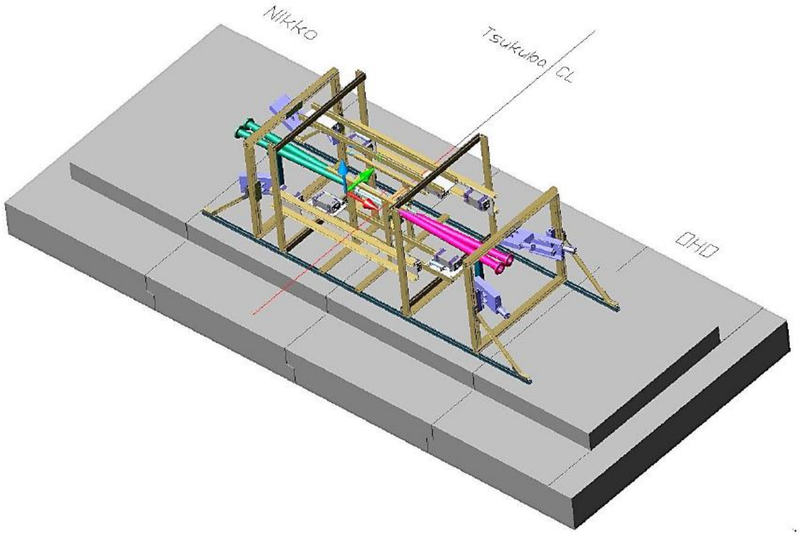




→Belle II Software is in a fairly advanced state

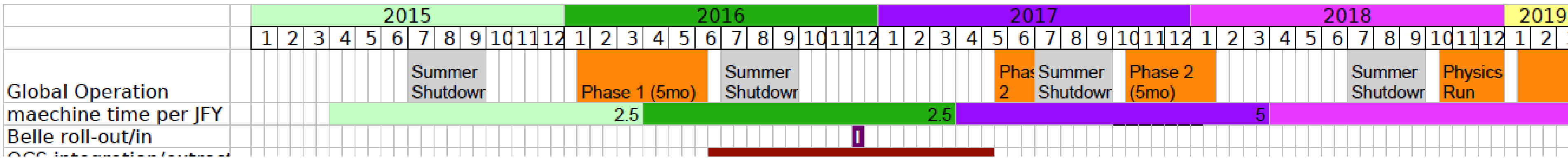
Some Belle II jargon

BEAST PHASE I: Simple background commissioning detector (diodes, TPCs, crystals). No final focus. Only single beam background studies possible [starts in Jan 2016].



BEAST PHASE II: More elaborate inner background commissioning detector. Full Belle II outer detector. Full superconducting final focus. *No vertex detectors.*

Belle II Schedule (Zoom-in on operations)



When do we start Belle II ?

BEAST PHASE I: Starts in Jan 2016

BEAST PHASE II: Starts ~May 2017 [some limited physics without vertex detectors]

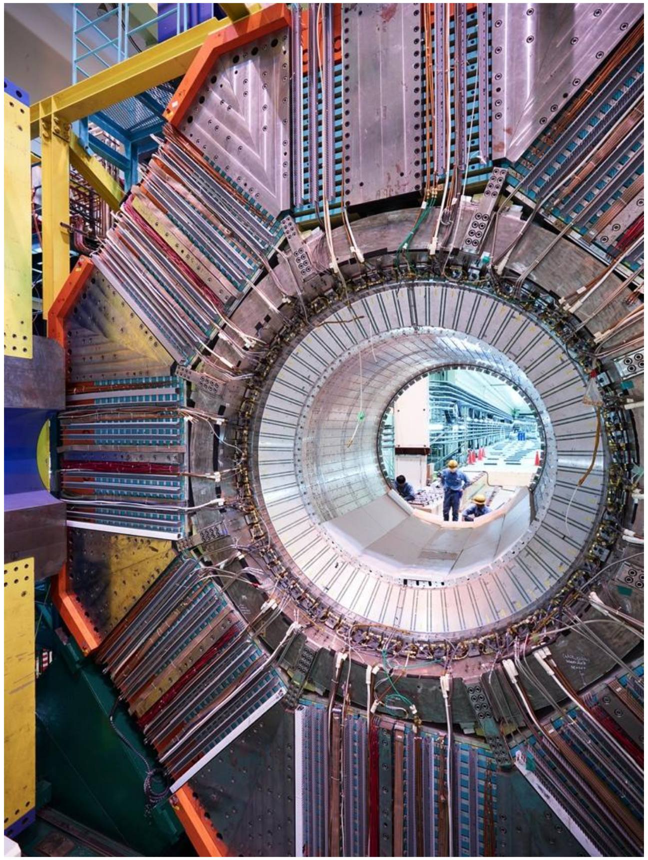
Belle II Physics Running: Fall 2018

Conclusion/Next Generation

- The e+ e- B factories confirmed that the KM phase is responsible for most of the observed CPV [Physics Nobel Prize 2008]
- Nevertheless, 10-20% NP effects are consistent with all current flavor data.
- LHCb has ruled out large CPV phases from NP in the B_s sector.
- "Missing energy B decays" provide important high—mass sensitivity to the charged Higgs in the multi-TeV range.
- LHC exps (CMS, LHCb) measured $B_s \rightarrow \mu^+ \mu^-$
- Angular anomalies in $B \rightarrow K^* l^+ l^-$ from LHCb with 3 fb^{-1}
- *Flavor physics is exciting and fundamental. (Did we just find NP ? This may be the path for the future of HEP.)*

SuperKEKB commissioning starts in January. Belle II Physics runs in 2018 and the LHCb upgrade in ~2020. These facilities will inaugurate a new era of flavor physics and the study of CP violation.

Backup slides



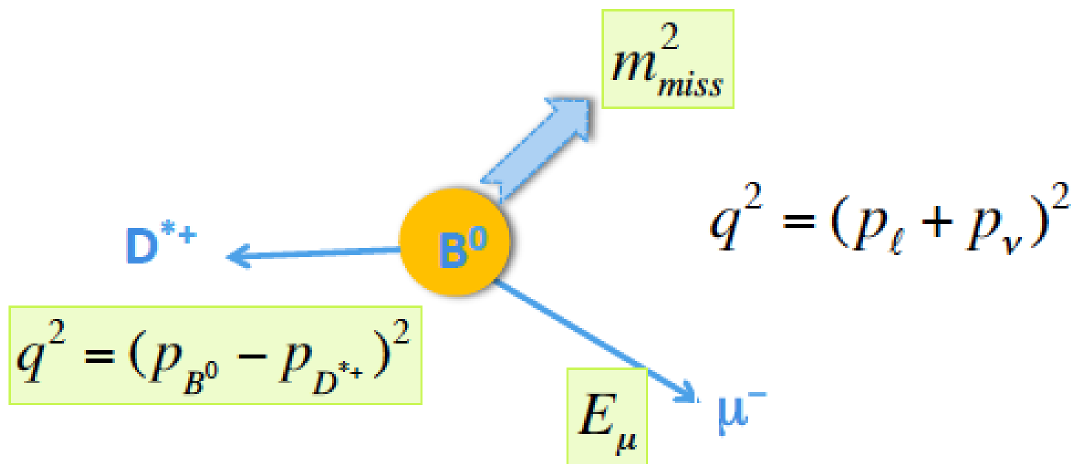
Belle II construction status

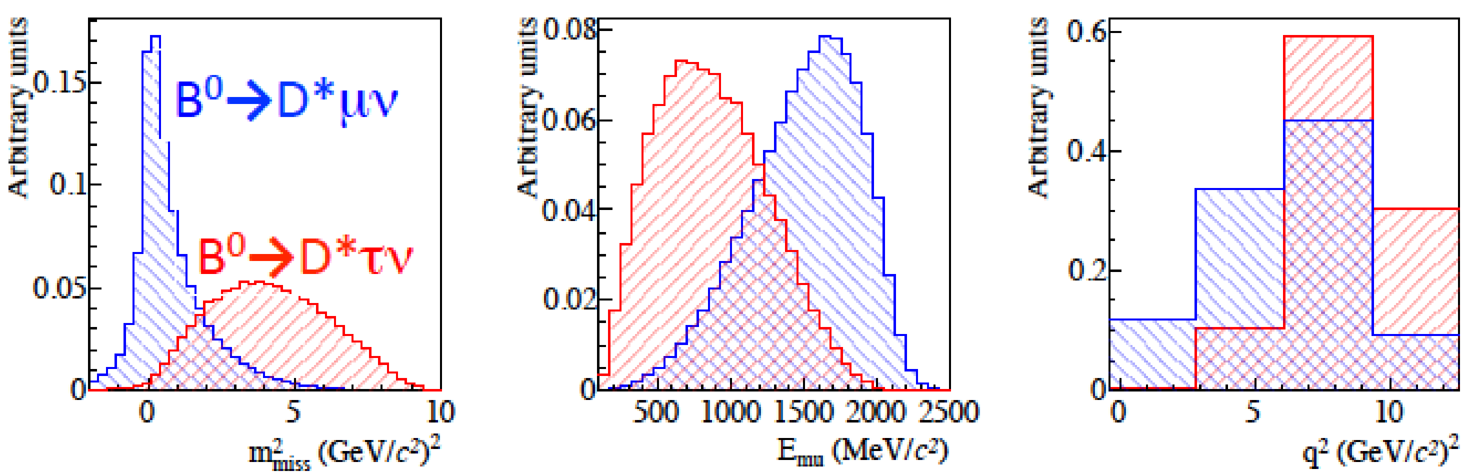
"Tensions are high, tempers are short."

Belle I Drift Chamber and Vertex Detector in the Ueno Science Museum in Tokyo

Separating $B^0 \to D^* \tau \nu$ from $B^0 \to D^* \mu \nu$

- 3 key kinematic variables computed in the B rest frame



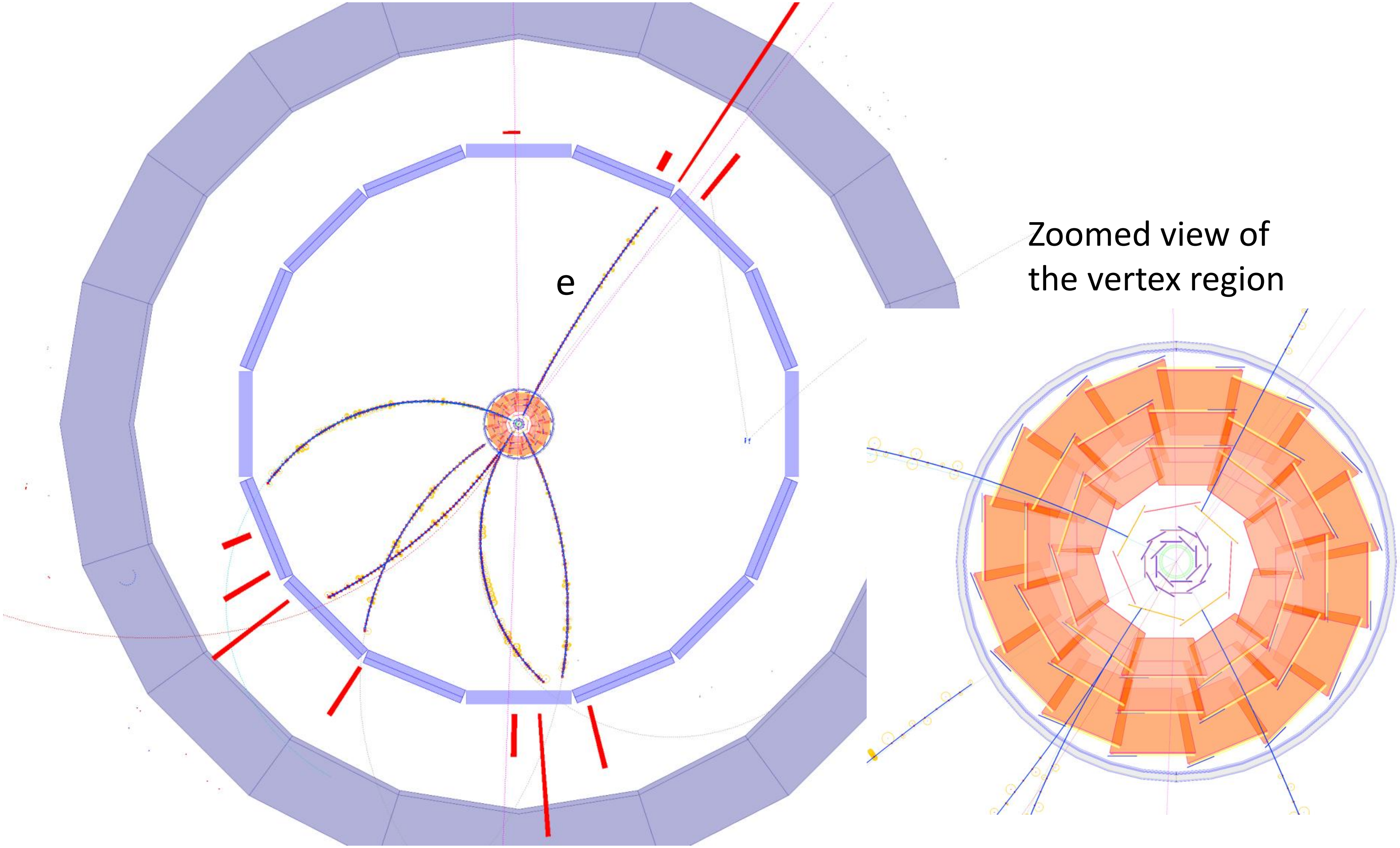


LHCb simulation

approximate B rest frame

“Missing Energy Decay” in a Belle II GEANT4 MC simulation

$B \rightarrow \tau\nu, \tau \rightarrow e\nu\nu$ $B \rightarrow D\pi, D \rightarrow K\pi\pi\pi$



Updated projections for B→K(*) nu nubar modes

TABLE I: Projections for the statistical uncertainties on the $B \to K^{(*)}\nu\bar{\nu}$ branching fractions.

Mode	$\mathcal{B}$ [10^{-6}]	Efficiency Belle [10^{-4}]	$N_{\text{Backg.}}$ 711 fb^{-1} Belle	$N_{\text{Sig-exp.}}$ 711 fb^{-1} Belle	$N_{\text{Backg.}}$ 50 ab^{-1} Belle II	$N_{\text{Sig-exp.}}$ 50 ab^{-1} Belle II	Statistical error 50 ab^{-1}	Total Error
$B^+ \to K^+\nu\bar{\nu}$	3.98	5.68	21	3.5	2960	245	23%	24%
$B^0 \to K^0_S\nu\bar{\nu}$	1.85	0.84	4	0.24	560	22	110%	110%
$B^+ \to K^{*+}\nu\bar{\nu}$	9.91	1.47	7	2.2	985	158	21%	22%
$B^0 \to K^{*0}\nu\bar{\nu}$	9.19	1.44	5	2.0	704	143	20%	22%
$B \to K^*\nu\bar{\nu}$ combined							15%	17%

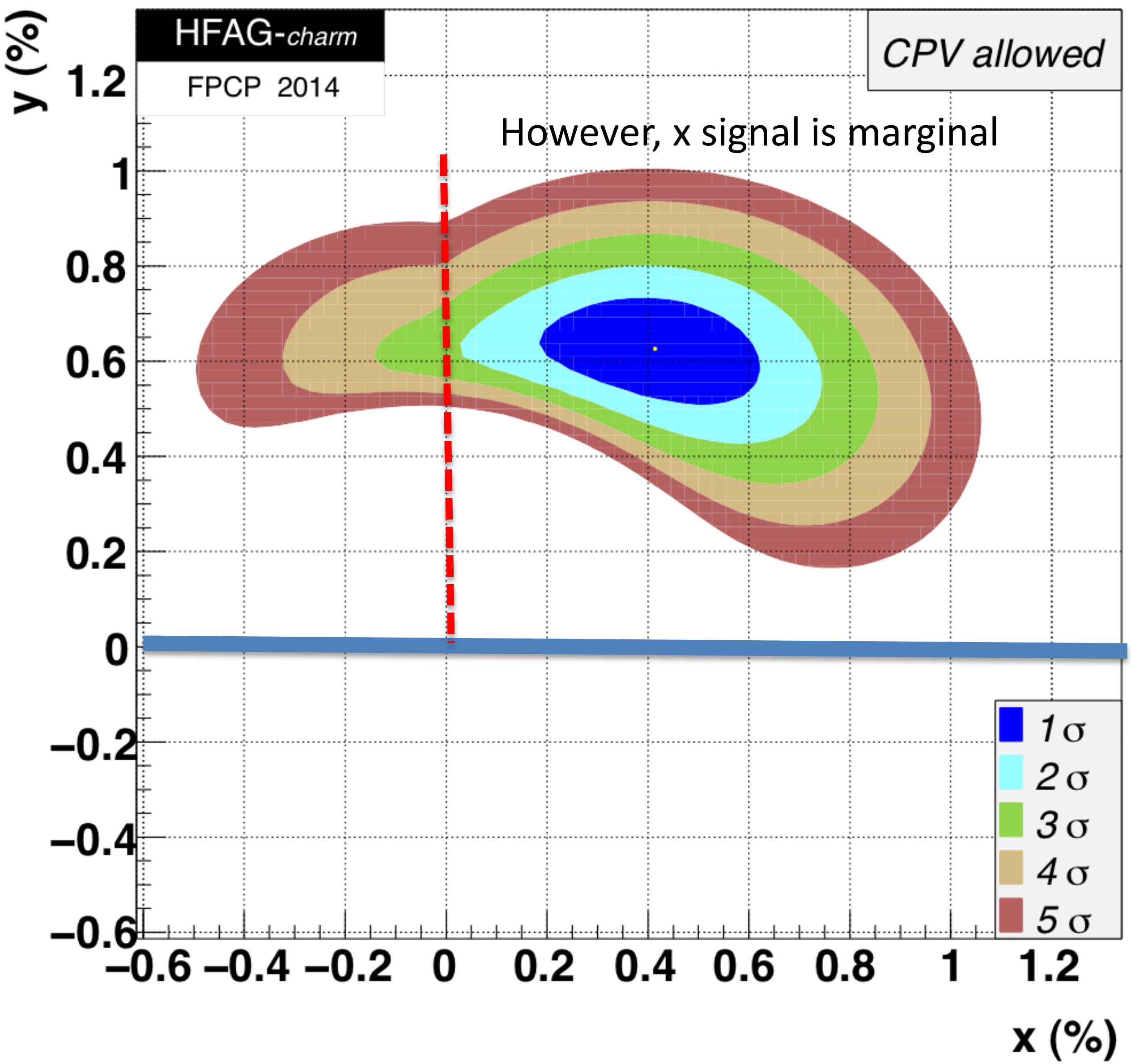
[1] A. J. Buras, J. Girrbach-Noe, C. Niehoff and D. M. Straub, JHEP **1502**, 184 (2015) [arXiv:1409.4557 [hep-ph]].

[2] O. Lutz *et al.* [Belle Collaboration], Phys. Rev. D **87**, no. 11, 111103 (2013) [arXiv:1303.3719 [hep-ex]].

[3] T. Kuhr, "$B \to h^{(*)}\nu\bar{\nu}$" , KEK-FF Workshop (2013).

P. Urquijo et al.

Mixing and CP violation in the D system



There is a very strong y signal

D mixing: Another new physics phase !

$$\varphi \sim \frac{2\eta A^2 \lambda^5}{\lambda} \sim O(10^{-3})$$

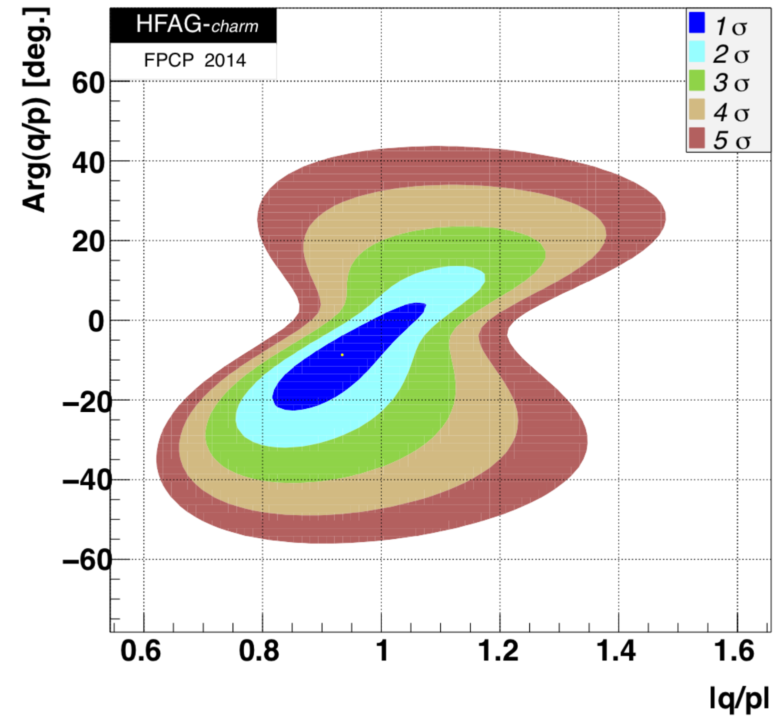
CPV in D system negligible in SM

CPV in interf. mix./decay:

$$\mathrm{Im}\frac{q}{p}\frac{\bar{A}_f}{A_f} \equiv (1+\frac{A_M}{2})e^{i\varphi} \neq 0; \varphi \neq 0$$

The existence of D mixing (if x is non-zero) allows us to look for another poorly constrained new physics phase but this time from up-type quarks.

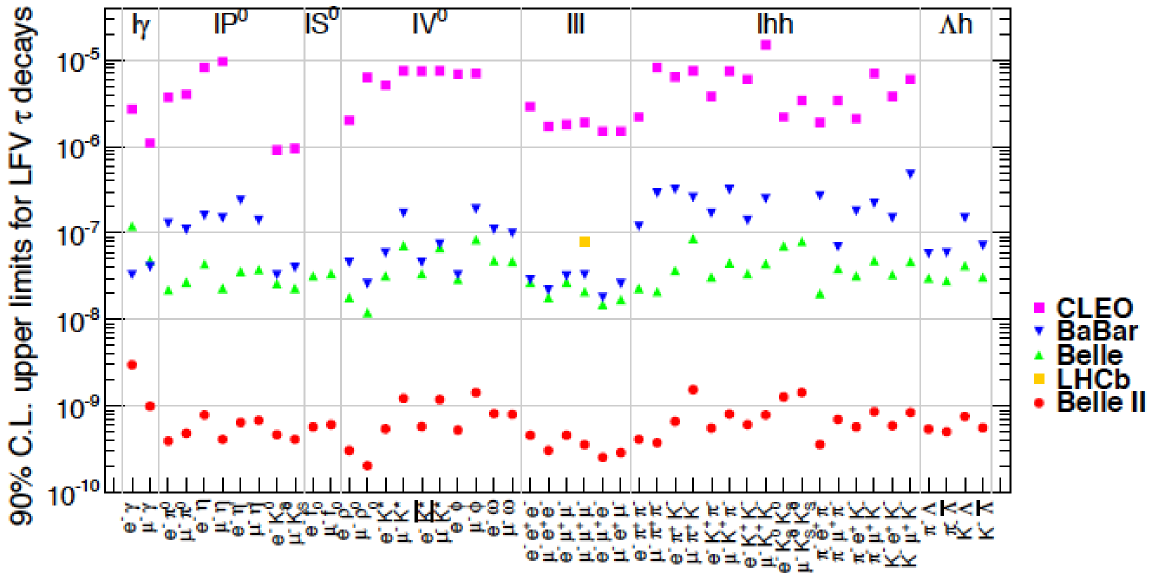
(c.f. CPV in B_s mixing)



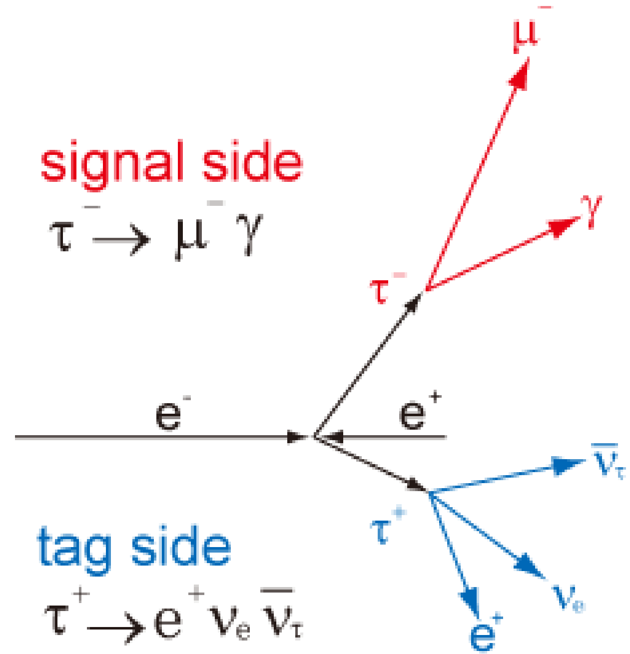
Current WA sensitivity $\sim\pm 20^0$, 50 ab^{-1} go below 2^0

Tau Lepton Flavor Violation

FIG. 5: LFV UL (90% C.L.) results from CLEO, BaBar and Belle, and extrapolations for Belle II (50 ab^{-1}) and LHCb updgrade (50 fb^{-1}).



Example of the decay topology



Belle II will push many limits below 10^{-9} ; LHCb has very limited capabilities.

CPV in the charged lepton sector

- There is mixing in the neutrino (neutral lepton) sector. CP violation is possible too.

<u>BaBar rate anomaly ??</u>

Is this interesting or ruled out by other constraints ?

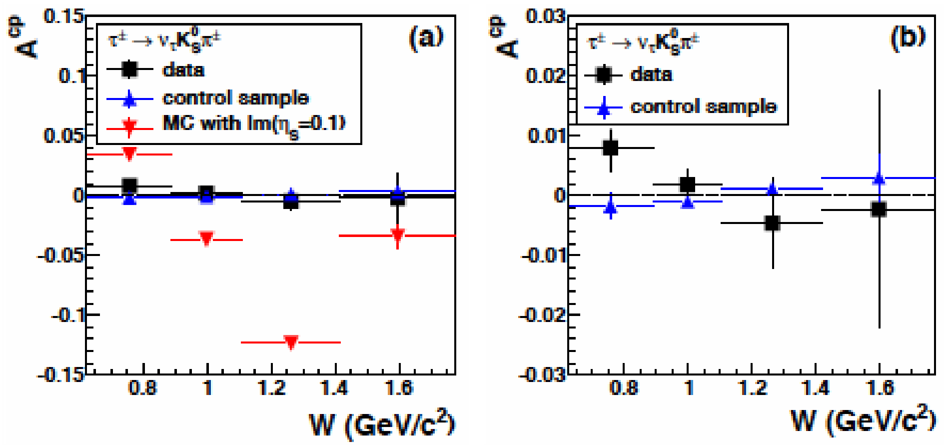


FIG. 2. (a) Measured CP violation asymmetry after background subtraction (squares). The vertical error bars are the statistical error and systematic errors added in quadrature. The CP asymmetry measured in the control sample is indicated by the blue triangles (statistical errors only) and the inverted red triangles show the expected asymmetry for $\Im(\eta_S) = 0.1$ [$\Re(\eta_S) = 0$]. (b) Expanded view (the vertical scale is reduced by a factor of five).

<u>*Can we explore at Belle II ?*</u>

Theoretical predictions for $\Im(\eta_S)$ can be given in context of a MHDM with three or more Higgs doublets [4, 5]. In such models η_S is given by [12]

$$\eta_S \simeq \frac{m_\tau m_s}{M_{H^\pm}^2} X^* Z \qquad (10)$$

if numerically small terms proportional to m_u are ignored. Here, $M_{H^\pm}$ is the mass of the lightest charged Higgs boson and the complex constants Z and X describe the coupling of the Higgs boson to the τ and ν_τ and the u and s quarks, respectively (see [5, 12]). The limit $|\Im(\eta_S)| < 0.026$ is therefore equivalent to

$$|\Im(XZ^*)| < 0.15 \frac{M_{H^\pm}^2}{1\,\mathrm{GeV}^2/c^4}. \qquad (11)$$

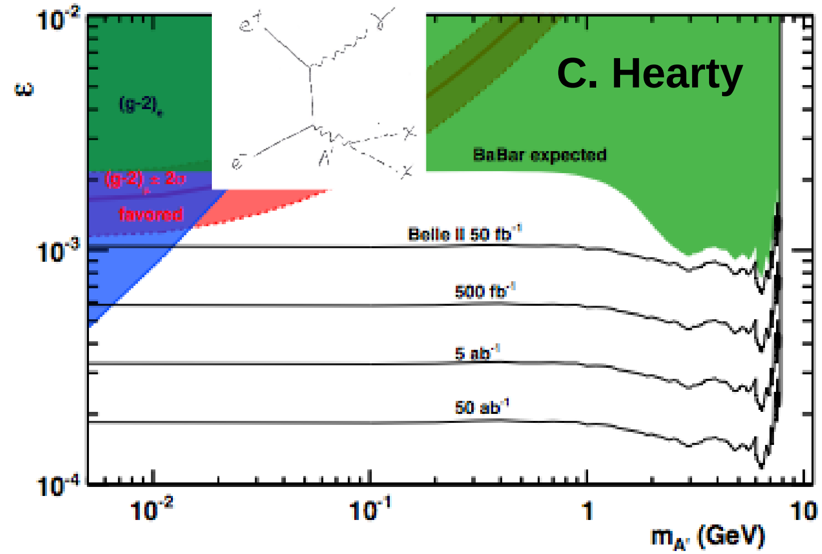
M. Bischofberger et al, Phys. Rev. Lett. 107, 131801 (2011)

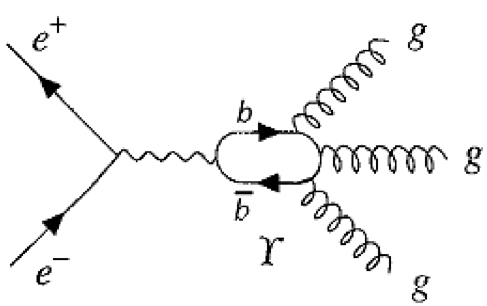
Beast Phase II & New Triggers

- Update to First-physics report: BELLE2-NOTE-PH-2015-003 Υ(2S), Υ(3S), Υ(6S), Scan proposals

- Beast Phase II Physics Task Force formed to study physics with this configuration (B. Fulsom).

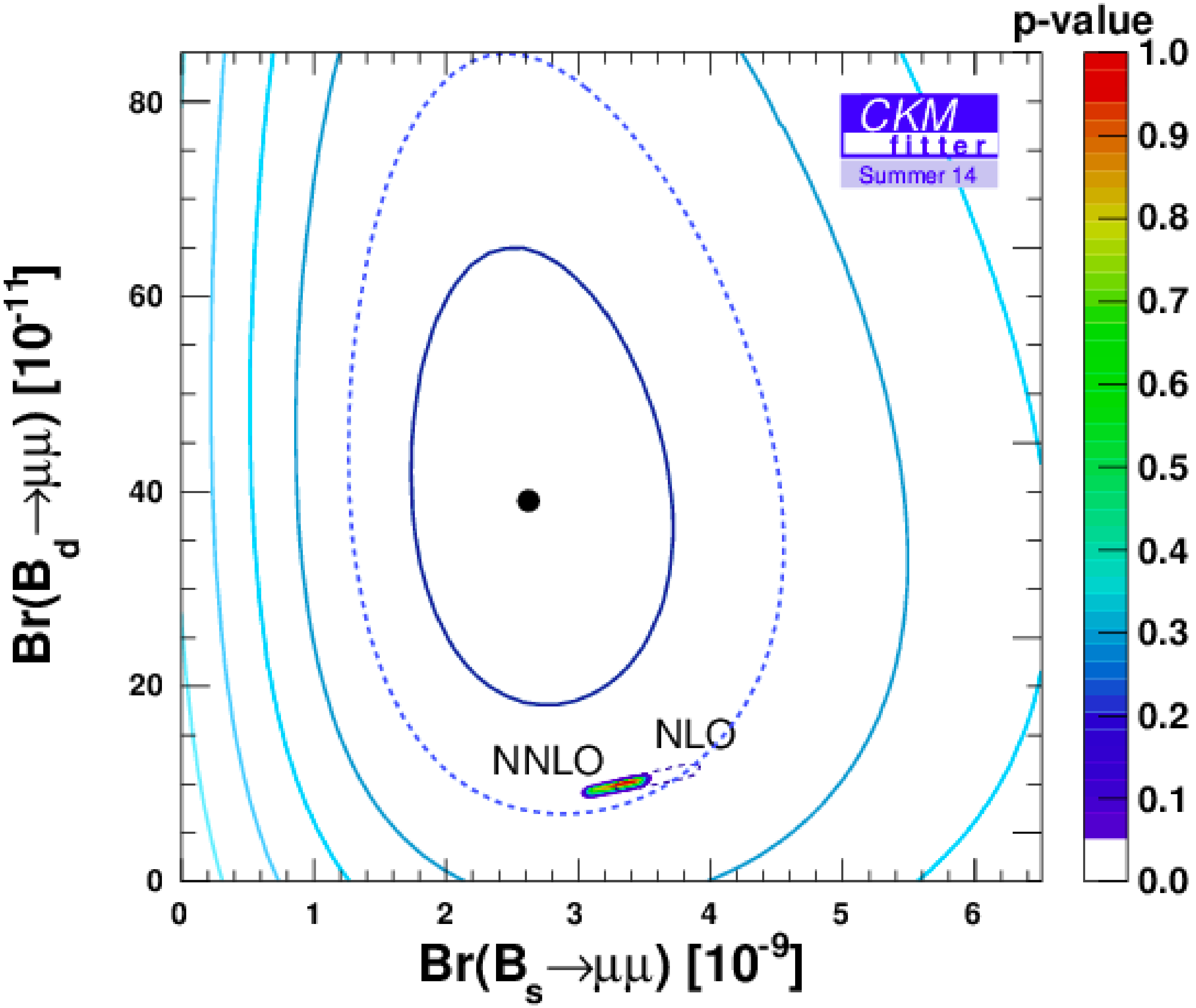
- Belle Υ(1S) decay data used for Pythia 8 MC tuning in Belle II (U. Tamponi).





Triggers		Some Ideas C-H. Li
Single Photon (γ)		• Cascade: different thresholds with separate pre-scale factors • Use different pre-scale factors for Barrel and Endcap
e^+e^-		• two Bhabha triggers, "accept" and "veto" • "accept" : flattening scheme • "veto": 2D→3D ECL Bhabha is being investigated • salvage: retain a pre-scaled sample of physics triggers without veto
$\mu^+\mu^-$		• independent CDC and KLM triggers for luminosity systematics
γγ		• reduce pre-scale to 10 instead of 100
γ+ 2 trks	γe^+e^- [hlt]	• dedicated triggers for calibration (CDC,ECL)
	$\gamma\mu^+\mu^-$	• dedicated triggers for detectors study (CDC, ECL, KLM)
	γh^+h^-	• high efficiency for all γ energies and h^+h^- invariant masses • one high energy cluster in ECL, one track in opposite hemisphere
Additional trigger information		• CDC-TOP-ECL-KLM Matching • More detectors information……

- HLT & L1 Trigger Menu under design. Evolving Trigger Menu (Link).


p-value
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CKM fitter
Summer 14
80
60
40
20
0
0
1
2
3
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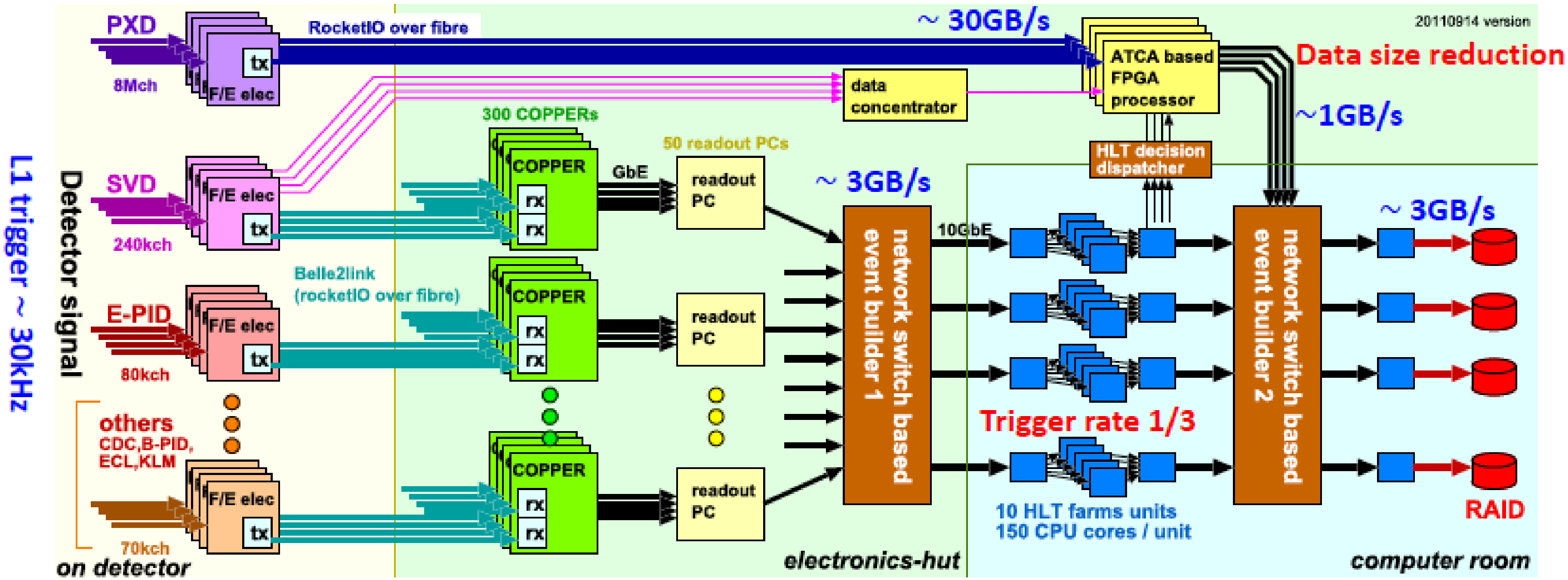
5
6
NNLO
NLO
Br(B_d→μμ) [10^-11]
Br(B_s→μμ) [10^-9]

Belle II

Data acquisition system



Discussion Topic: What additional *Theoretical Work* is required to determine whether NP is present in B decays ?

Participants: Wolfgang Altmannshofer, Christoph Bobeth, Jorge Martin Camalich, Robert Fleischer, Zoltan Ligeti, Rahul Sinha

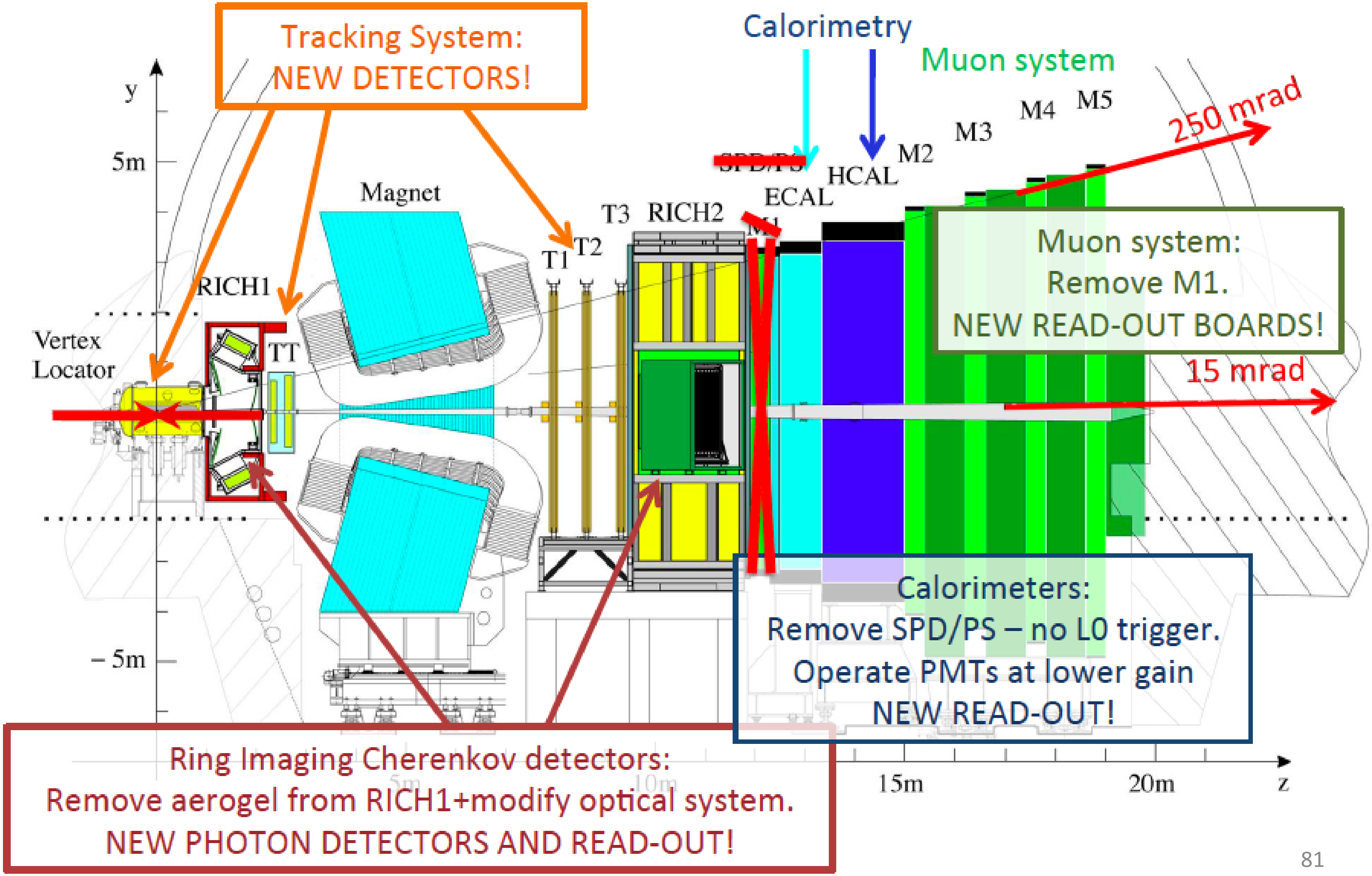
Nagoya
FPCP15
roundtable

鵜飼
“ukai”

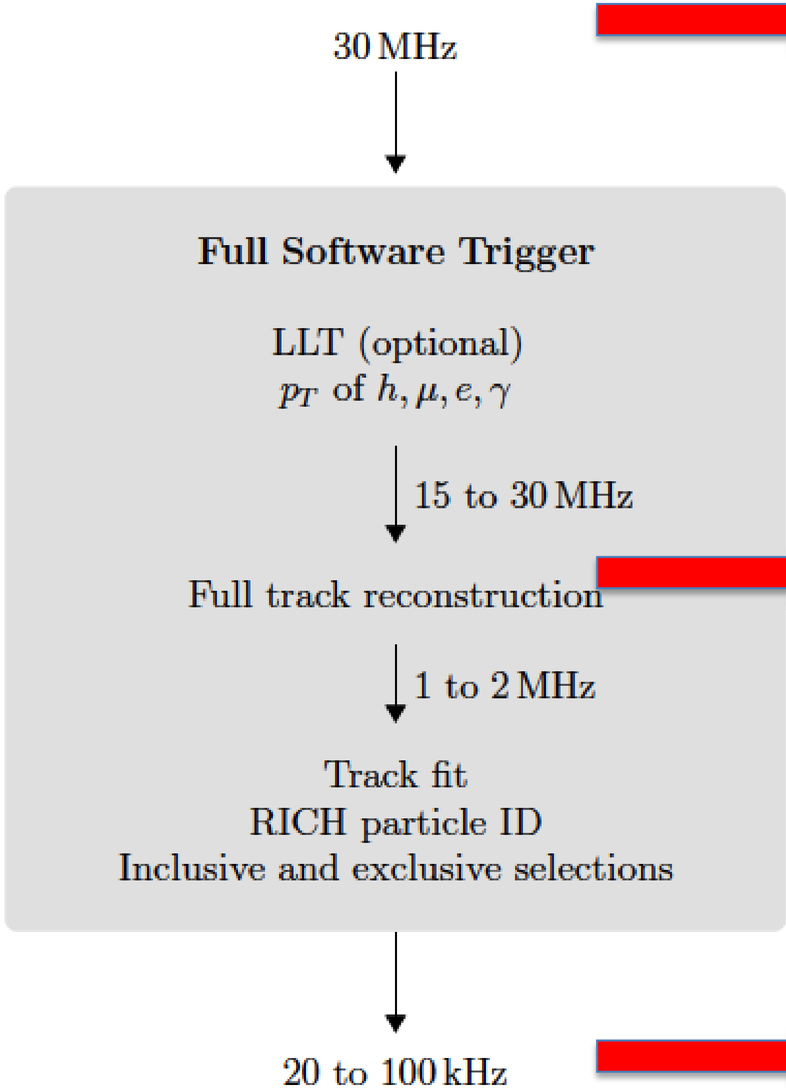
Cormorant Fishing on the Nagara River during the Edo Period

Discussed in Nakada-san's talk

Upgraded LHCb detector



LHCb Upgrade: *Key Feature* is Trigger-less readout



- 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.

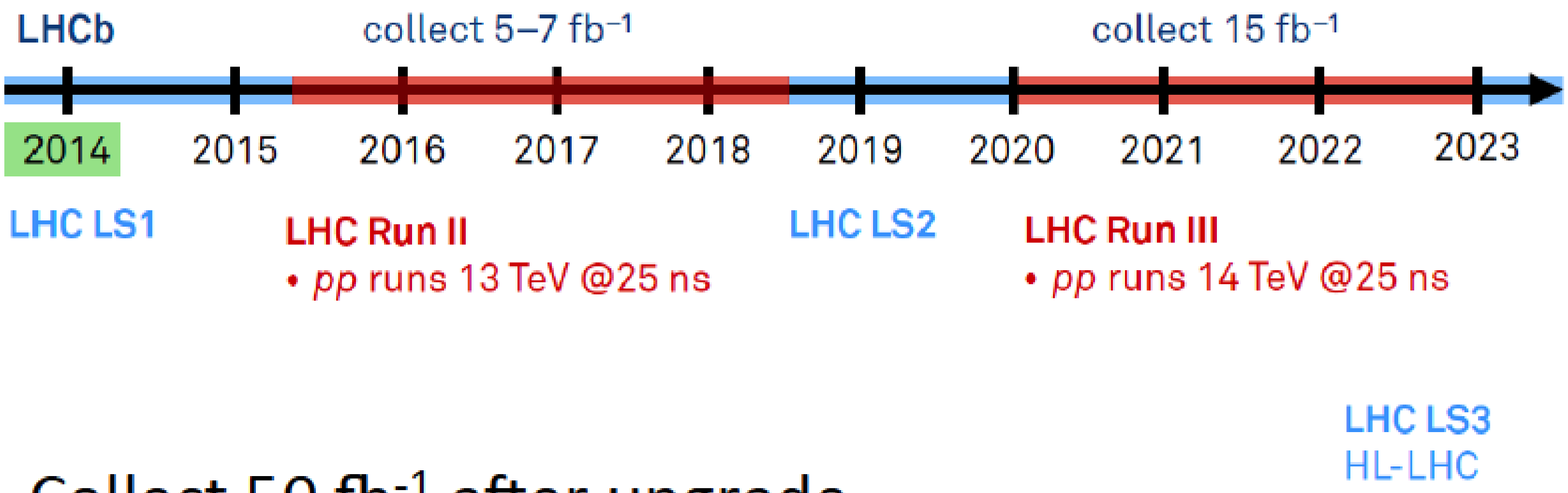
- Perform simplified Kalman track fit.
- Add RICH information.
- Inclusive and exclusive selections.

- 2 – 10 GBytes/s to storage.

LHCb upgrade timeline

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

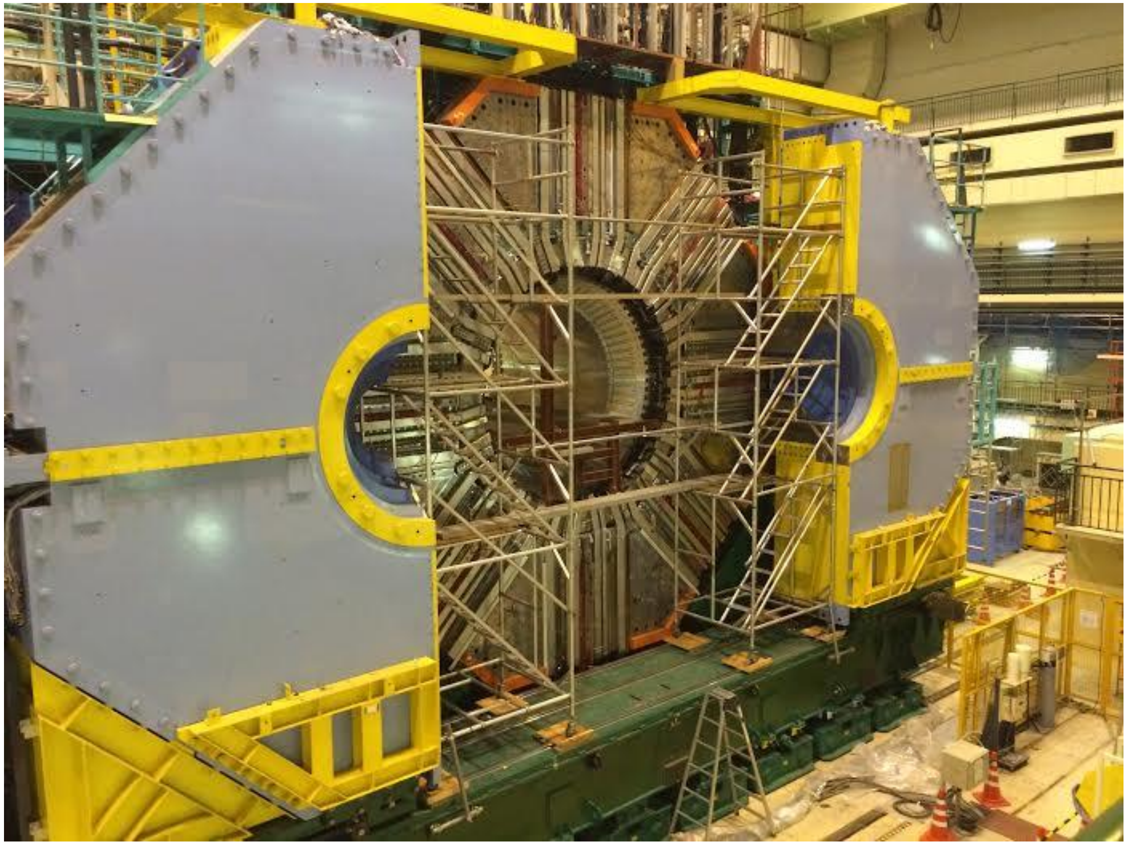
Expect (1-2) x 10^{33} /cm^2 /sec



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

<u>Upgraded trigger and DAQ is the key feature</u>

Belle II@Tsukuba Hall, KEK



Belle II detector with barrel KLM upgrade as well as forward and backward muon endcap upgrades now installed.

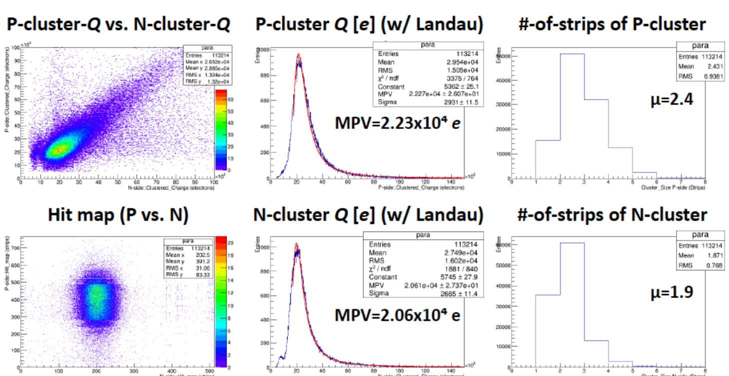
Belle II at IPMU in 柏の葉, Japan

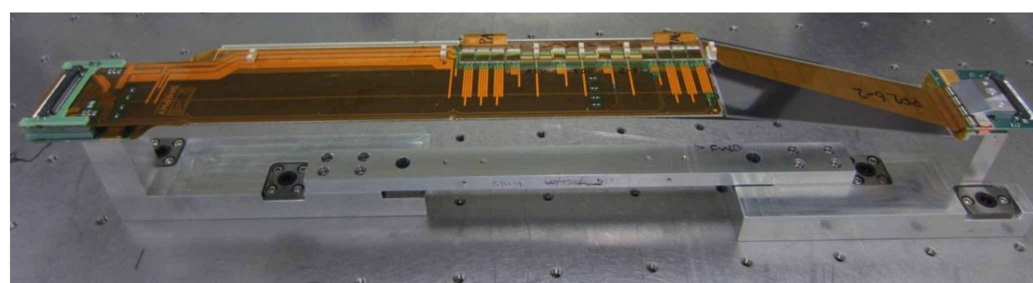
Constructing two layers of the Belle II SVD detector in the clean room on the 1st floor. Dr T. Higuchi is the leader.

Test Production by late Sept;
Detector production starts ~ Nov 2015

Japan (Layer 6) and India/Tata Institute (Layer 4)

^{90}Sr Source Test [2] (SBW990)





L4 mechanical prototype

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

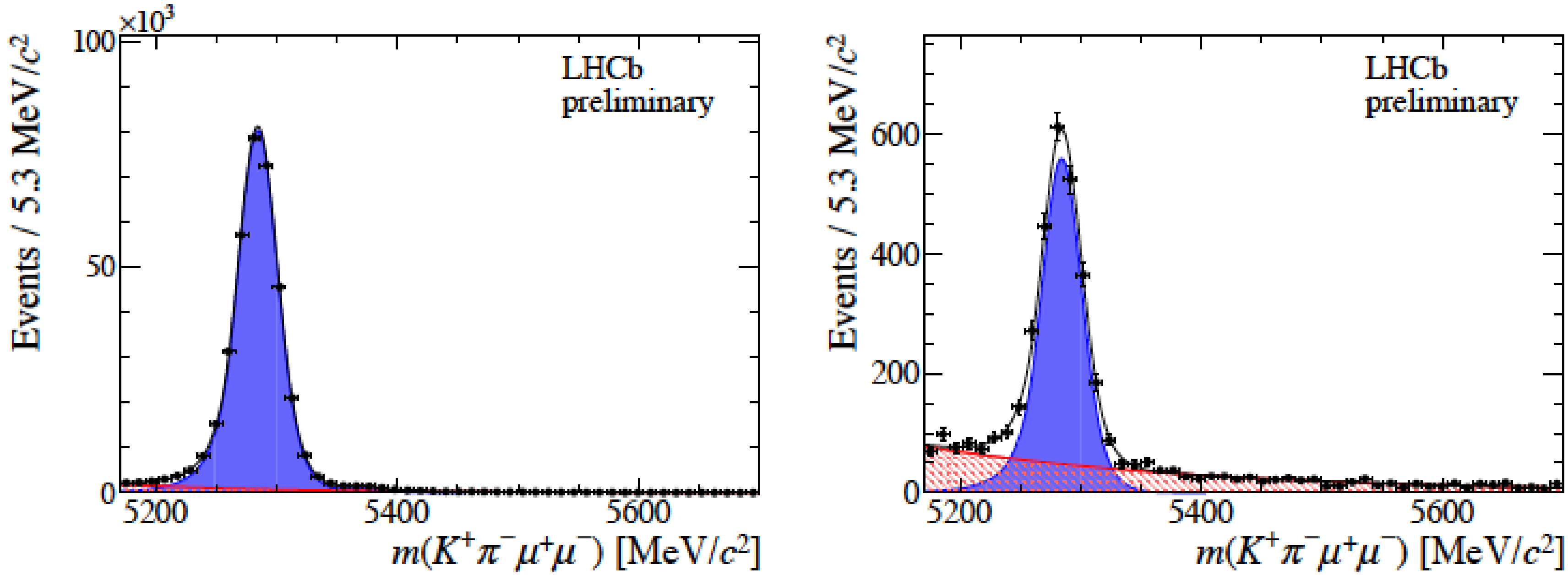
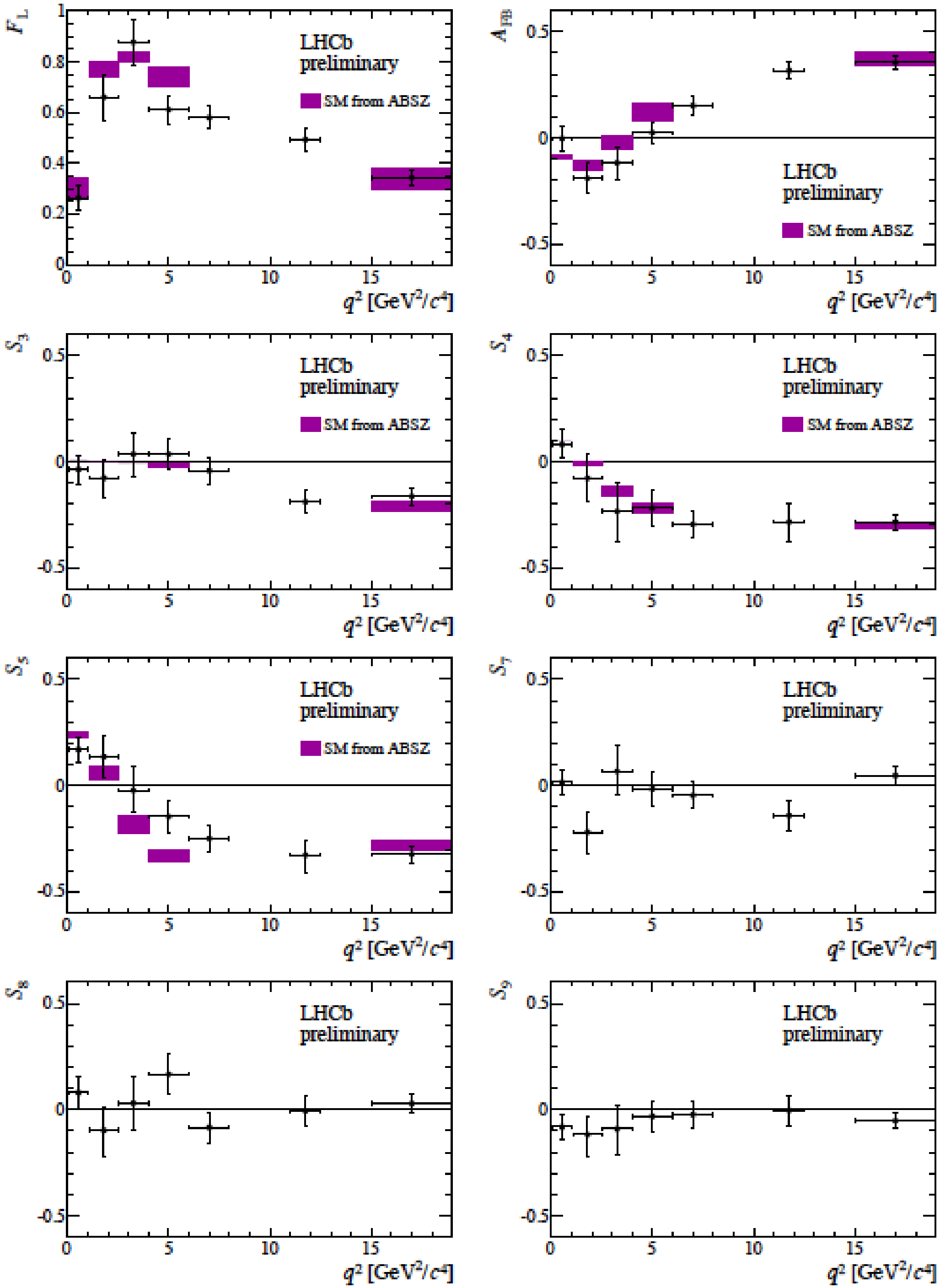


Figure 3: Invariant mass $m(K^+\pi^-\mu^+\mu^-)$ for (left) the control decay $B^0 \to J/\psi K^{*0}$ and (right) the signal decay $B^0 \to K^{*0}\mu^+\mu^-$, integrated over the full q^2 range. The $B^0 \to K^{*0}\mu^+\mu^-$ signal yield integrated over q^2 is determined to be 2398 ± 57. Overlaid are the projections of the total fitted distribution (black line) and its different components. The signal is shown by the blue component and the background is shown by the red hatched component.



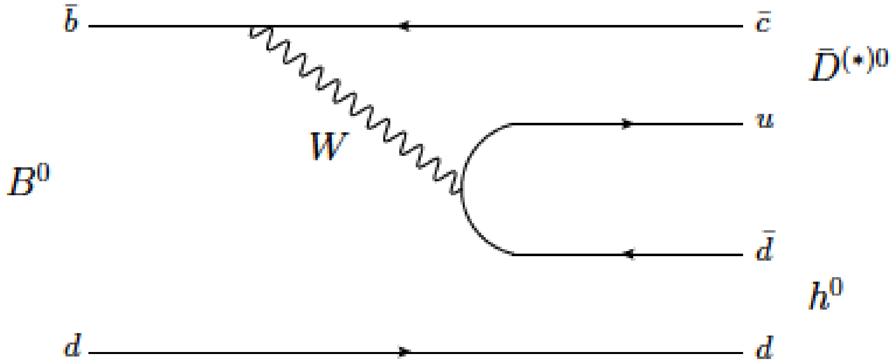
F_L
LHCb preliminary
SM from ABSZ
A_{FB}
LHCb preliminary
SM from ABSZ
S_3
LHCb preliminary
SM from ABSZ
S_4
LHCb preliminary
SM from ABSZ
S_5
LHCb preliminary
SM from ABSZ
S_7
LHCb preliminary
S_8
LHCb preliminary
S_9
LHCb preliminary
q^2 [GeV^2/c^4]

B factories: *Check CP violation in b→c [ubar d] processes*

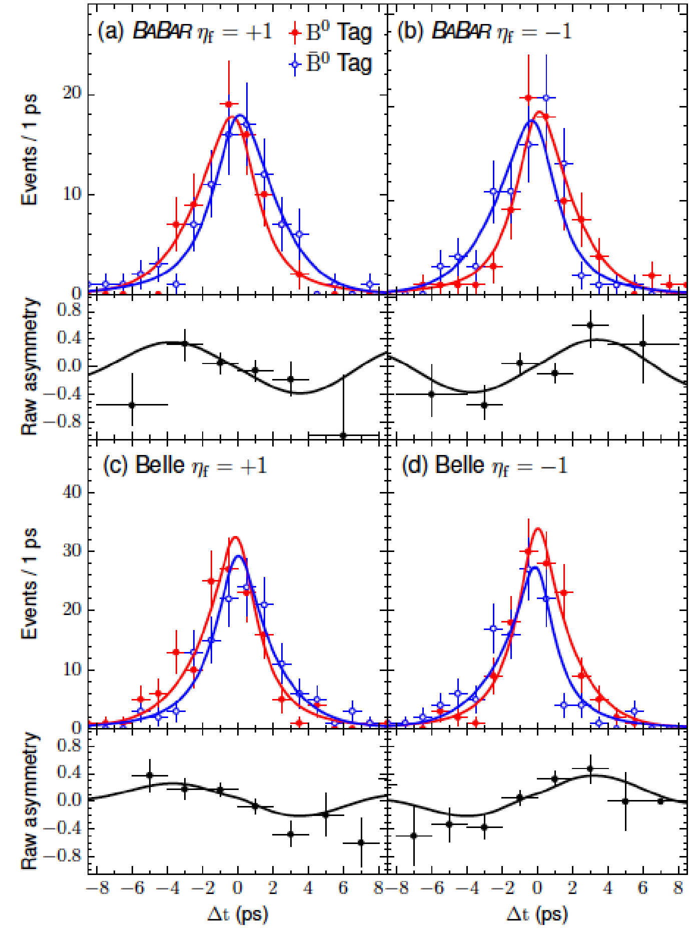
2015: First joint BaBar-Belle data analysis

M. Rohrken et al

"Color-suppressed" B→D h



where D^0 is a CP eigenstate and $h^0=\pi^0$, η, ω



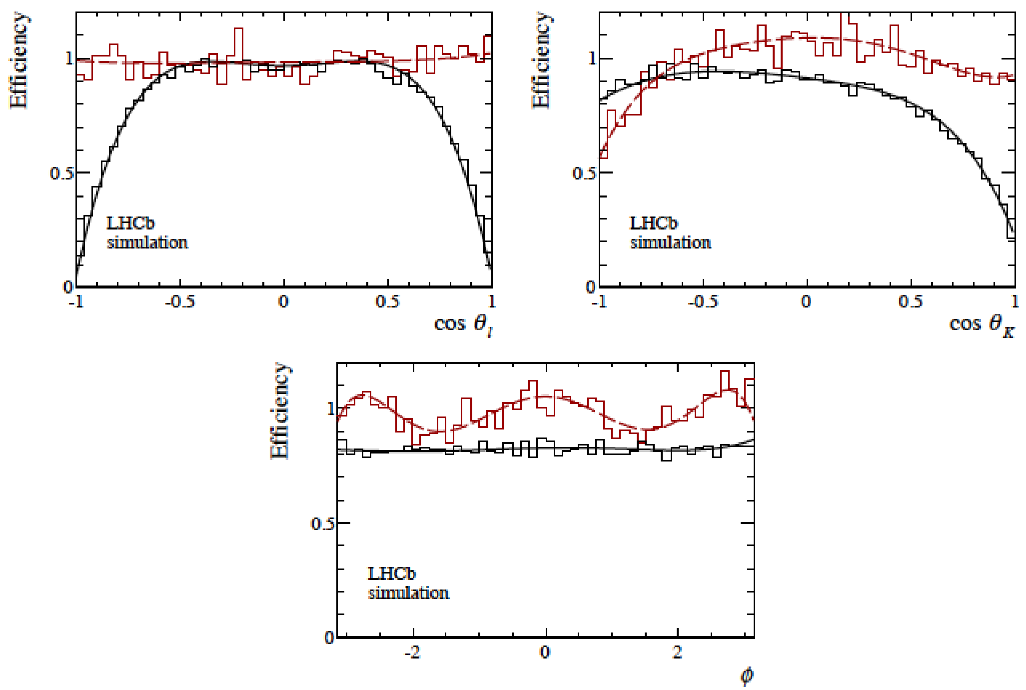
Combining Belle and BaBar datasets, ~1260 signal events, obtain a 5.4σ CP violation signal➔First observation

$\sin(2\beta_{eff})=0.66\pm0.10(stat)\pm0.06(sys)$

Phase of V_{td} again

Conclusion: CP violation in b→c ubar d modes is the same as in b→c cbar s modes (e.g. B→J/ψ K_S)

Efficiency at low q^2 for Belle II ?



LHCb detection efficiency plots.

Figure 2: Angular efficiency in $\cos\theta_\ell$, $\cos\theta_K$ and ϕ, as determined from a principal moment analysis of simulated three-body $B^0 \to K^{*0}\mu^+\mu^-$ phase-space decays. The efficiency is shown for the regions $0.1 < q^2 < 0.98\,\mathrm{GeV}^2/c^4$ (black solid line) and $18.0 < q^2 < 19.0\,\mathrm{GeV}^2/c^4$ (red dashed line). The histograms indicate the distribution of simulated three-body $B^0 \to K^{*0}\mu^+\mu^-$ phase-space decays used to determine the acceptance. The absolute normalisation of the dsitributions is arbitrary.

How important are the di-electron modes that Belle II does well ? (see the effect of the *photon pole* more clearly; NP from right handed currents ??)

More backup

J. Bernabeu and F. Martinez-Vidal, published in RMP 87, 165 (2015)

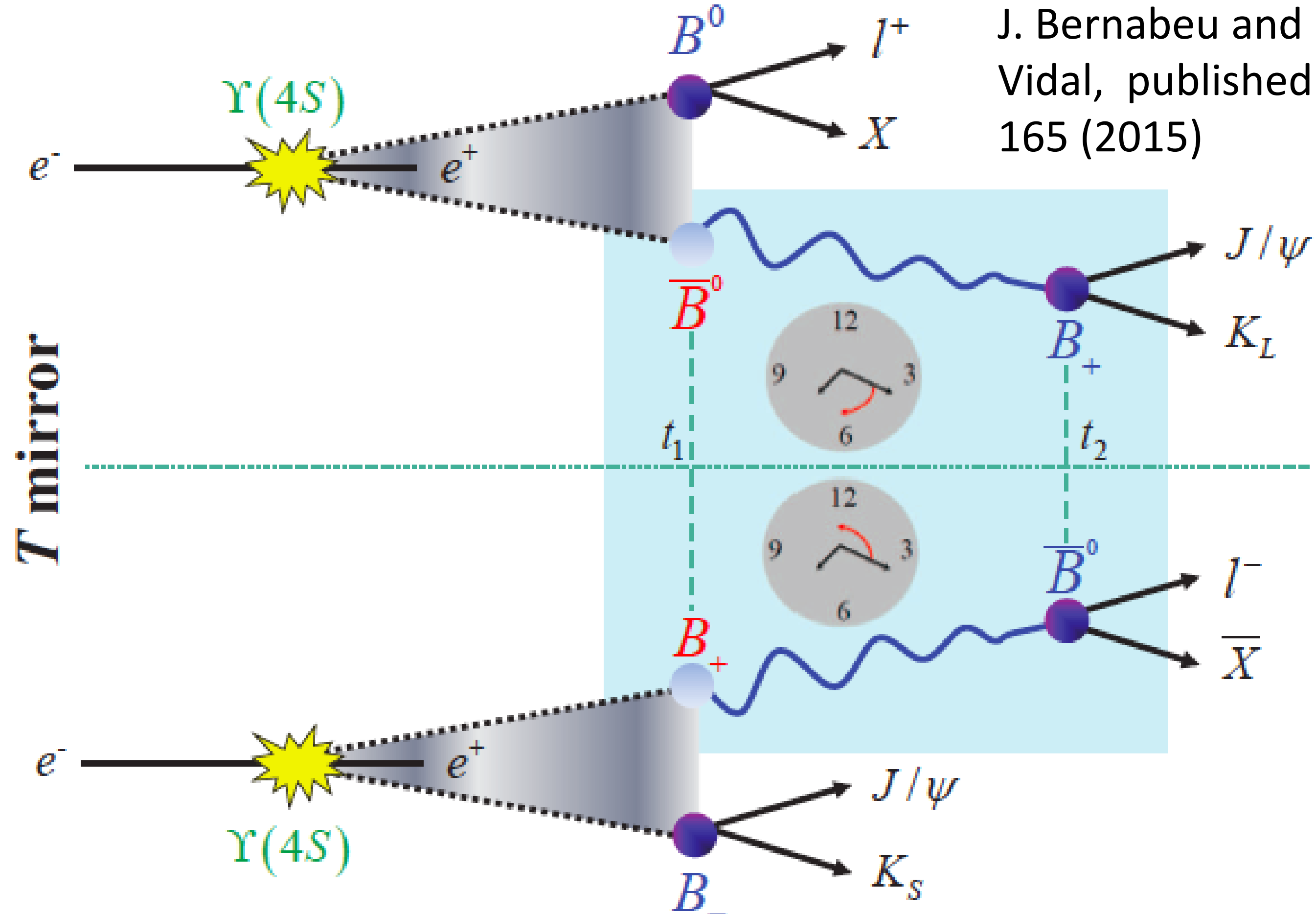
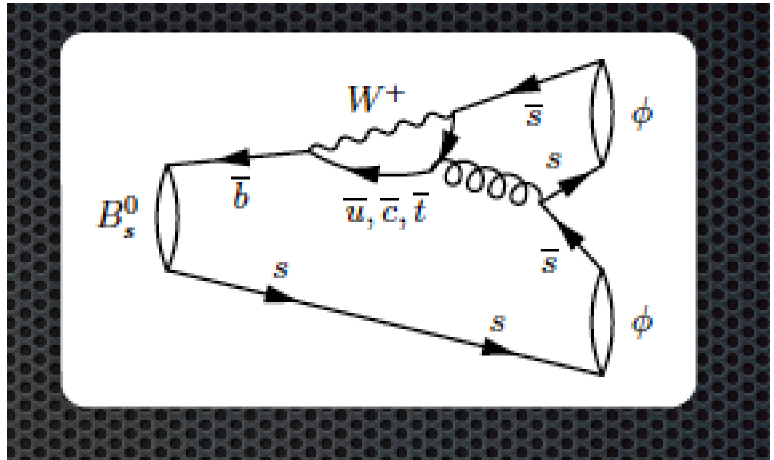
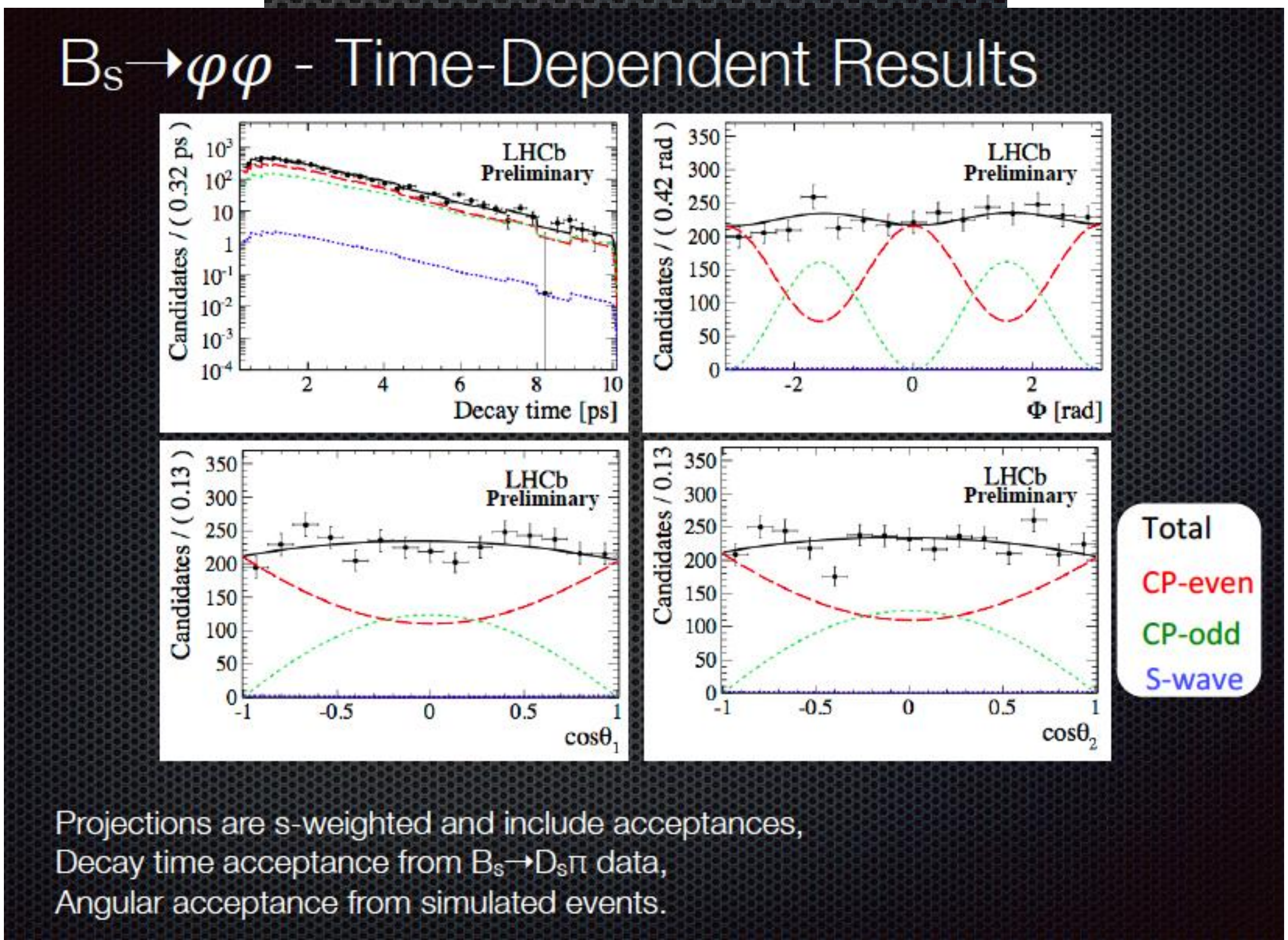


FIG. 11. Foundations of the time-reversal experiment. Electron-positron collisions at the asymmetric B factory produce $\Upsilon(4S)$ resonances, each of which decays through strong interaction in an entangled pair of B mesons. When one B meson decays at t_1, the identity of the other is "tagged" without 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 $J/\psi K_L^0$ 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].

But LHCb dominates on these B_S modes

M.Needham@ICHEP2014





Signal model

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

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

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

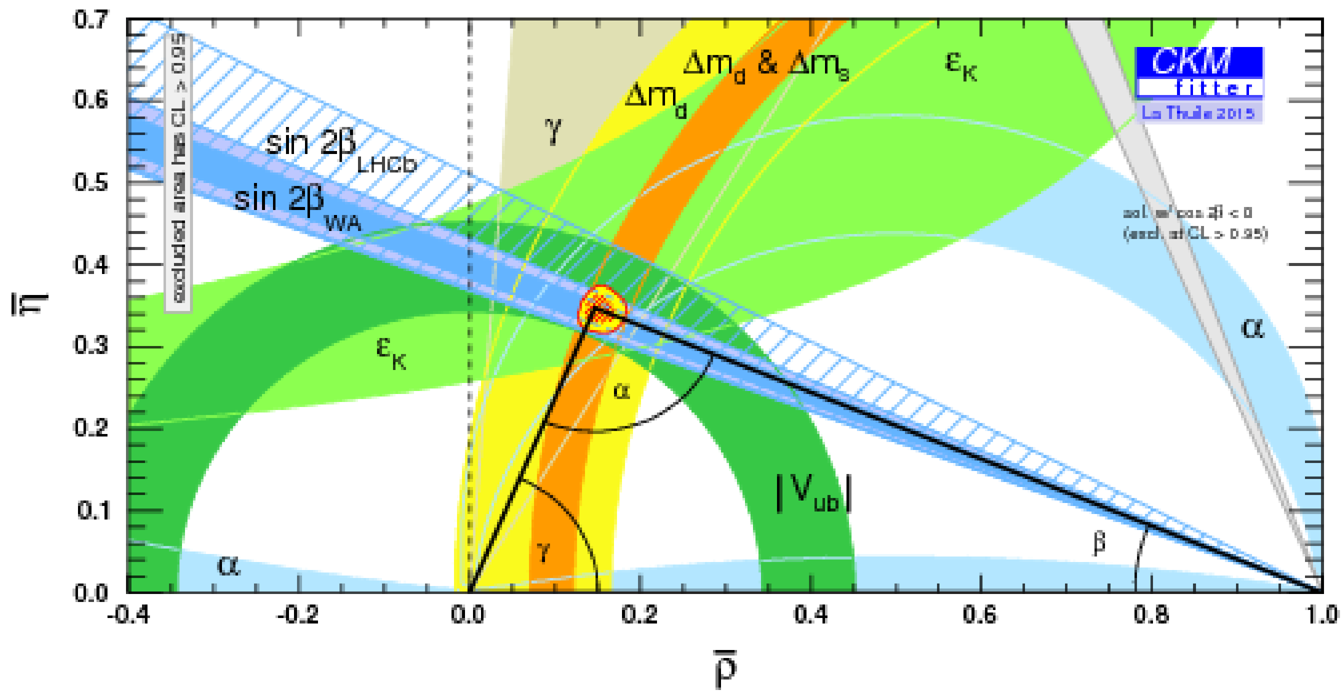
i	$g_i(\theta_T, \psi_T, \phi_T)$	N_i	a_i	b_i	c_i	d_i
1	$2\cos^2\psi_T(1-\sin^2\theta_T\cos^2\phi_T)$	$\|A_0(0)\|^2$	1	D	C	$-S$
2	$\sin^2\psi_T(1-\sin^2\theta_T\sin^2\phi_T)$	$\|A_\parallel(0)\|^2$	1	D	C	$-S$
3	$\sin^2\psi_T\sin^2\theta_T$	$\|A_\perp(0)\|^2$	1	$-D$	C	S
4	$-\sin^2\psi_T\sin 2\theta_T\sin\phi_T$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

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

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

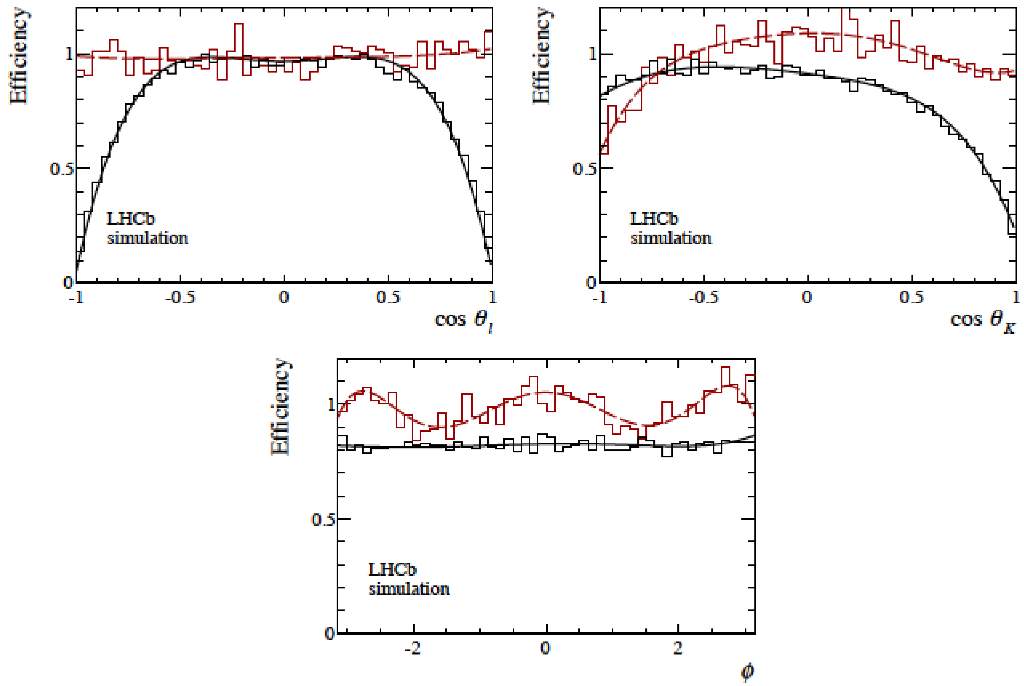
$\Delta\Gamma_s > 0$: we use previous LHCb results. α physics parameters ($\Delta\Gamma_s$, ϕ_s, $c\tau$, $|A_0|^2$, $|A_S|^2$, $|A_\perp^2|$, $\delta_\parallel$, $\delta_{S\perp}$, $\delta_\perp$)

CKMFitter with LHCb sin(2β) included



Efficiency at low q^2 for Belle II ?

LHCb detection efficiency plots.



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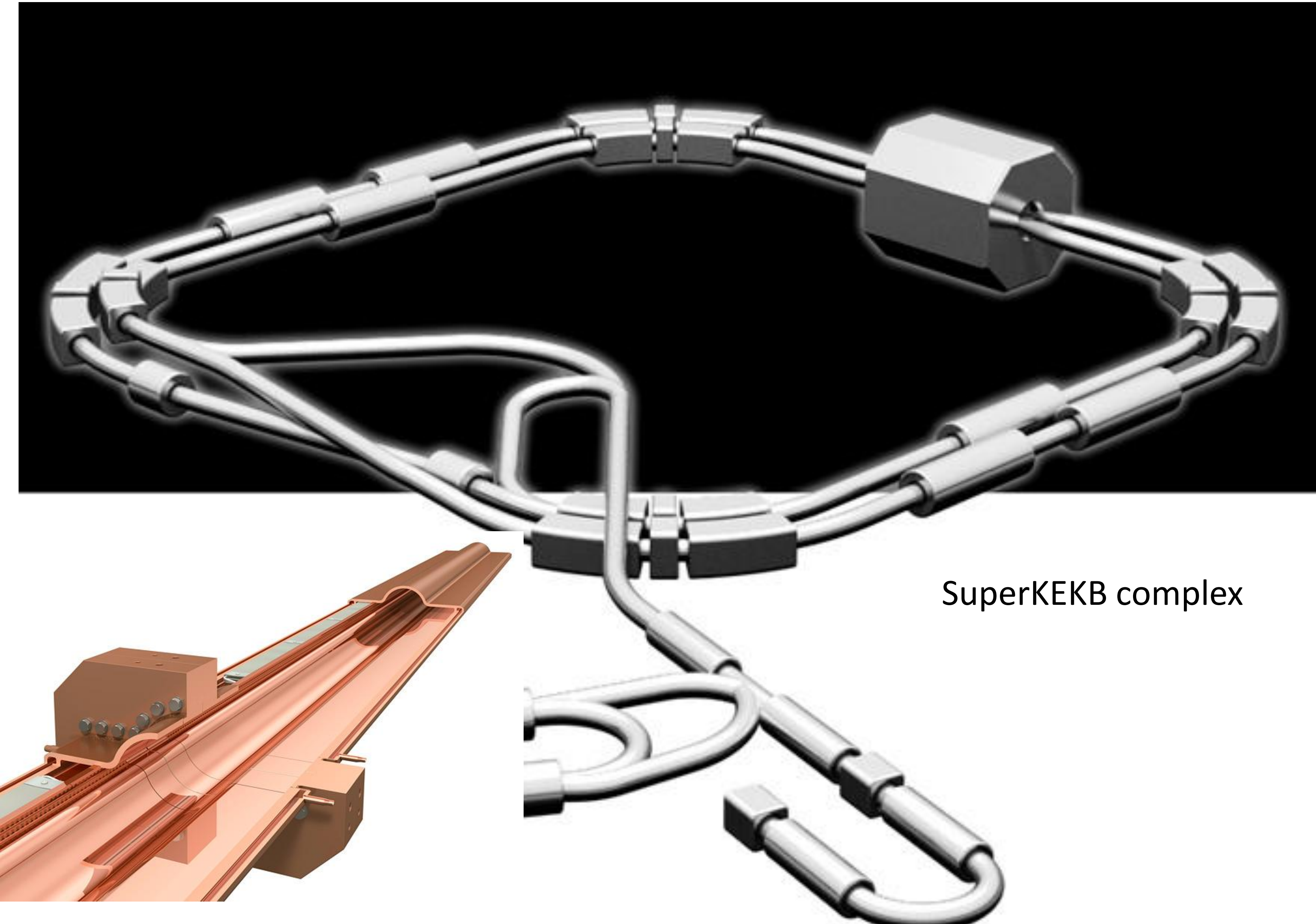
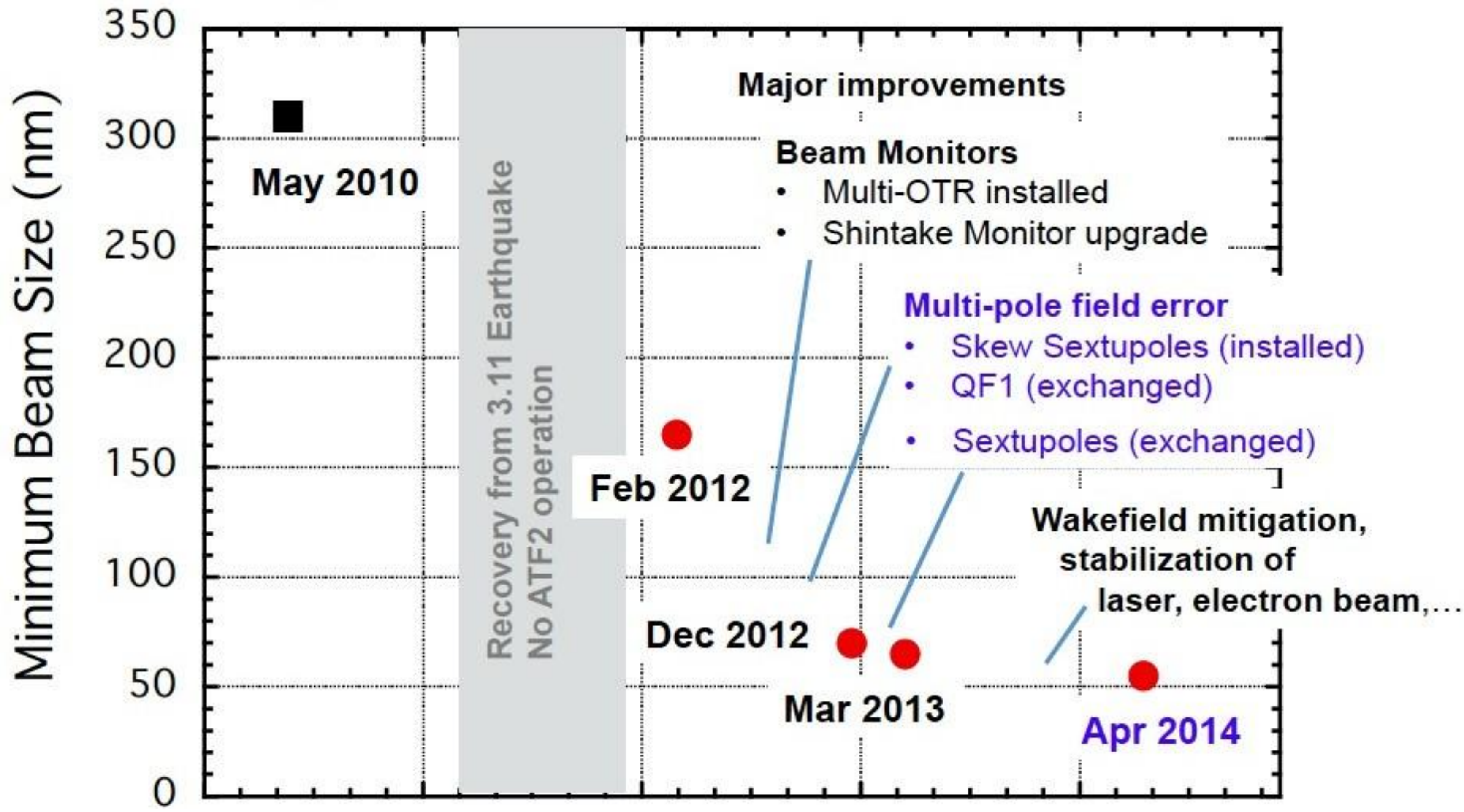


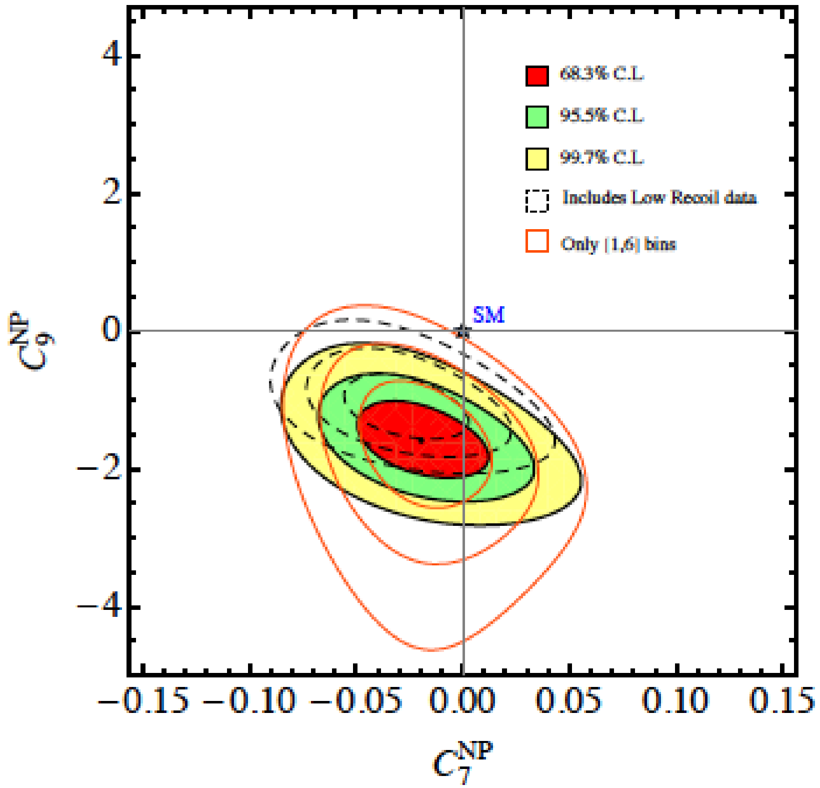
SuperKEKB complex

ATF2 nanobeams

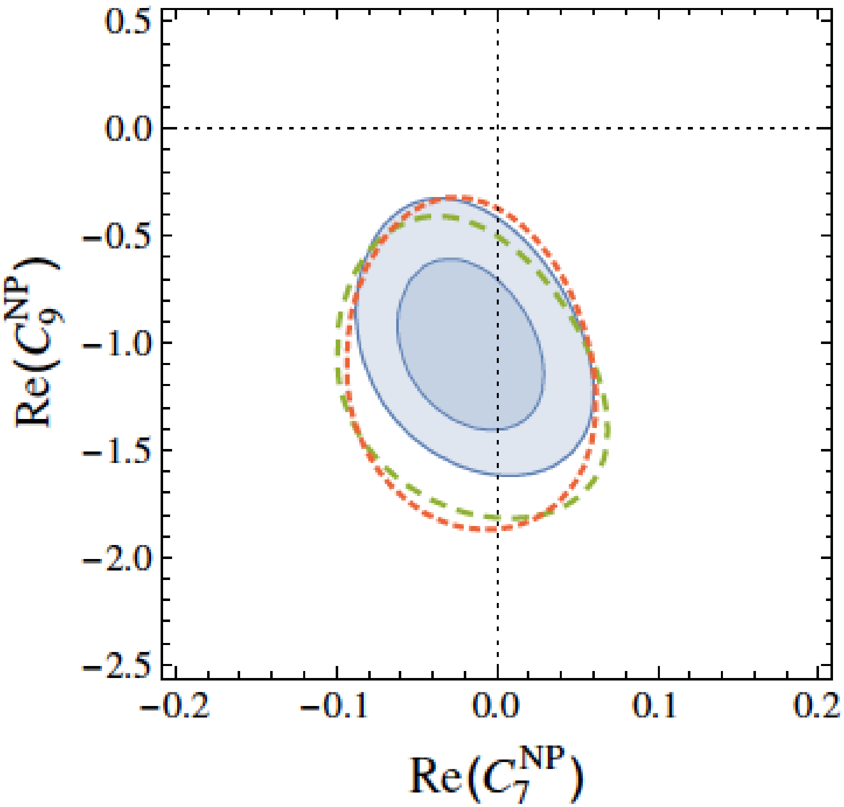


NP Fits

Descotes-Genon, Matias, JV 1307.5683



Altmannshofer, Straub 1503.06199



“Missing Energy” Decays

Tokyo Sky Tree

Tsutentaku tower, Osaka