Flavor Physics Experiments

SLAC Summer Institute 2016

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University of Maryland
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Outline

- Flavor physics and CP Violation beyond kaons:
  - Early B physics experiments: 1980,..
    - Preparing for CPV measurements
  - B factories and the Hadron colliders

The CKM project:
Verification of CPV mechanism in Standard Model & CKM Metrology

- Search for New Physics effects in flavor physics measurements
- Future Flavor Experiments
  - Physics reach of future experiments
- Summary

Theoretical implications & vision discussed in lectures by V. Crigiliano & J. Zupan

1980: V. Fitch and J. Cronin awarded Physics Nobel Prize for their discovery of CP violation in kaons

Kaon system was the only known source of observed CPV
Origin still unclear
The CKM picture yet to be tested

From Nobel Lectures, 1980

Rev. Mod. Phys V53, P367 & P373

Whether the *CP* violation that we observe today is a "fossil remain" of these conjectured events in the early universe is a question that cannot be answered at present. This is to say, does the *CP* violation we observe today provide supporting evidence for these speculations? We simply do not know enough about *CP* violation. Our experimental knowledge is limited to its observation in only one extraordinarily sensitive system that nature has provided us. We need to know the theoretical basis for *CP* violation, and we need to know how to reliably extrapolate the behavior of *CP* violation to the very high energies involved.

There are, however, on the horizon new systems which show some promise of giving additional information about *CP* violation. These are the new neutral mesons, D^0, B^0, B_s^0 (composed of $c\bar{u}$, $b\bar{d}$, and $b\bar{s}$ quarks), and their antiparticles $\bar{D}^0, \bar{B}^0, \bar{B}_s^0$. These mesons have the same general properties as K mesons. They are neutral particles that, with respect to strong interactions, are distinct from their own antiparticles, and yet are coupled to them by common weak decay modes. While we may not expect any stronger *CP* impurities on the eigenstates (the parameter analogous to ε), we might expect stronger effects in the decay amplitudes (the parameter analogous to ε'). We might expect this since the *CP* violation comes about through the weak interactions of the heavy quarks, c, b, t, which participate only virtually in K decay, but can be more influential in heavy neutral meson decay. At present, D mesons can be made rather copiously at the e^+e^- storage ring SPEAR at SLAC, (Lüth, 1979) and B mesons are beginning to be produced at the e^+e^- storage ring CESR at Cornell (Andrews *et al.*, 1980; Finocchiaro *et al.*, 1980).

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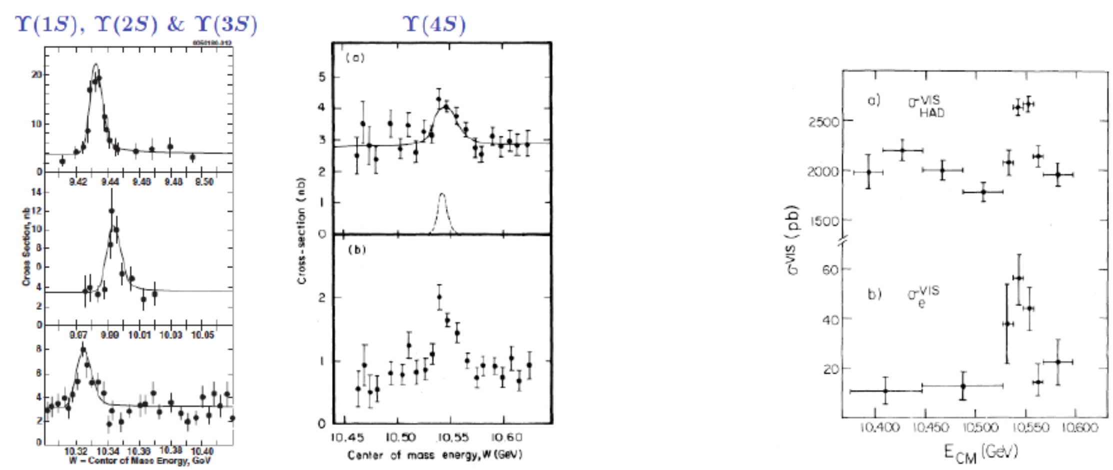
B mesons 1981

- Existence of the narrow Υ resonances & b quark established at FNAL, DORIS
- CLEO & CUSB had observed $\Upsilon(4S)$ – 22 MeV above the $B\bar{B}$ threshed. PRL 45, 219 (1981)
- CLEO observed enhanced e & μ rates at the 4S- PRL 46, 84(1981)
  - Evidence for weakly decaying B meson: $B(B \to Xe\nu) = 13 \pm 3 \pm 3\%$



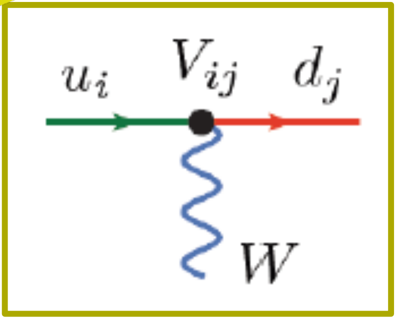
Current Status

CP Violation Beyond Kaons

- CP Violation in the B meson system:
  - CPV measured in many channels, and beyond Mixing
    - Indirect CPV in interference of decay and mixing
    - Direct CPV in the decay amplitude
  - Time-Reversal (T) violation observed in the B system
    - In balance with observed CPV in B, supporting CPT invariance.
  - K and B systems are sole sources of CPV & T-Violation
    - No evidence for CPV in the charm system
    - No evidence for EDM
    - Plans underway to measure CPV in the lepton sector

Current Status

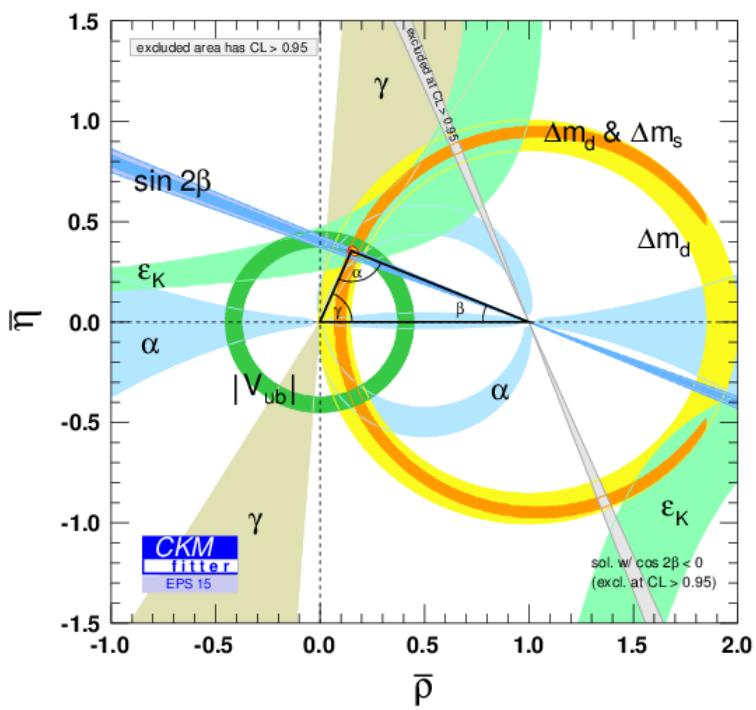
CP Violation vs Standard Model



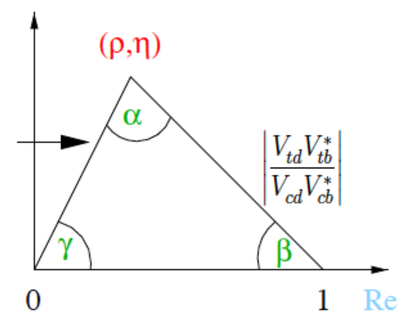
$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\,\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\,\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

All CPV effects correlated & governed by a single parameter- η

The CKM picture able to account for all observed CPV effects & flavor interactions



Unitarity of the CKM matrix



Flavor Physics experiments today
Physics reach/goal - in a nutshell

- Heavy Flavor remains the primary source of information on discreet symmetries- CP,T,CPT
  - Are there CPV sources beyond SM?

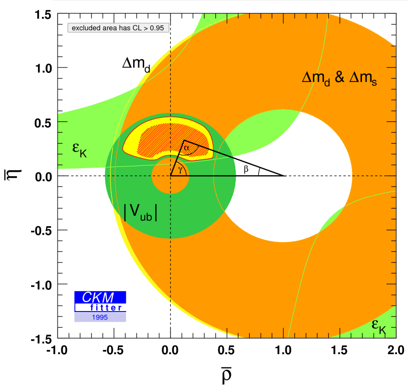
Deep connection to the problem of baryon asymmetry in the universe

- Powerful probe of New Physics effects:
  - Rare flavor processes have a track record of spotting the presence of new particles and interactions before their direct observations. Several strategies at work:
    - CKM-metrology (α,β,γ, β_s, $|V_{ub}|$, $|V_{cb}|$, $|V_{td}|$,.....)
    - FCNC processes ($b\to s\gamma$, $b\to sl^+l^-$, $b\to s\nu\bar{\nu}$, $B\to l^+l^-$,.....)
    - tree level processes; e.g. lepton Flavor Universality tests,..
- A laboratory for testing QCD predictions

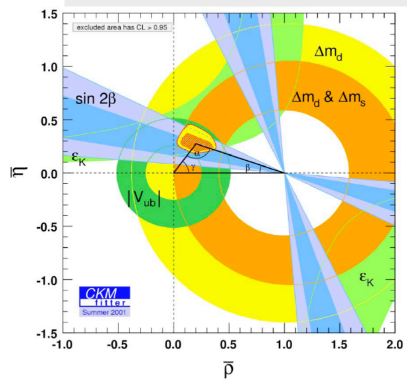
A brief historical detour
Starting in 1980's

Experimental Evolution of the CKM picture & the search for New Physics in flavor decays

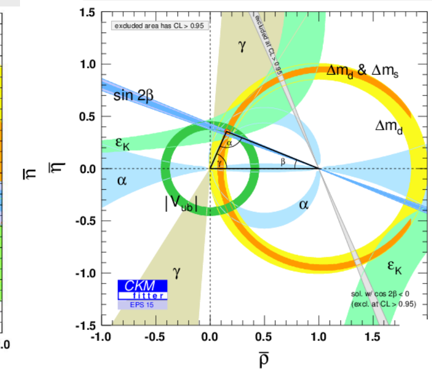
Last century



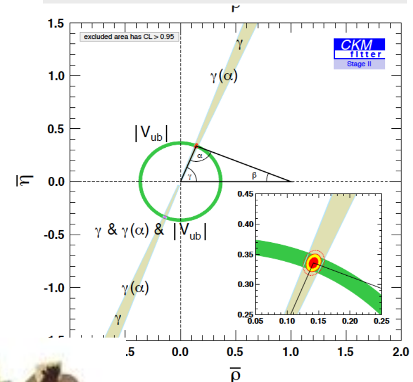
2001



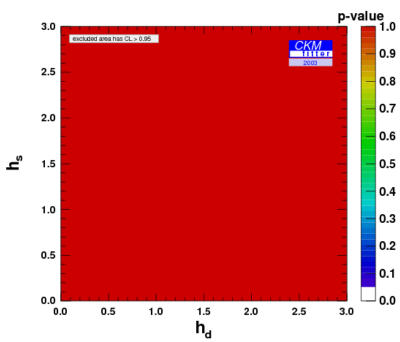
Today

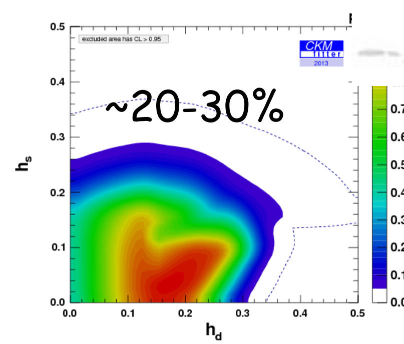


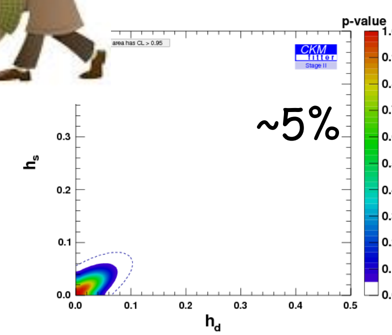
2025+



Constraint on NP/SM amplitude
See (arXiv: 1309.2293)







The required elements of a program for CPV Measurements

NOTES ON THE OBSERVABILITY OF *CP* VIOLATIONS IN B DECAYS

I.I. BIGI
Institut für Theor. Physik der RWTH Aachen, D-5100 Aachen, FR Germany

A.I. SANDA[1]
Rockefeller University, New York 10021, USA

Received 16 June 1981

We describe a general method of exposing *CP* violations in on-shell transitions of B mesons. Such *CP* asymmetries can reach values of the order of up to 10% within the Kobayashi–Maskawa model for plausible values of the model parameters. Our discussion focuses on those (mainly non-leptonic) decay modes which carry the promise of exhibiting clean and relatively large *CP* asymmetries at the expense of a reduction in counting rates. Accordingly we address the complexities encountered when performing *CP* tests with a high statistics B meson factory like the Z^0 (and a toponium) resonance.

And Carter & Sanda (1980)

Indirect CPV due to the interference of decay and mixing amplitudes in modes common to B and B(bar)

$$B_d^0 \searrow \; \psi K_S + X,\ D\bar{D}[F^+F^-]K_S + X\,, \; \nearrow \bar{B}_d^0$$

Rare processes

- Long B lifetime [i.e. suppressed $|V_{cb}|$] (MARK-II & MAC at PEP 1983).
- Large $B_d^0 \Leftrightarrow \bar{B}_d^0$ mixing [UA1,ARGUS (1987), CLEO (1988)]

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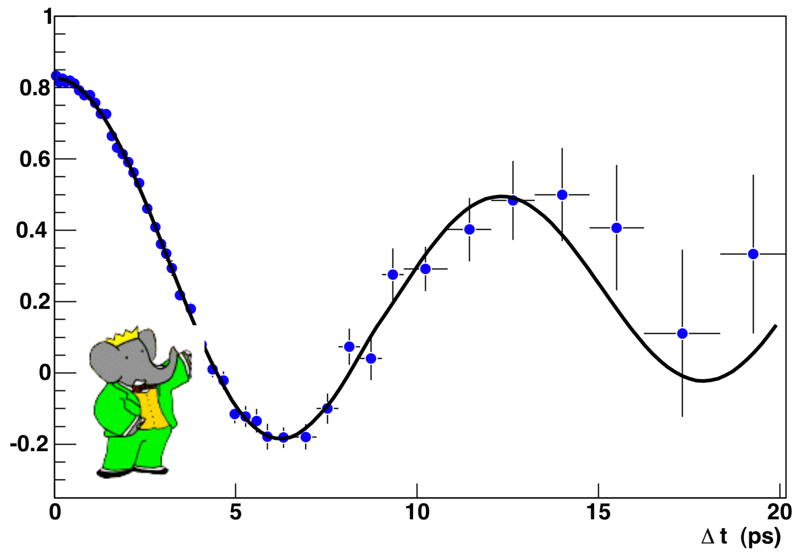
- Two decades later CDF and D0 at Tevatron established $B_s^0 \Leftrightarrow \bar{B}_s^0$

$B^0 \Leftrightarrow \bar{B}^0$ oscillation Today

Time evolution of a state prepared as B^0

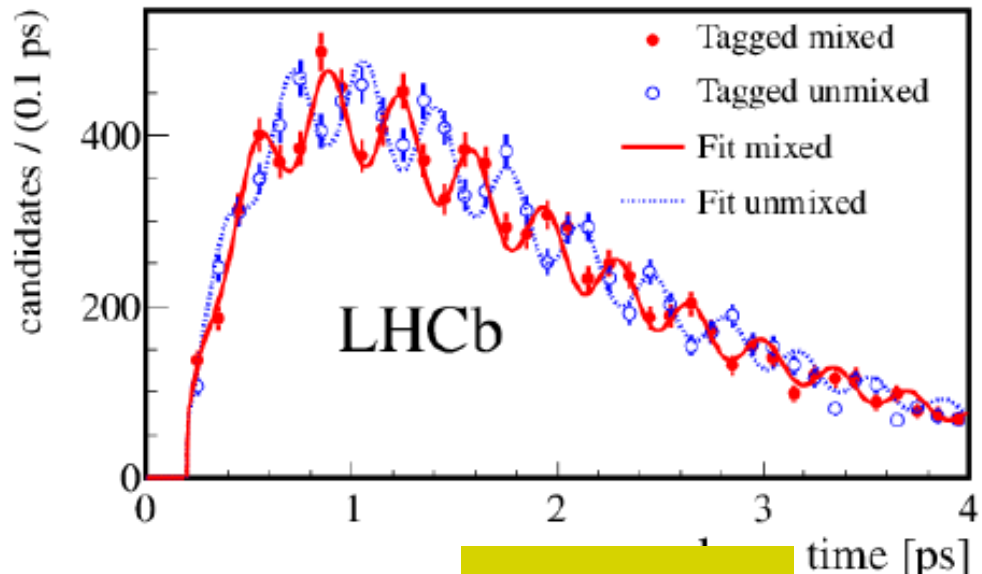
$B_d^0(\bar{b}d) \Leftrightarrow \bar{B}_d^0(b\bar{d})$



~81 GHz

$\propto m_t^2 \,|V_{tb}^* V_{td}|^2$

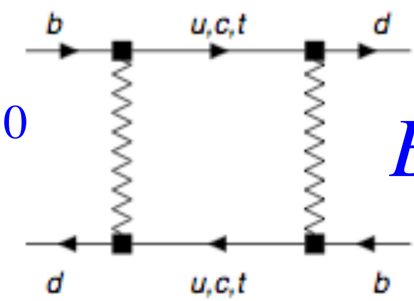
$B_s^0(\bar{b}s) \Leftrightarrow \bar{B}_s^0(b\bar{s})$



~2.82 THz

$\propto m_t^2 \,|V_{tb}^* V_{ts}|^2$

$\bar{B}^0$



B^0

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- A B factory: Large number of B mesons; Preferably boosted for time-dependent measurements.

Towards a B Factory
Flavor Physics Landscape for 1990's

- 1993:
  - End of hope for SSC
  - Approval of high luminosity asymmetric energy electron-positron B factories at SLAC & at KEK
  - CLEO continuing to run with symmetric machine

- 1999: Both B Factories begin operation
  - CPV in B decays observed in 2001

- CDF and D0, having found the top, with their innovative Silicon vertex trackers produce first hint of CPV in B, and later B^0_s oscillations

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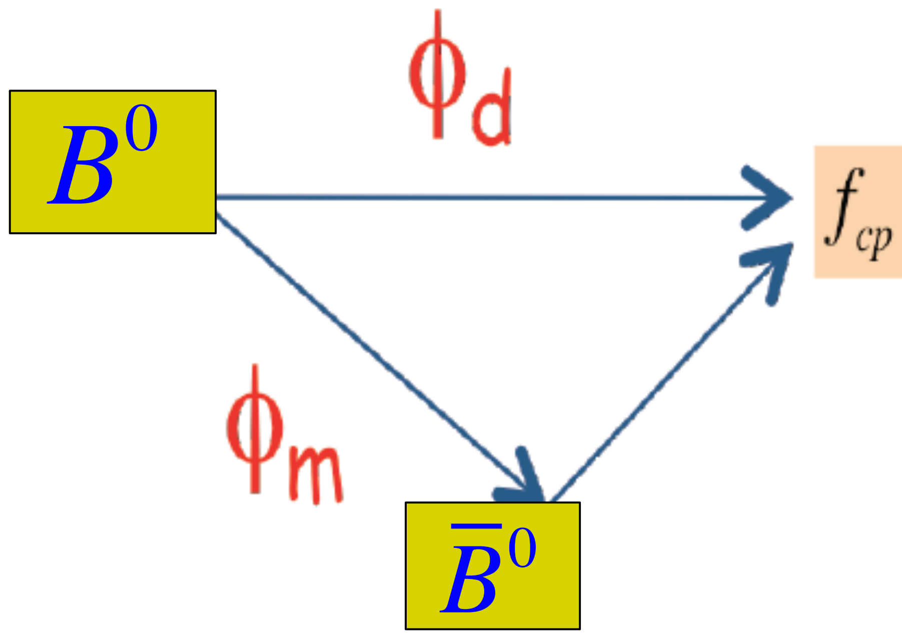
By 1990's all elements in place for building the "CP" interferometer

"CP" interferometer to access the phase of CKM

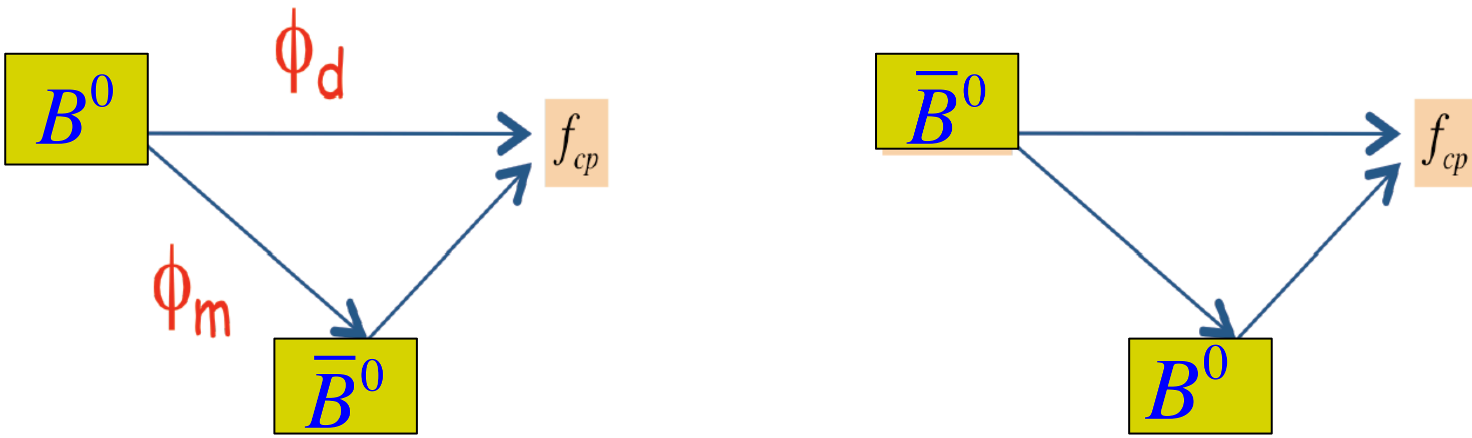
Bigi, Sanda & Carter (81)



With careful set up of both initial and final states

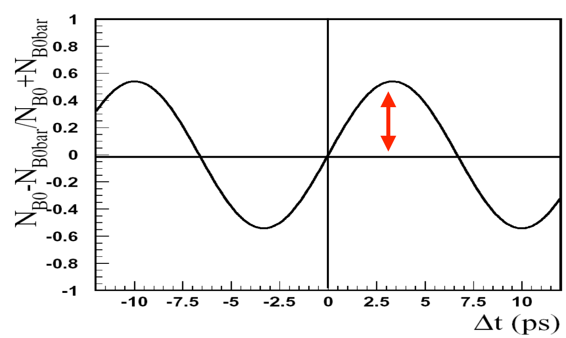
$$|\langle f_{cp} | H | B^0 \rangle|^2 \propto |A_{f_{cp}}|^2 e^{-\Gamma t}[1 - \sin 2(\phi_m - \varphi_d) \sin \Delta m t]$$

"CP" interferometer to access the phase of CKM

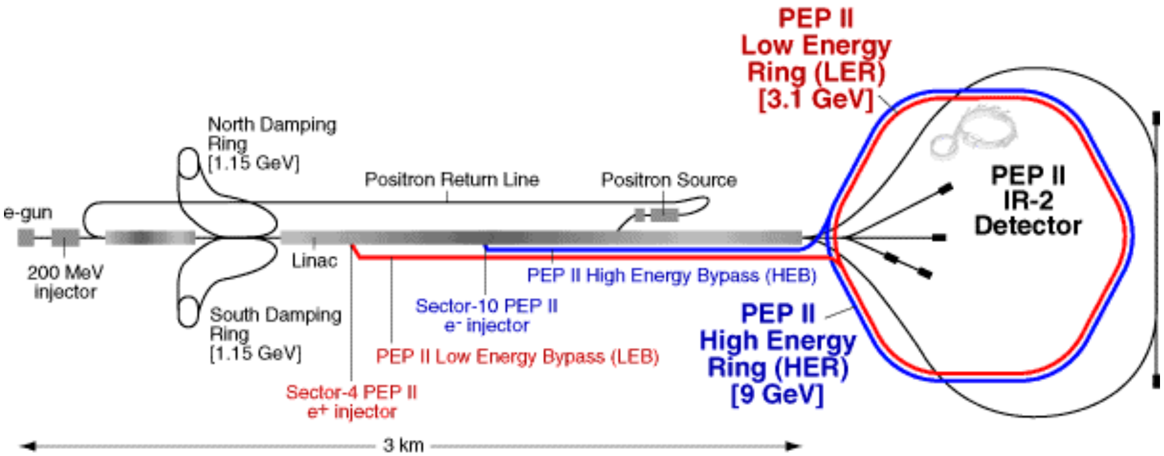


$$A_{cp}(t) = \frac{\Gamma(B^0(t) \to f_{cp}) - \Gamma(\bar{B}^0(t) \to f_{cp})}{\Gamma(B^0(t) \to f_{cp}) + \Gamma(\bar{B}^0(t) \to f_{cp})} = \sin 2(\varphi_m - \varphi_D) \sin \Delta m t$$

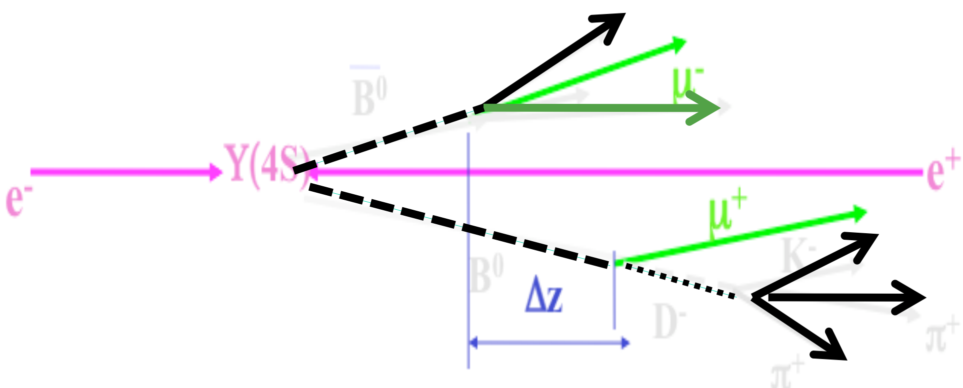
With careful set up of both initial and final states



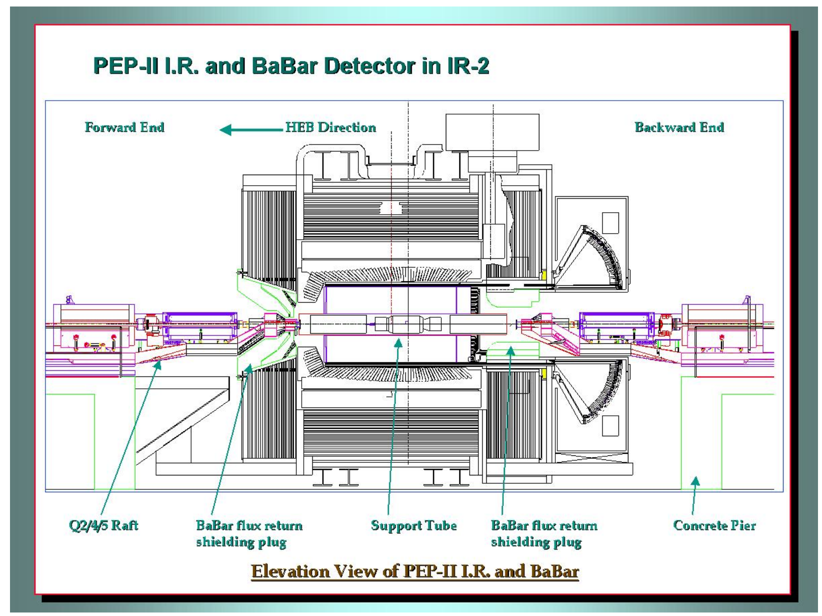
B^0_d Mesons at the e+e- B Factories (SLAC, KEK)



$\Upsilon(4S) \rightarrow B^0 \bar{B}^0$
in $J^{cp} = 1^{-}$
The B meson pair in an entangled state
Key to CP & T-Violation measurements



~250 μm



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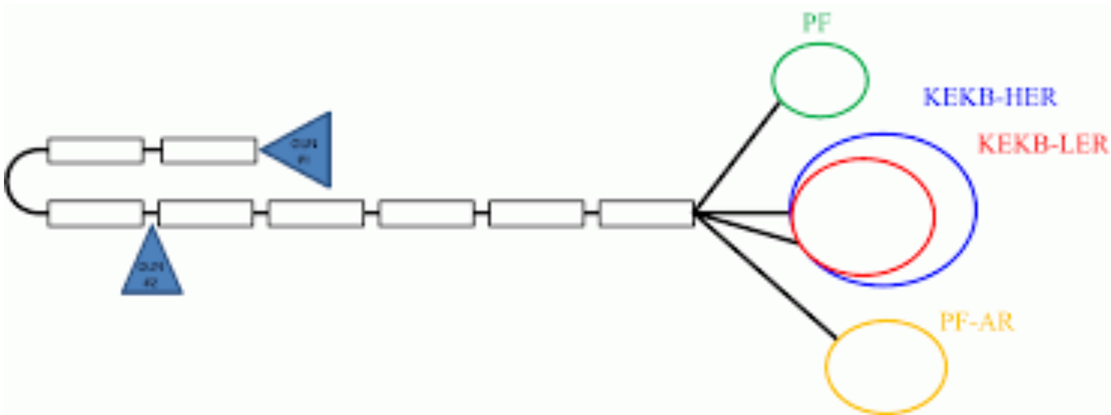

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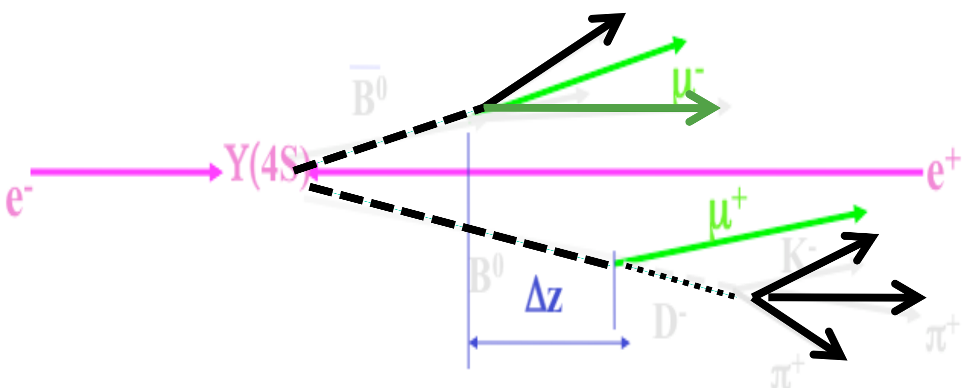

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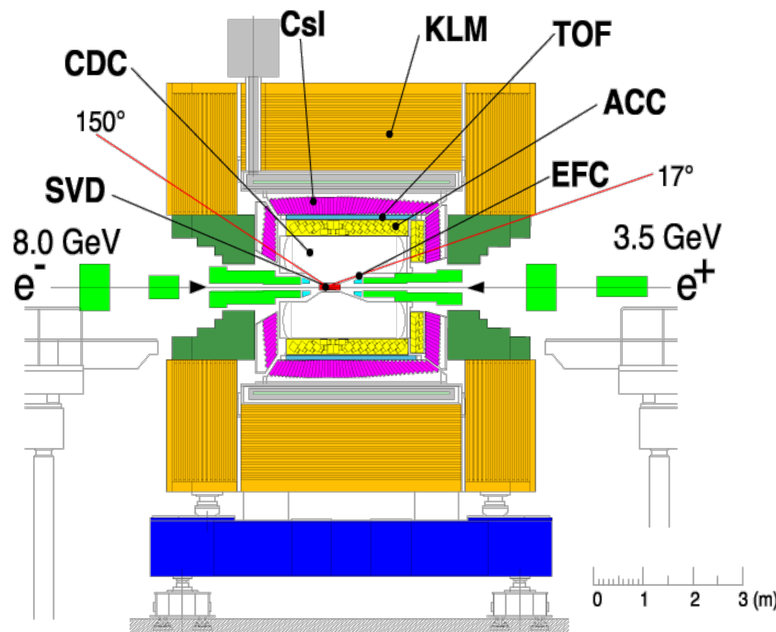
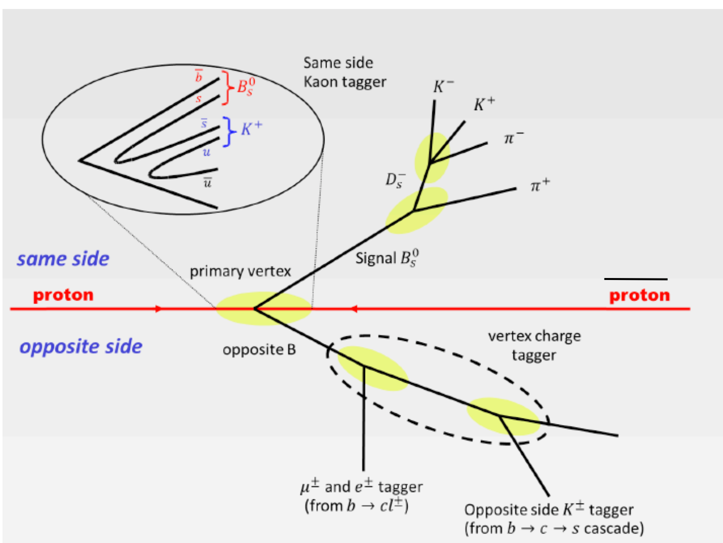
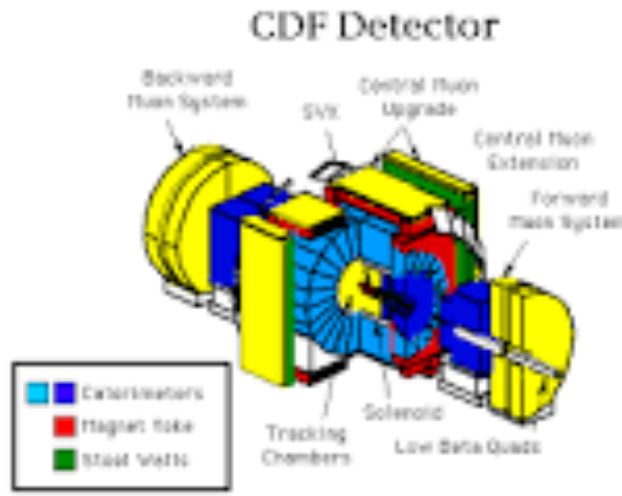
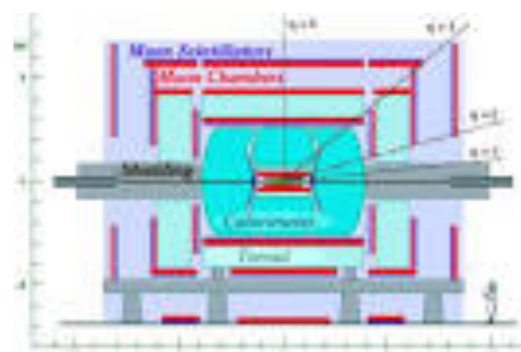


b-hadrons at Hadron Colliders (Tevatron, LHC)







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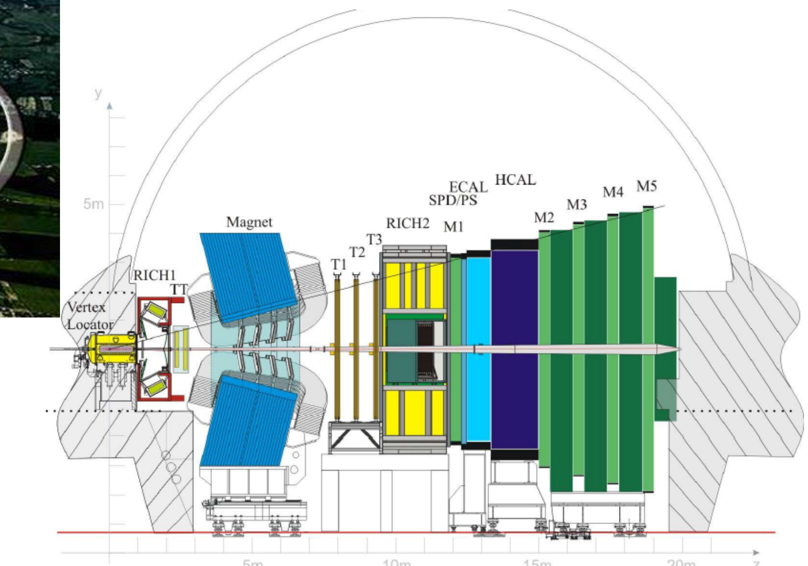
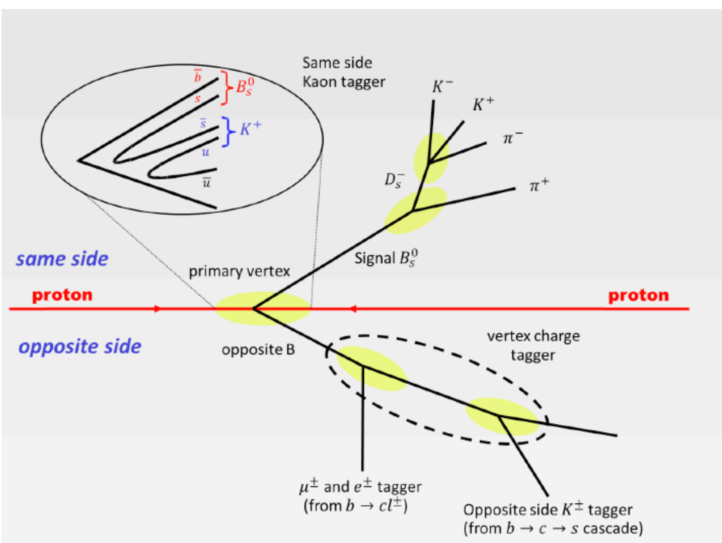
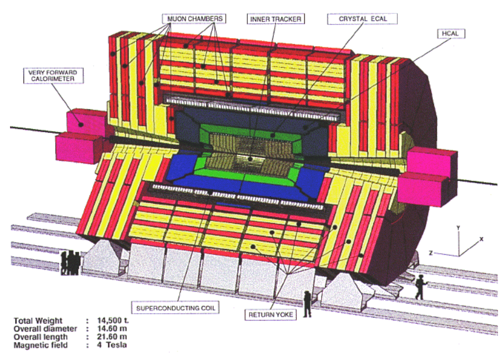
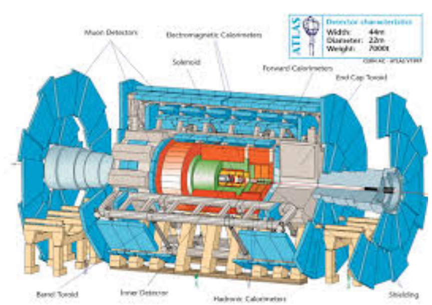
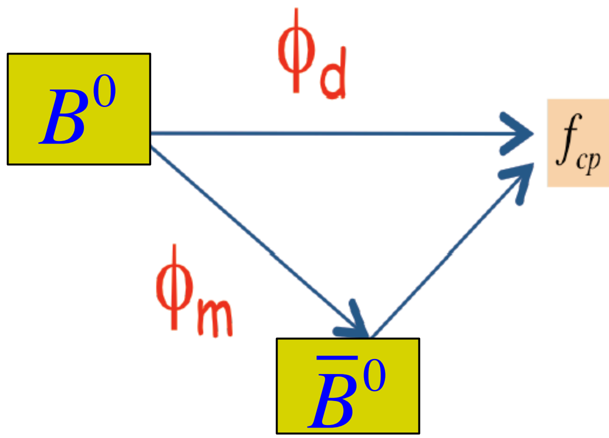


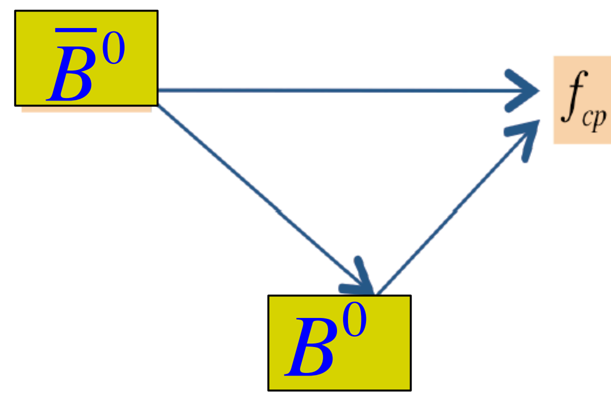


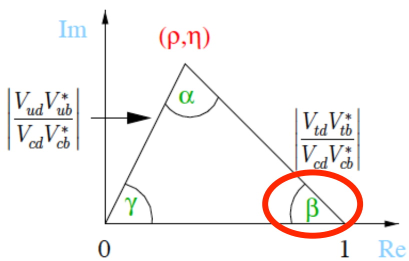




"CP" interferometer to access the phase of CKM





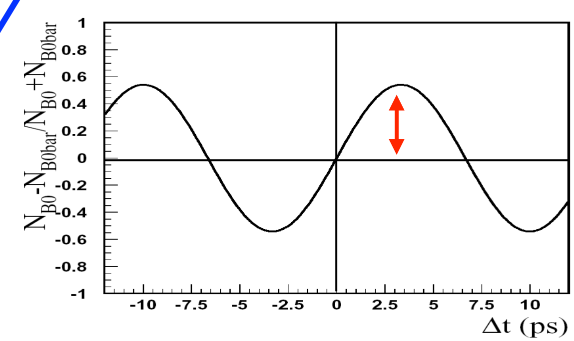


$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\,\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\,\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

With careful set up of both initial and final states

$B_d \rightarrow J/\psi\, K^0_s$ :: $\sim \arg(V_{td}^*) \sim 25^o$

$B_s \rightarrow J/\psi\, \phi$ :: $\sim \arg(V_{ts}^*) \sim 1^o$

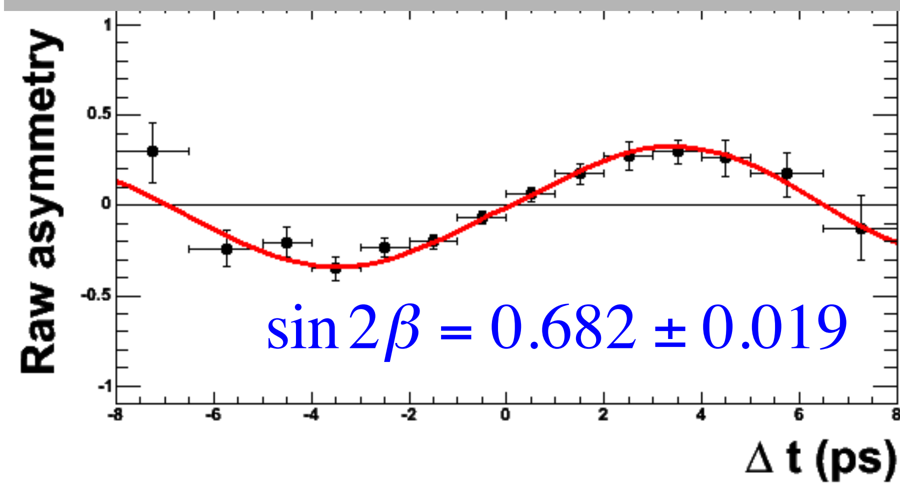


$$A_{CP}(t) = \sin\Phi \sin(\Delta m t)$$

$B_d \to J/\psi\ K^0_s$

$$\Phi_d = 2\beta \sim 2\arg(V^*_{td})$$

$\beta=(21.5\ ^{+0.8}_{-0.7})^O$



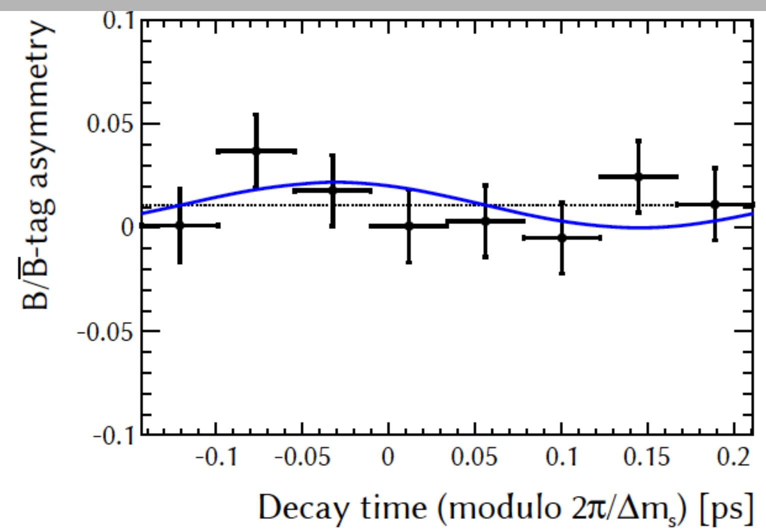
$\sin 2\beta = 0.682 \pm 0.019$

$\beta \approx 25^O (SM)$

$B_s \to J/\psi\ \phi$

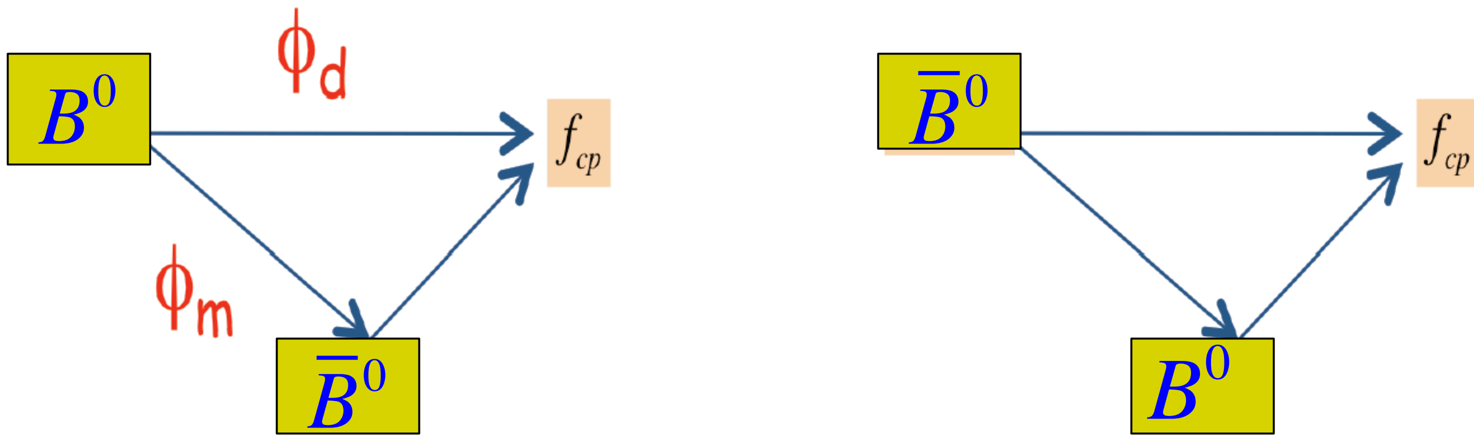
$$\Phi_s = 2\beta_s \sim 2\arg(V^*_{ts})$$

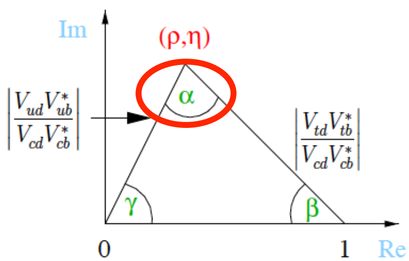
$\beta_s=(-0.43\pm1)^O$



$\beta_s \approx 1^O (SM)$

"CP" interferometer to access the phase of CKM





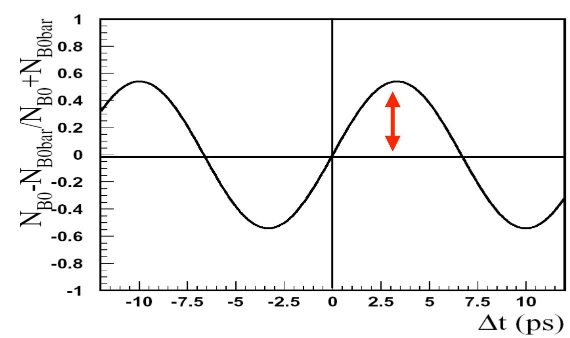
$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\,\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\,\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

With careful set up of both initial and final states

$B_d \rightarrow \pi^+\pi^-$ ::

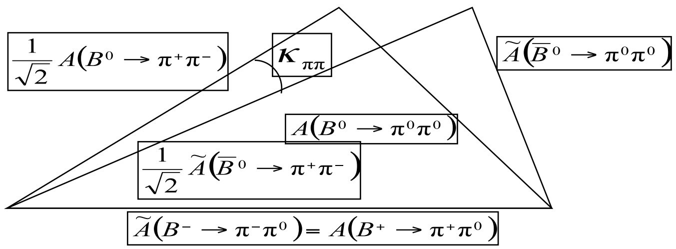
$B_d \rightarrow \rho^+\rho^-$

$\sim \arg(V_{ub}V_{td})$



Measurement of the angle α

Br& CPV in B→ππ

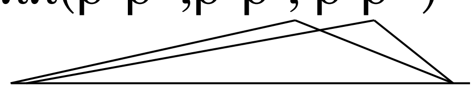


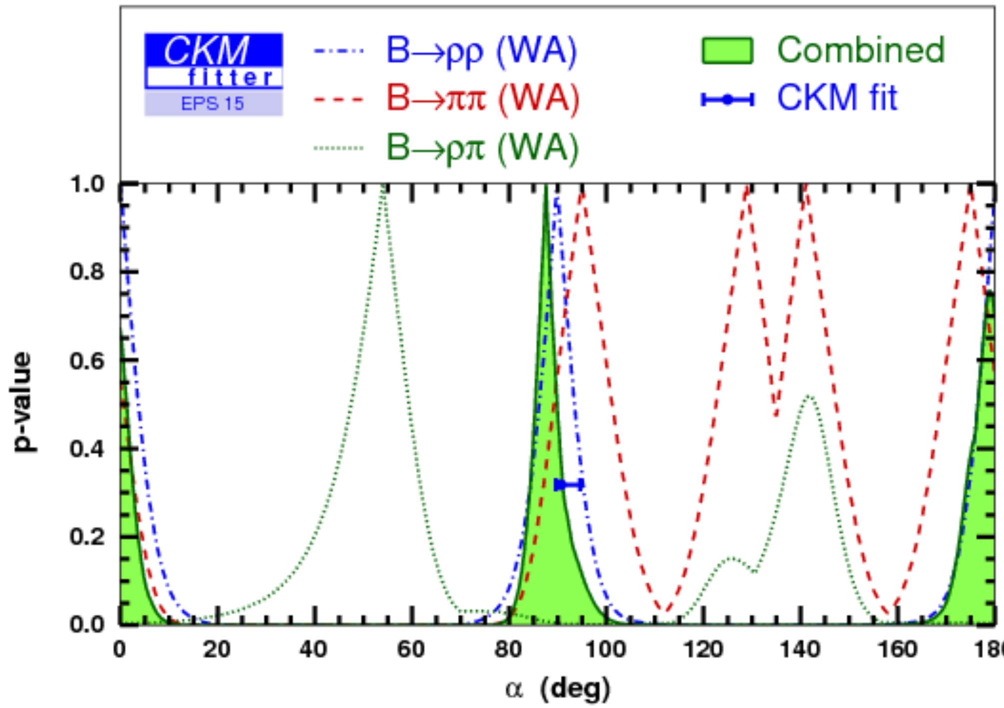
The full Time-dependent Dalitz Analysis of

B→πππ($\rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$, $\pi^+\pi^-\pi^0$)

The entire B→ρρ components for isospin analysis & Time-dependent CPV

B→πππ($\rho^+\rho^-$, $\rho^+\rho^0$, $\rho^0\rho^0$)



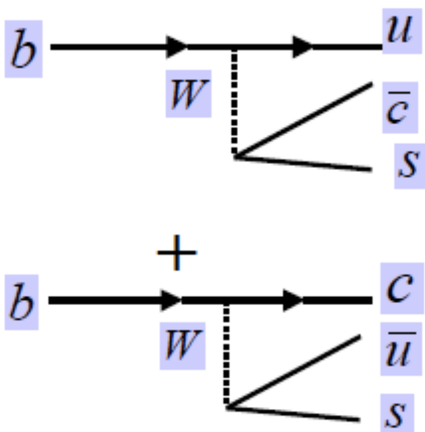


$$a = (87.6^{+3.5}_{-3.3})^o$$

Measurement of $\gamma = \arg\left(\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}\right)$

Yet another interferometer involving only tree level processes

b->c & b->u



$\propto A\lambda^{3}(\rho + i\eta)$

$B^{-} -> \bar{D}^{0}K^{-}$

$\propto A\lambda^{3}$

$B^{-} -> D^{0}K^{-}$

f - common to D^{0} & $\bar{D}^{0}$

$\gamma+\delta_u$

δ_c

Rare processes with effective $Br \sim 10^{-7}$

$$A[B^{-} \to (D \to f)K^{-}] = A_c A_f e^{i(\delta_c + \delta_f)} + A_u A_{\bar{f}} e^{i(\delta_u + \delta_{\bar{f}} - \gamma)}$$

Rates and CP asymmetries depend on γ & $r_B = \left|\frac{A(B^{-} \to \bar{D}^{0}K^{-})}{A(B^{-} \to D^{0}K^{-})}\right|$

& strong phases $\delta_B = \delta_u - \delta_c$ & $\delta_D = \delta_f - \delta_{\bar{f}}$

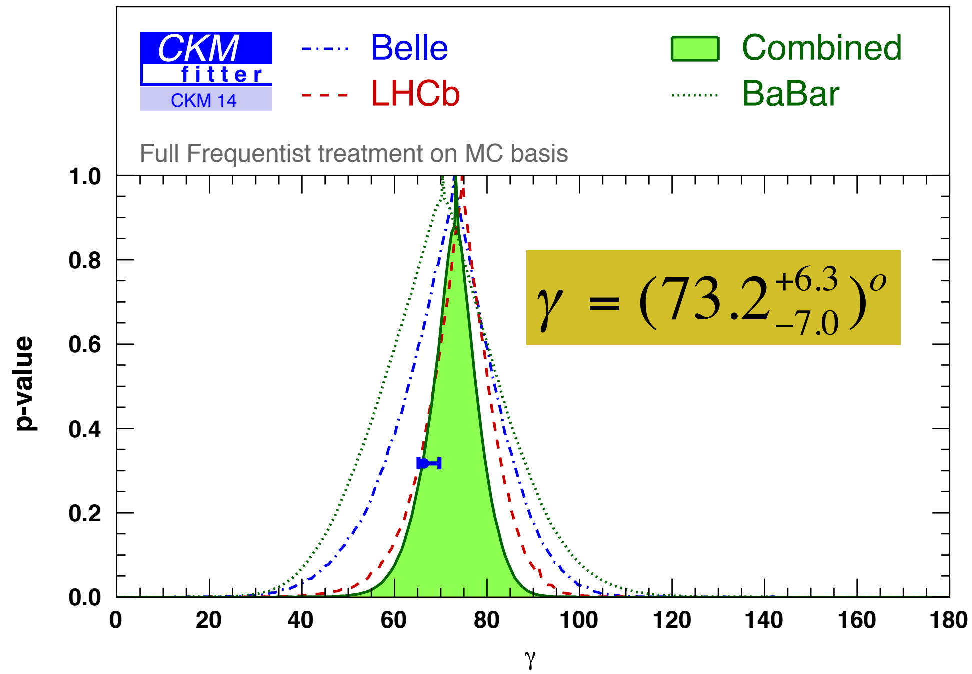
Measurement of γ

- D->f_{cp} (K^+K^-, $\pi^+\pi^-$, $K^0{}_s\pi^0$...) (GLW- Gronau, London, Wyler)

- D→Cabibbo Favord (b->u) & Doubly Cabibbo suppressed Decay (b->c) (ADS – Atwood, Dunietz, Soni)

- D->3-body ($K_s\pi^+\pi^-$, $K_sK^+K^-$) – Dalitz analysis –combining both features – (GGSZ- Giri, Grossman, Soffer, Zupan)

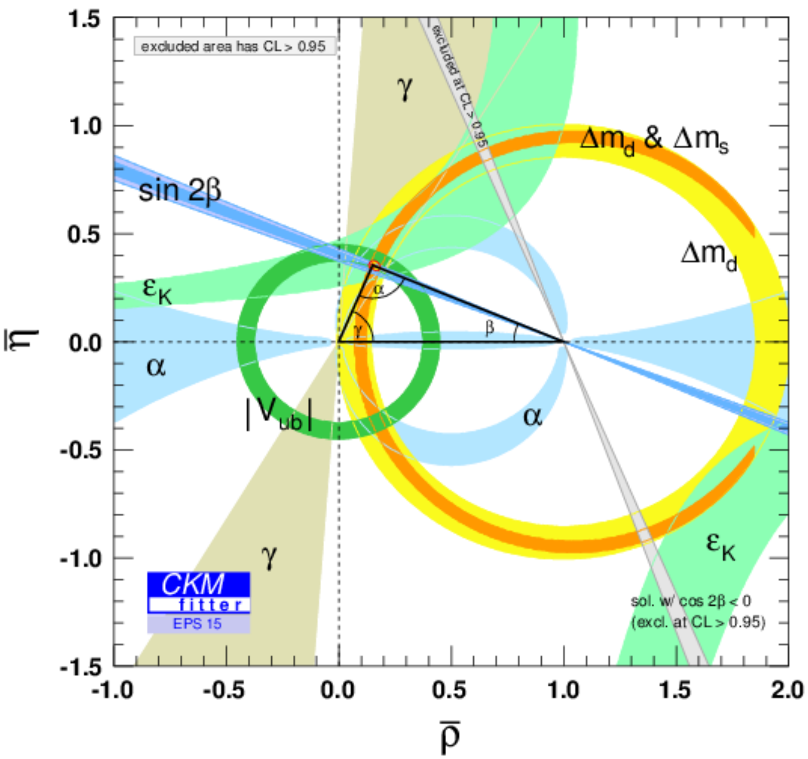
- Extract γ, r_B, δ_B from data;
  - Needs external input for δ_d (ADS & GGSZ) - a major sources of uncertainty



Status of CKM (2015)

All is well with the CKM picture at O(10%) level:

$$\alpha + \beta + \gamma = (182.6 \pm 7.2)^o$$



	Direct	CKM fit
α	$= \left(87.6^{+3.5}_{-3.3}\right)^o$	$\left(91.5^{+4.2}_{-1.3}\right)^o$
β	$= \left(21.85^{+0.68}_{-0.67}\right)^o$	$\left(25.22^{+0.78}_{-1.79}\right)^o$
γ	$= \left(73.2^{+6.3}_{-7.0}\right)^o$	$\left(66.9^{+1.0}_{-3.7}\right)^o$
$-2\beta_s$	$= -0.033 \pm 0.033$	$-0.0365^{+0.0012}_{-0.0013}$

Sin2β tension (driven by B→τν)

$$\sin 2\beta = 0.691 \pm 0.019 (meas) \qquad 0.748^{+0.030}_{-0.032} (fit)$$

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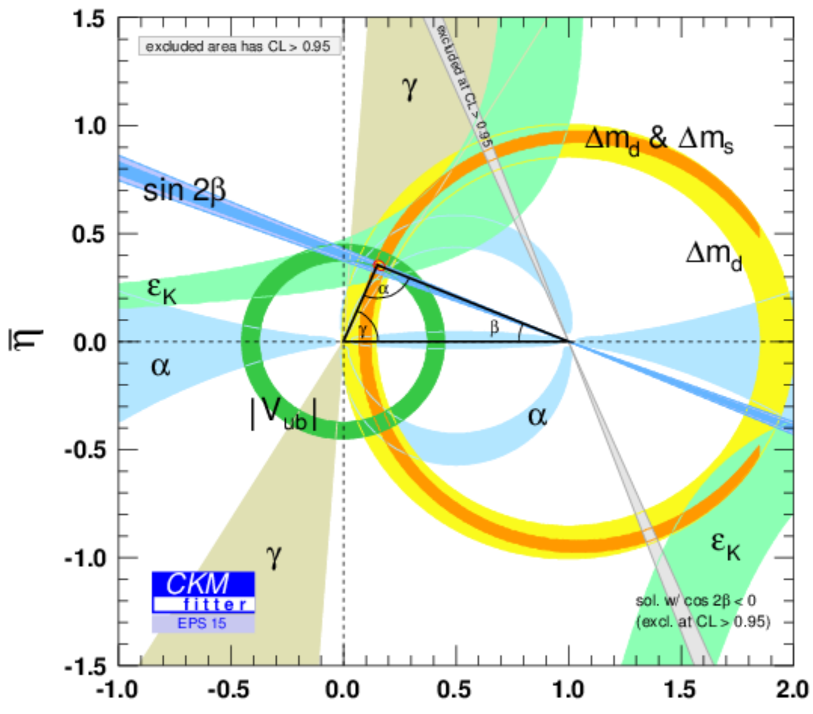

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Is there room for New Physics?
CPV sources beyond SM?

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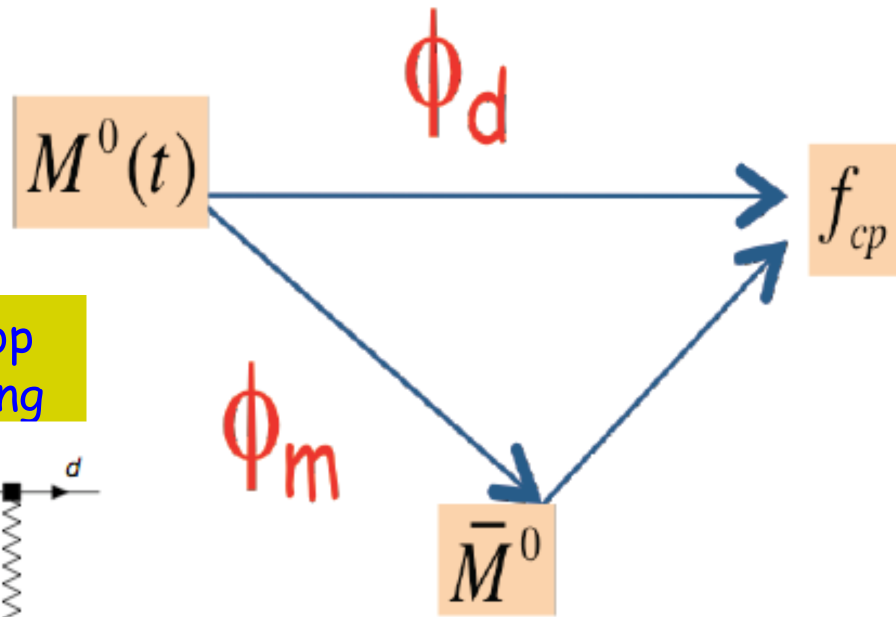
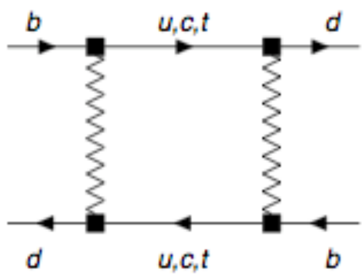
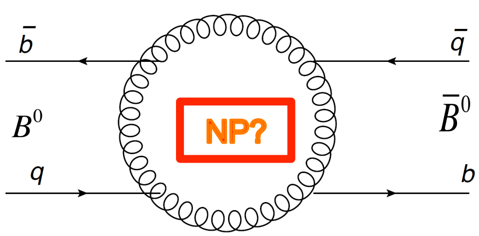


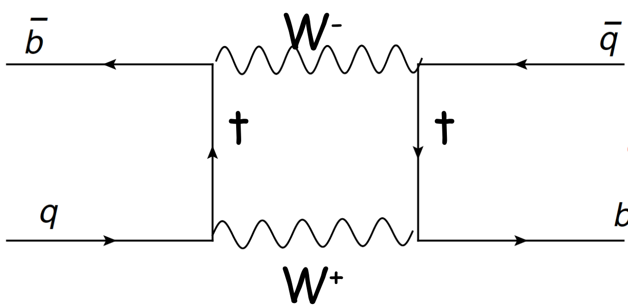
Through new loop diagrams in mixing



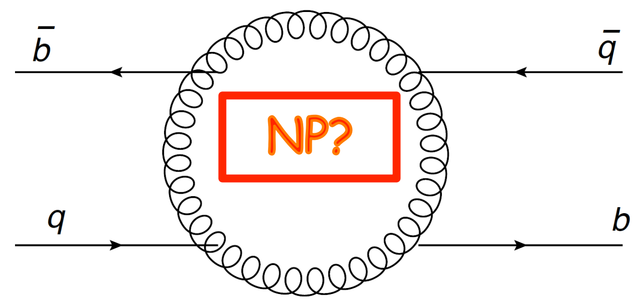


How much NP is allowed?

- Example: The Neutral Meson Oscillation



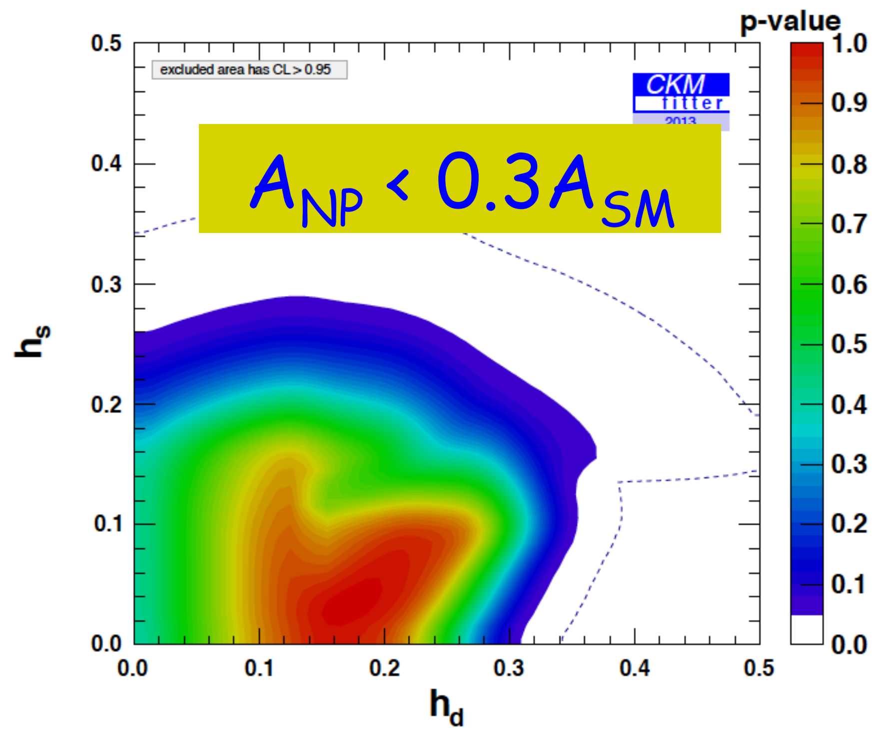
$$\propto \frac{|V_{tq}|^2 m_t^2}{M_W^4}$$



$$\propto \frac{|C|^2}{\Lambda_{NP}^2}$$

Charles et al (arXiv: 1309.2293)
Fit the data allowing NP amplitude

$$M_{12} = M_{12}^{\rm SM} \times \left(1 + h\, e^{2i\sigma}\right)$$



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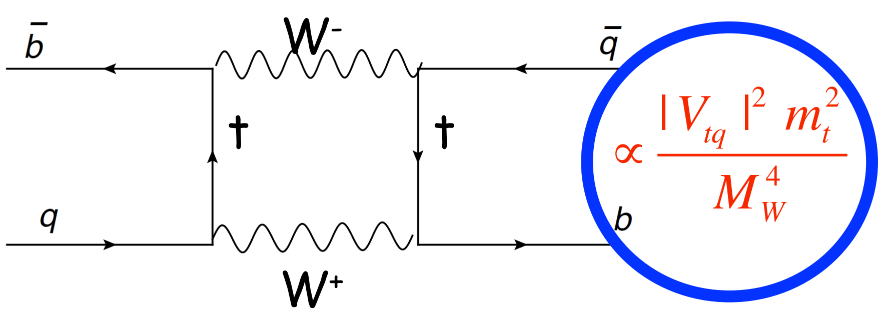
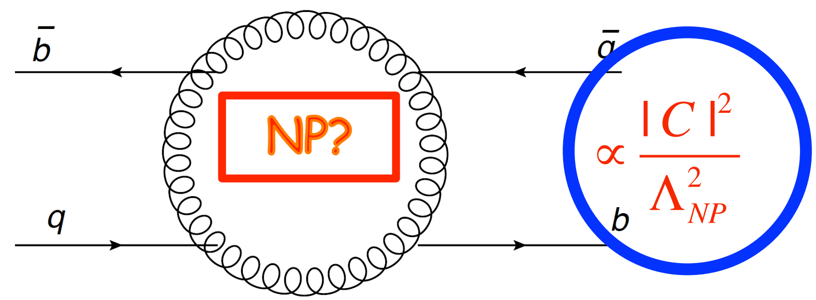


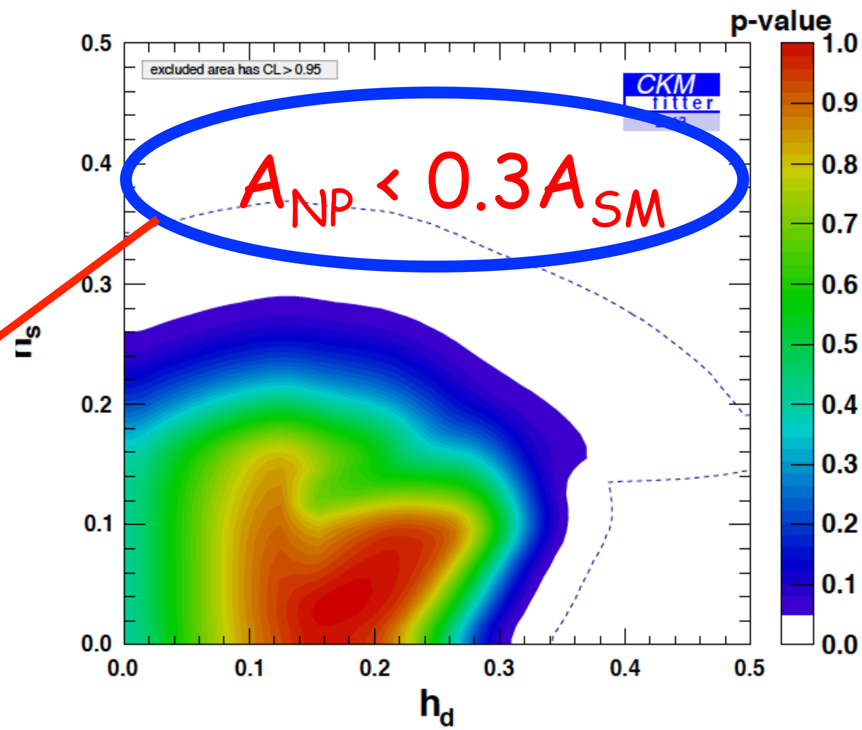


Charles et al (arXiv: 1309.2293)
Fit the data allowing NP amplitude

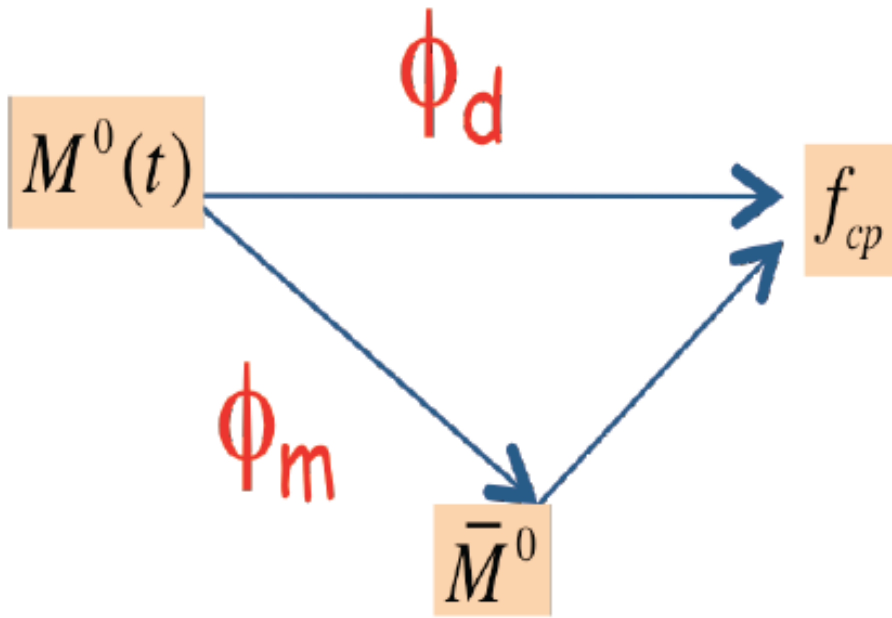
$$M_{12} = M_{12}^{\rm SM} \times \left(1 + h\, e^{2i\sigma}\right)$$

For C=1

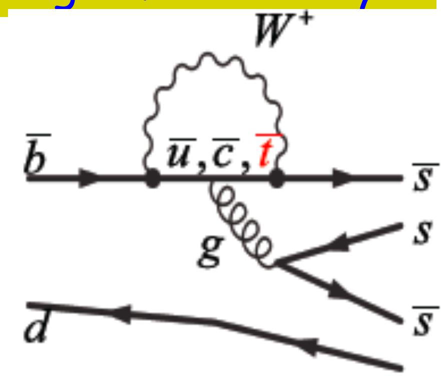
$$\Lambda_{NP} \gg 10^3 TeV$$

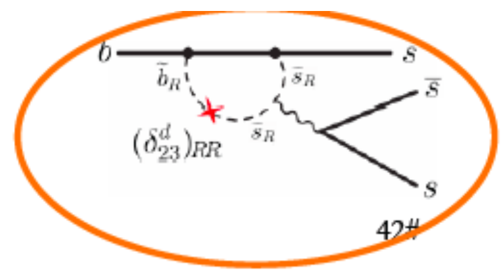


Is there room for New Physics? CPV sources beyond SM?



Through new loop diagrams in decay:





New Physics loops can lead to deviation of CPV from sin2β

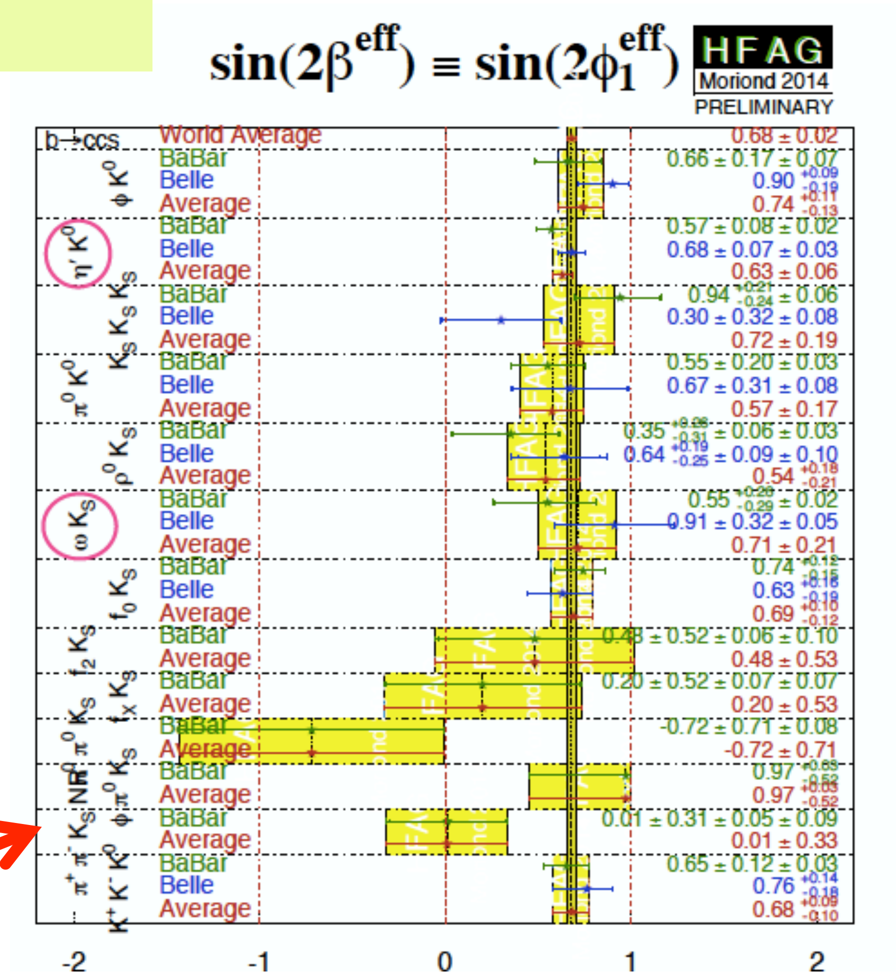
Penguin dominated B^0 decays measurements of "sin2β", "ϕ_s"

Update

New B^0_s addition to this program

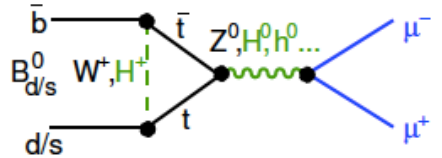
ϕ_s from a $B_s \to \phi\phi$ (penguin dominated process)-Analog of $B^0 \to \phi K_s$

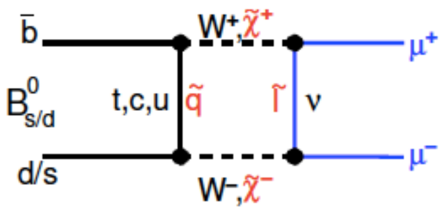
$\phi_s = -0.17 \pm 0.19 \pm 0.03$ (rad)
$\lambda = 1.04 \pm 0.15 \pm 0.03$
Consistent with no CPV
& SM ϕ_s

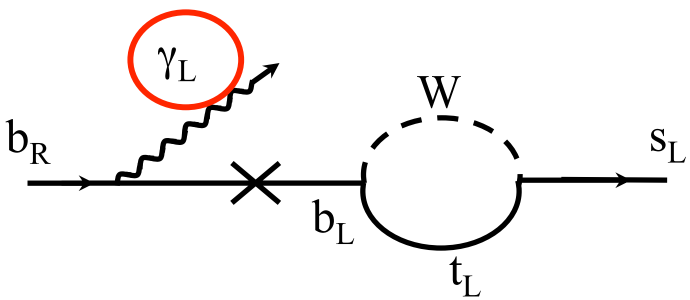


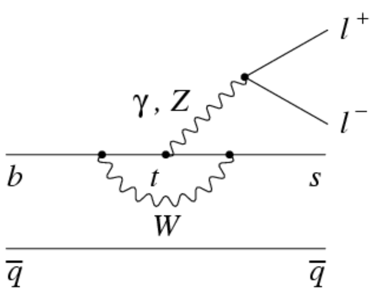
current results are consistent with SM. But theoretical uncertainties unknown (range of 0.02→0.1 was suggested in the past)

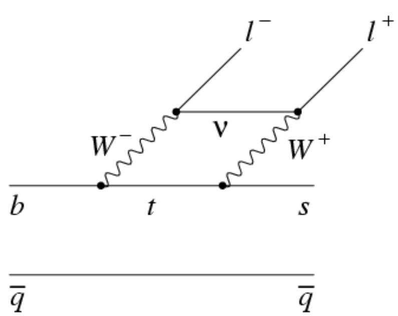
Broader program of search for New Physics with Flavor
Some very rare processes studied extensively











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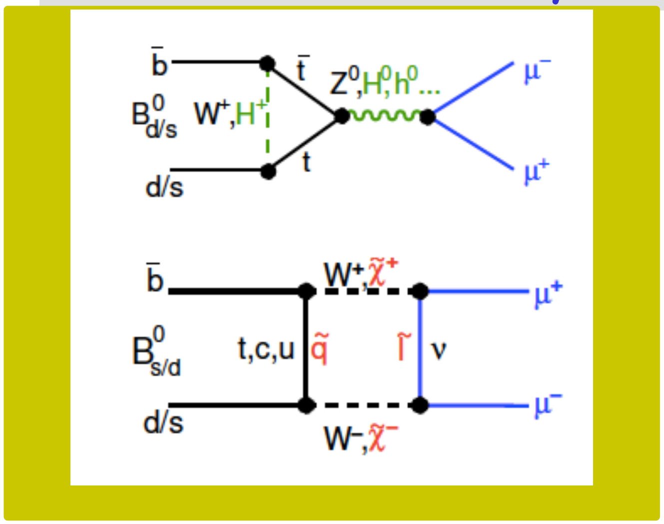
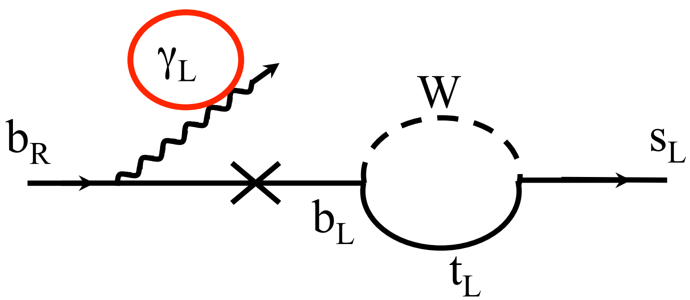
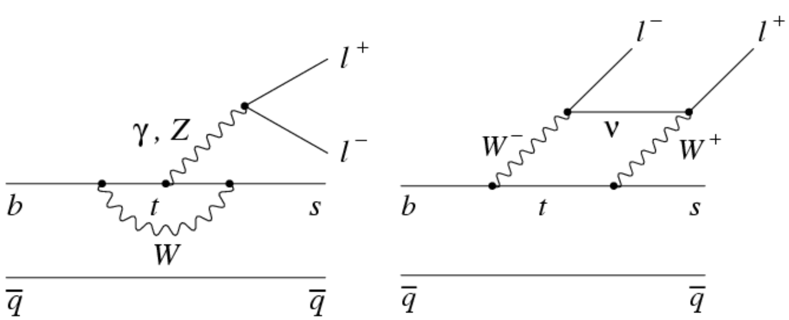


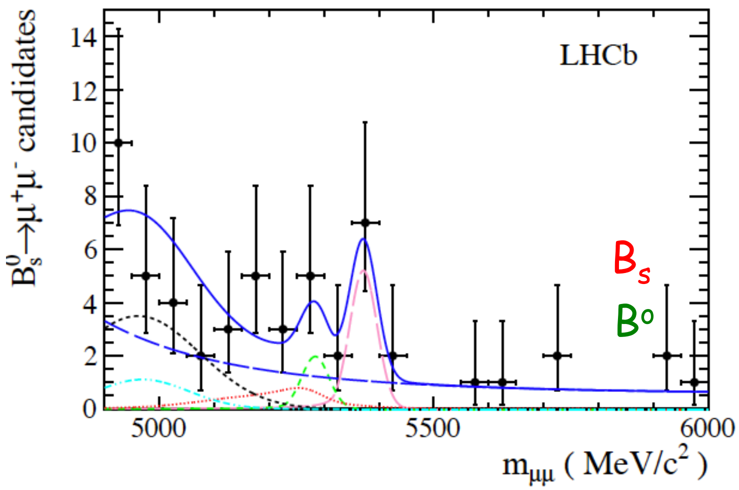
$SM: Br(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$

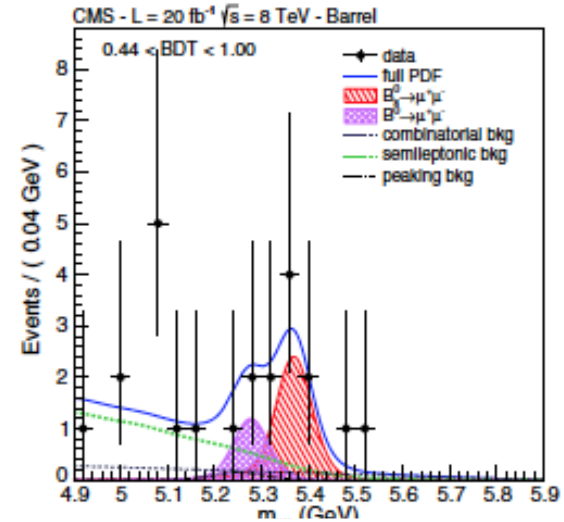
Finally Seen (LHCb & CMS) – consistent with SM
Major impact on New Physics parameter space

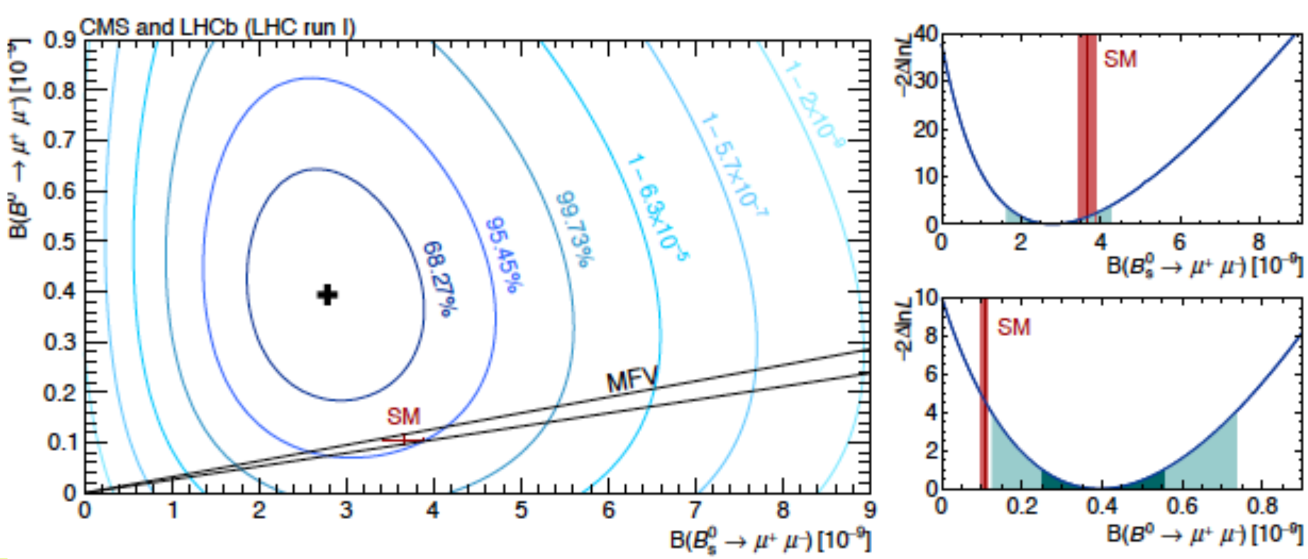




$B^0_s \to \mu^+\mu^-$:finally seen







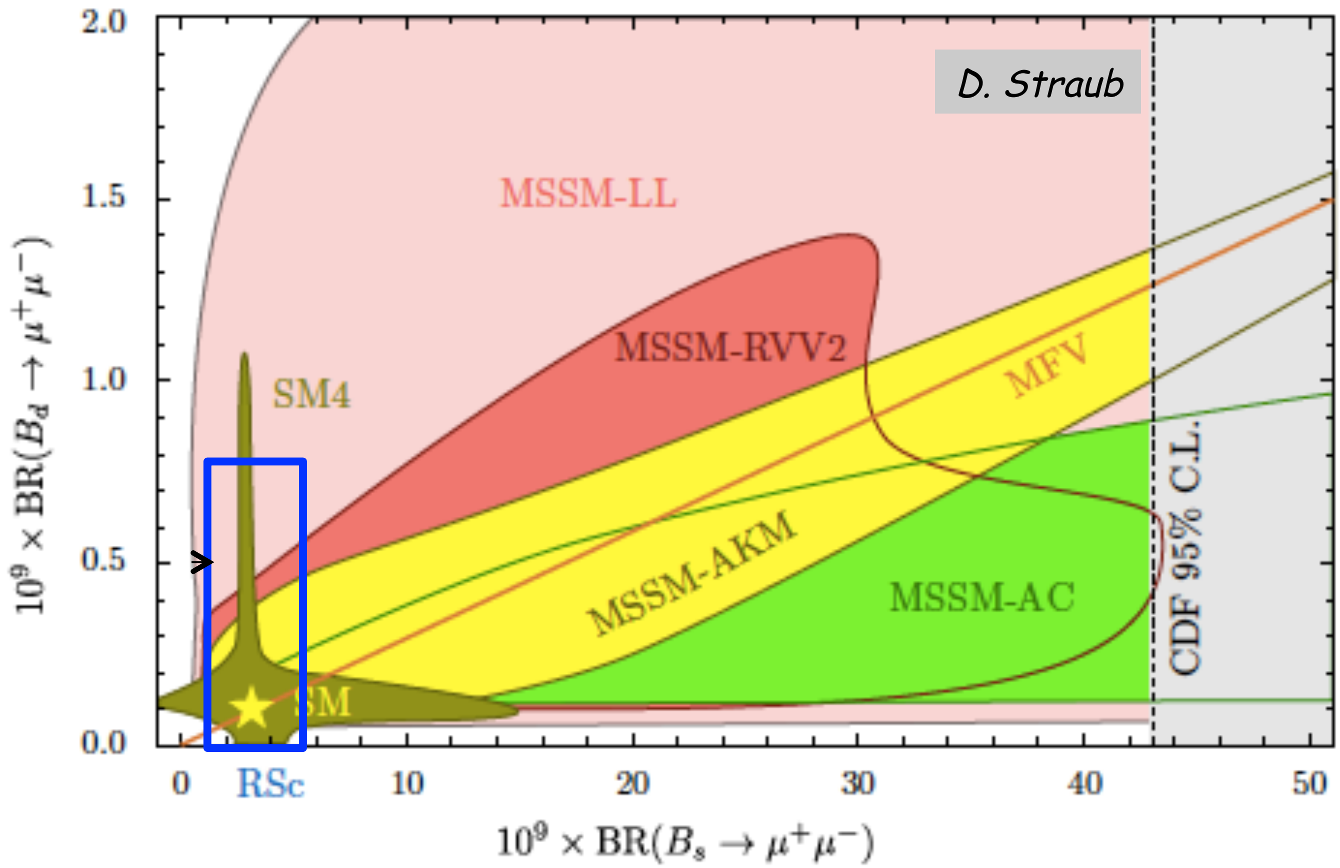
- SM is triumphant

Major impact on SUSY parameter space

Most constraining at large tanβ

$$B(B_{s,d} \to \mu^+\mu^-) \propto m_\mu^2 \tan^6 \beta$$

LHCb & CMS results



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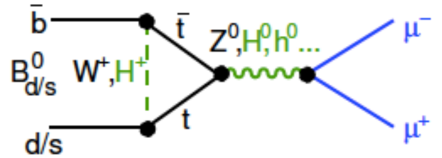
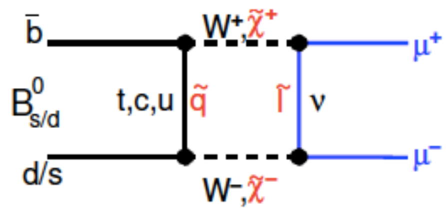
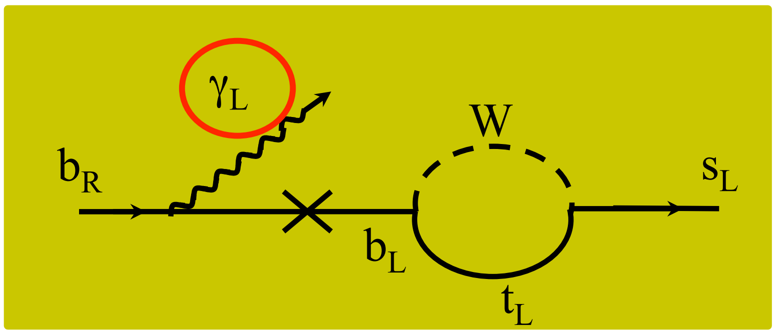
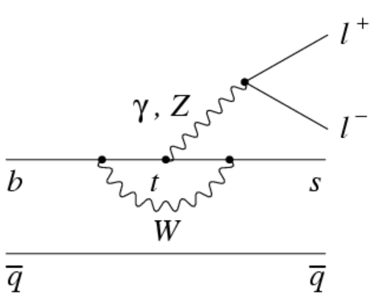


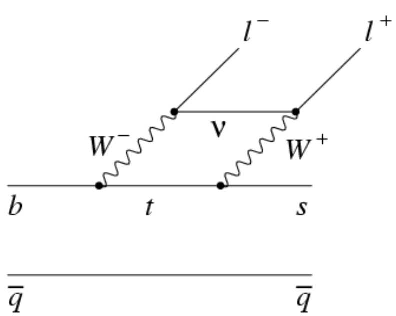




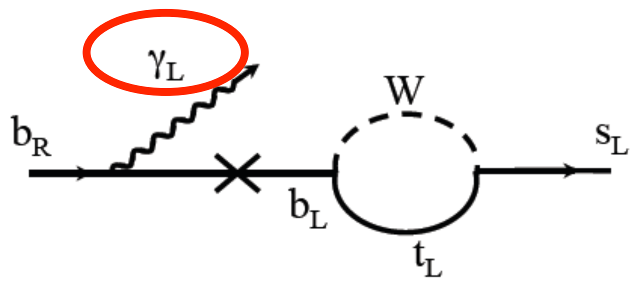
A key probe of NP in B decays
Observables: Rate, CPV, γ polarization
powerful probe of new scalars, right handed currents,..

Precise measurements to await the Super Flavor expt's & theory progress





Evolution of $b \to s\gamma$ (the original/standard NP probe in B's)



Very slow progress

Initial observation at CLEO- 1995

$$Br(b \to s\gamma) = (2.32 \pm 0.57 \pm 0.35) \times 10^{-4} (Exp)$$

$$= \quad (3.28 \pm 0.33) \times 10^{-4} (SM\ /\ Th)$$

2011: Measurements at the B factories

$$B(B \to X_s\gamma)[E_\gamma > 1.6 GeV) = (3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$$

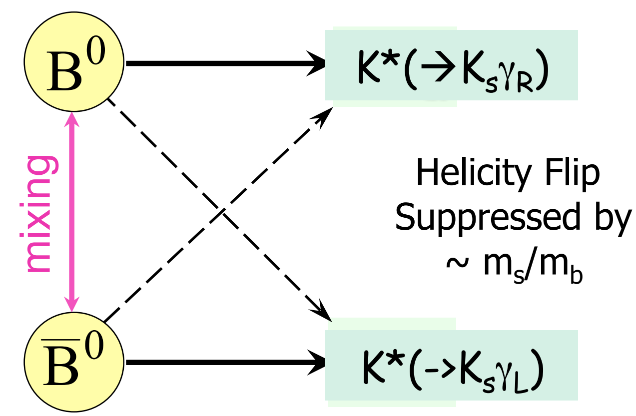
$$B(B \to X_s\gamma)_{NNLL}[E_\gamma > 1.6 GeV) = (3.15 \pm 0.23) \times 10^{-4}$$

First attempt at measuring photon polarization at BaBar & Belle via time-dependent CPV in $B \to K^0_s \pi^0 \gamma$ *(Gronau, Soni, Atwood)*

consistent with SM, but plenty room for NP

Recent LHCb results with $B_s \to \phi\gamma$ also consistent with SM at 2 sigma level.

Major item on menu of Belle-II and LHCb-upgrade($B_s \to \phi\gamma$)



Broader program of search for New Physics with Flavor

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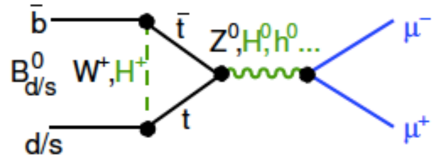
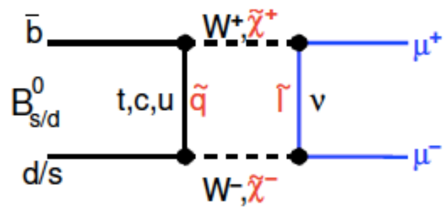
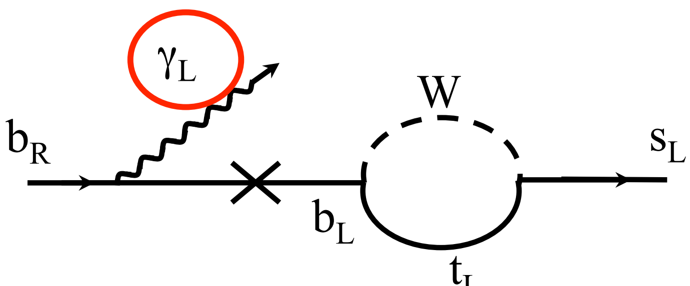
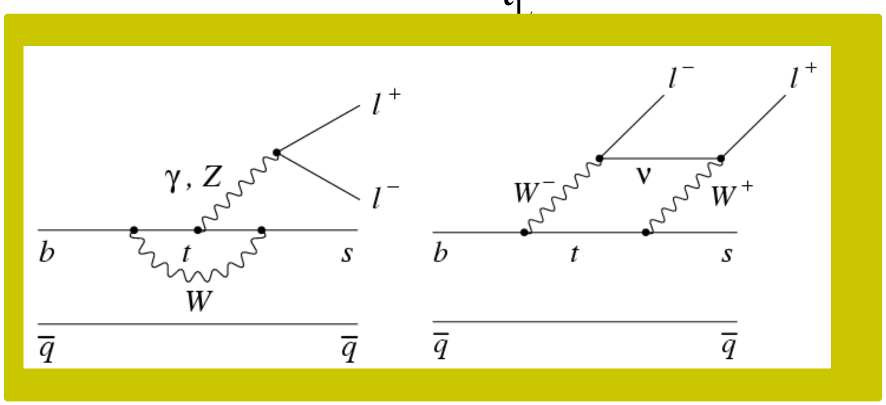








Recent precise measurements from LHCb show interesting hints of deviations from SM- including tests of Lepton Flavor Universality

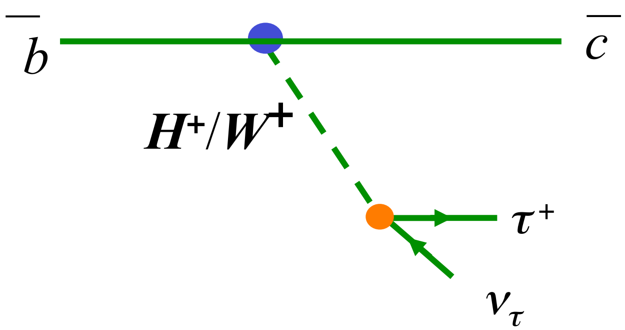
$b \rightarrow s\nu\nu$ at super flavor expt's.

Broader program of search for New Physics with Flavor

Lepton Flavor Universality via Tree-Level B decays to tau

The key observables:

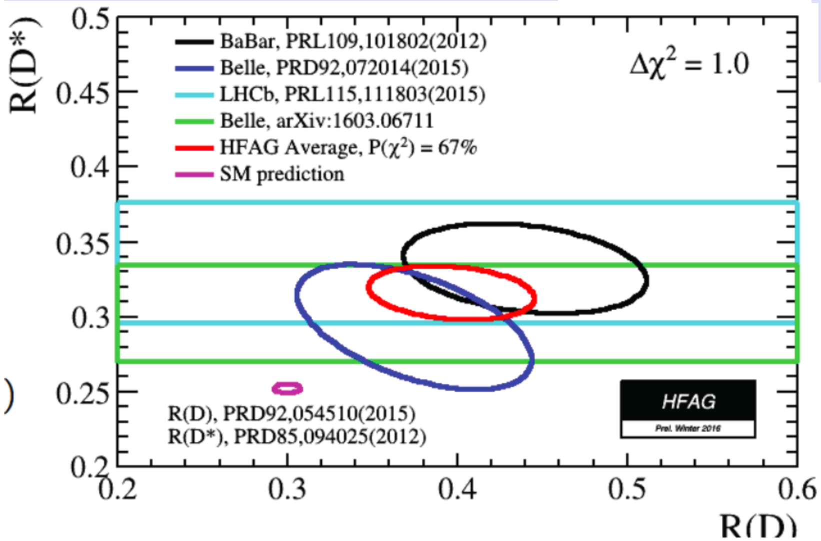
$B \to D^{(*)}\tau\nu$



$$R(D^{(*)}) = \frac{B(\bar{B} \to D^{(*)}\tau\bar{\nu})}{B(\bar{B} \to D^{(*)}\mu\bar{\nu})}$$

- These are theoretically very "clean"
- Computed in HQFT or LQCD
- Form-Factor Uncertainties largely cancel
- Helicity suppressed amplitudes dominate uncertainties
- Precisions range 1-3%

Current Status



There are more areas of tension with SM- and slowly growing; all in need of plausible SM explanations ..or (NP?)

- Inclusive vs exclusive V_{ub} and V_{cb}
- Sin2β tension (direct vs CKM fit)
- Di-muon Asymmetry
- Lepton universality tests (e.g. B->$D^{(*)}\tau\nu$,..)
- Tensions in radiative decays
- Kπ-puzzle
- large direct CPV in B
- ...

Ultimately the Data itself may set the direction if some of the current tensions survive:

Future

Aiming for at least x10 better precision

Need x100 statistical power; much higher intensity accelerator/experiments

Need a matching large leap in precision of theoretical inputs

Further in future:

Initial studies have began on “LHCb upgrade phase-2”

The past decade saw major advances in possibilities for future flavor experiments

- A new novel accelerator concept emerged for realization of an e+e- Super Flavor factory at ~X100 intensity of SLAC and KEK B factories

- Heavy flavor physics at hadron colliders successfully demonstrated by Tevatron & LHC experiments. LHCb detector & trigger concepts proved very successful with spectacular results.

- Kaon experiment: NA62 (CERN) & KOTO (KEK) : Rare kaon decays at Br~ 10^{-10} $K^+ \rightarrow \pi^+ \nu\nu$ & $K_L \rightarrow \pi^0 \nu\nu$ –Discussed in detail in lectures by Vincenzo Cirigliano

- Lepton Flavor Violation Experiments: CLFV: $\mu \rightarrow e\gamma$ (at ~10^{-13}) with MEG , $\mu N \rightarrow eN$ (at 10^{-16} level) with Mu2e @FNAL and COMET@Jparc.

The past decade saw major advances in possibilities for future flavor experiments

- A new novel accelerator concept emerged for realization of an e+e- Super Flavor factory at ~X100 intensity of SLAC and KEK B factories

- Heavy flavor physics at hadron colliders successfully demonstrated by Tevatron & LHC experiments. LHCb detector & trigger concepts proved very successful with spectacular results.

- Kaon experiment: NA62 (CERN) & KOTO (KEK) : Rare kaon decays at Br~ 10^{-10} $K^+ \to \pi^+\nu\nu$ & $K_L \to \pi^0\nu\nu$ –Discussed in detail in lectures by Vincenzo Cirigliano

- Lepton Flavor Violation Experiments: CLFV: $\mu \to e\gamma$ (at ~10^{-13}) with MEG , $\mu N \to eN$ (at 10^{-16} level) with Mu2e @FNAL and COMET@Jparc.

Super Flavor Experiments

At LHC: Endowed with large production cross section: its mostly about trigger & pile-up

σ_{cc}~6 mb (7 TeV) σ_{τ}~80 μb (7 TeV)
σ_{bb}~280 μb(7 TeV) (~500 at 13 TeV)

LHCb at L~2-4x10^{32}/cm^2/s
Expect ~8/fb by 2018
B_d, B_u, B_s, B_c, Λ_b,…
LHCb upgrade aimed for 2018
To operate at L~2x10^{33}/cm^2/s
expect ~5/fb/year (total of ~50/fb)

- CMS and ATLAS players

in some key areas

- e+e- Super B factory
- Small cross-section; its mostly about luminosity (xsection ~1 nb)

Asymmetric energy $e^+ + e^-$ colliders to operate in the $\Upsilon(4S)$ region as well as in the charm threshold region.

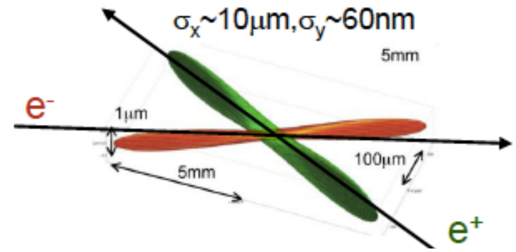
- SuperB, Italy (originated the concept – but failed to be funded)
- Super KEKB in Japan- well underway
- At L ~8x10^{35} /cm^2/s

  Aiming for a data set of ~ 50 /ab
  - ~10^{11} B decays
  - ~10^{11} tau decays
  - ~10^{11} charm decays

Belle-II at SuperKEKB

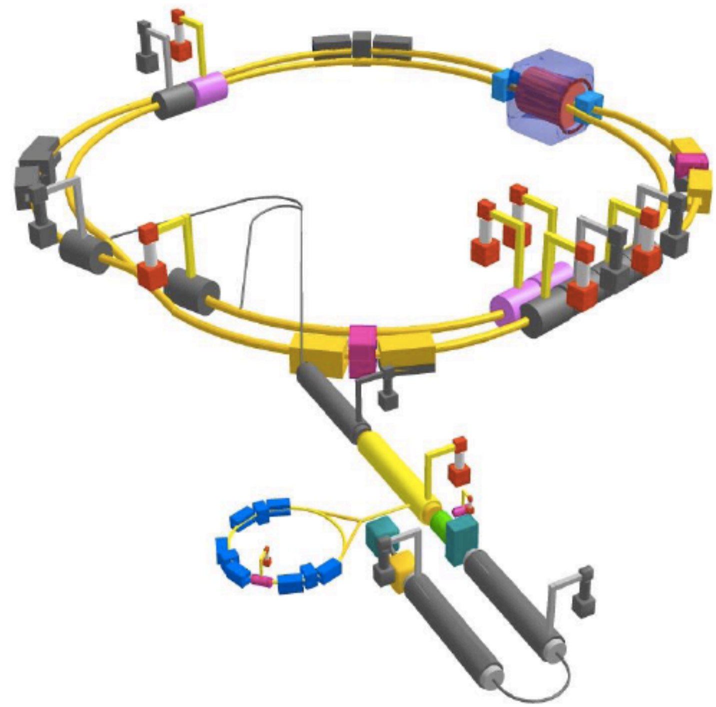
Asymmetric Energy e+e- collider at goal peak Luminosity 8×10^{35} /cm^2/s aiming for 50 ab^{-1}

Design based on Nano-beam scheme proposed by P. Raimondi (Frascati), tight focusing, larger crossing angle & higher I_b

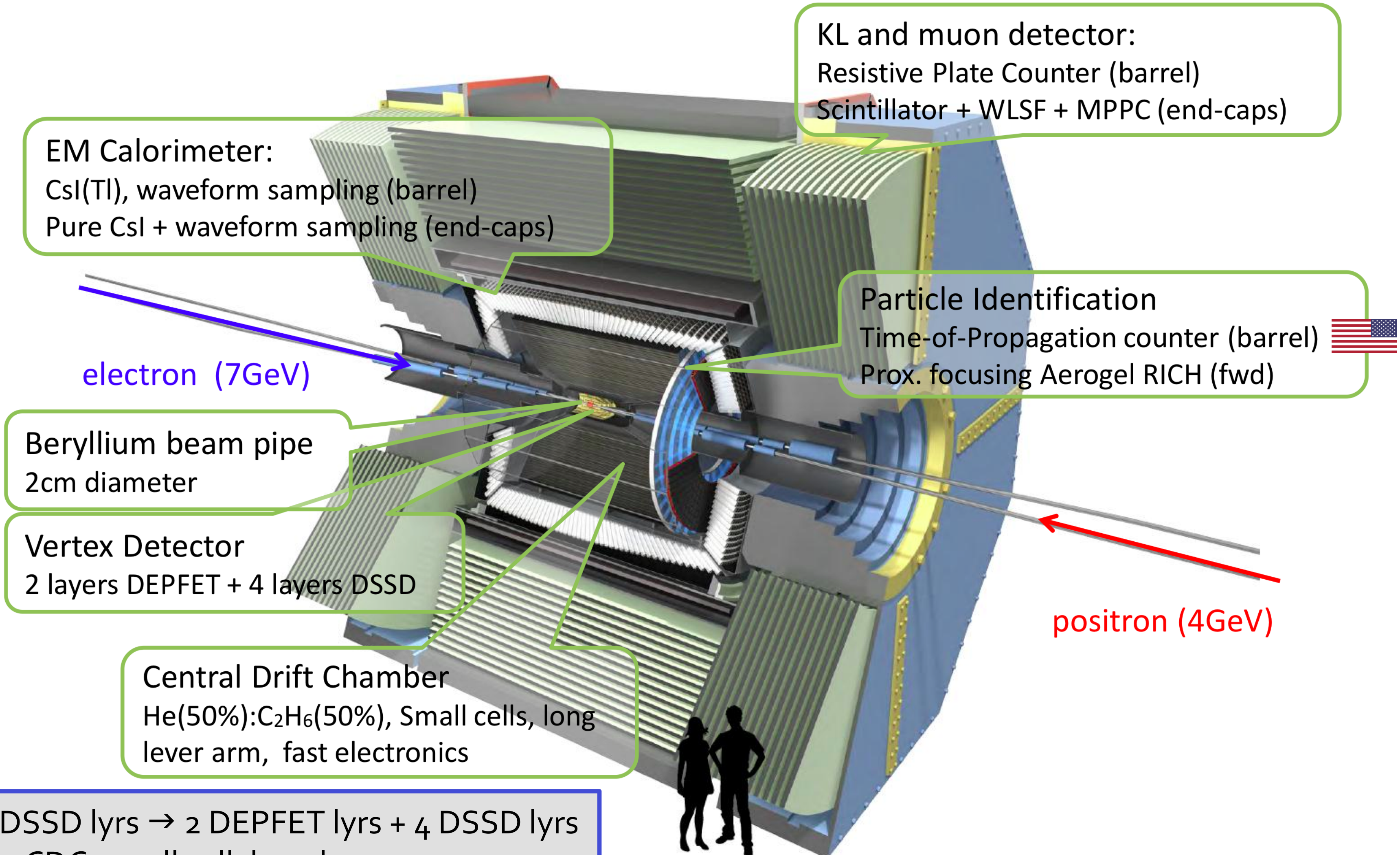


Accelerator Upgrade

- low emittance electron injector
- New positron damping ring
- New vacuum chambers
- New HER and LER lattice and long dipoles for low emittance
- New IR for low β*
- Modified and additional RF for higher currents



Belle II Detector



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC → Scintillator +SiPM (end-caps)

From Y. Ohnishi (KEK) – ICHEP 2016

Schedule

***Phase-1**: February 1st, 2016 - July 28th, 2016.* ✓

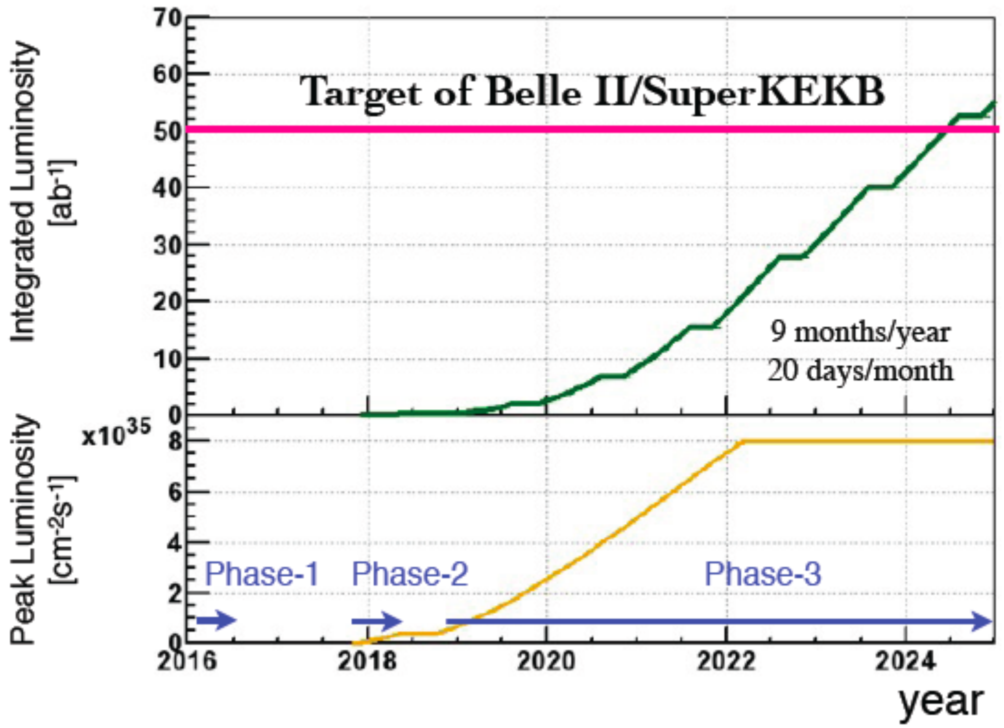
No final focus system, vacuum scrubbing, low emittance tuning

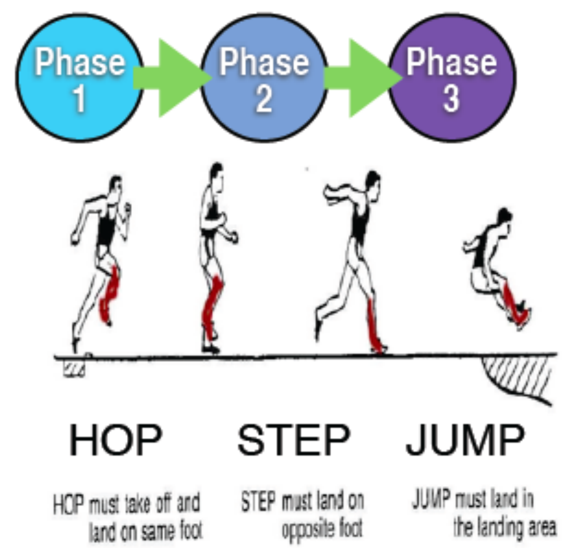
***Phase-2**: November 2017 - April 2018*

Final focus system, Belle II without vertex detector, **the first collision**

***Phase-3**: October 2018 -*

Physics run **with full detector**, squeezing beta and increasing currents





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The LHCb upgrade

The upgrade is designed to run at luminosity of (1-2)x10^{33} $cm^{-2}s^{-1}$; Aiming for 50 fb^{-1}

- Requires new approach to the LHCb trigger scheme to overcome L0 (1MHz) limitation.

➔ New Trigger Apporach:

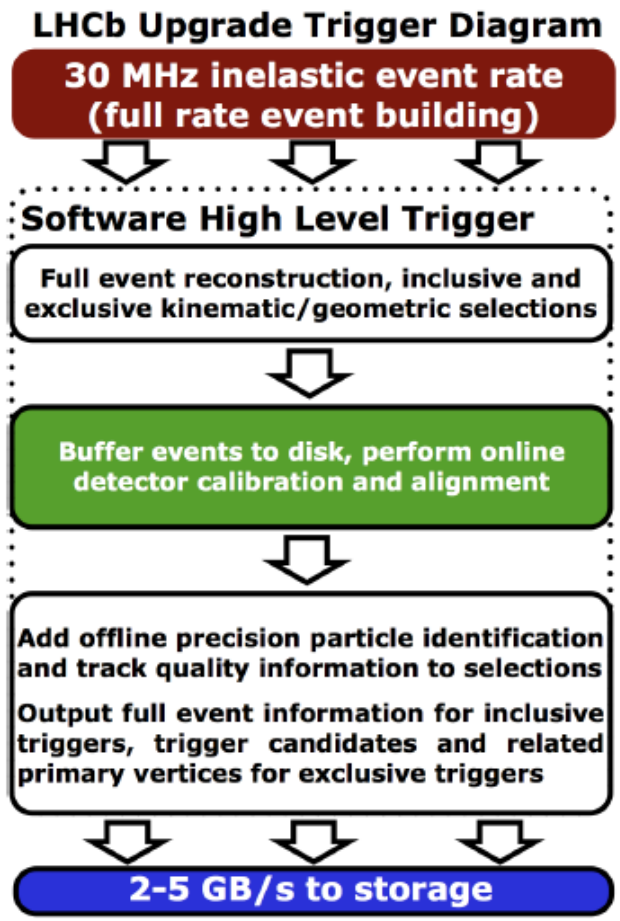
➢Remove L0 (hardware) trigger

➢Readout the detector at the 40 MHz LHC clock rate

➢Move to a fully flexible software trigger

=>>Major upgrade of LHCb detector required to cope with increase occupancy, data rate, radiation dose & to preserve efficiency and low ghost rate:

Replace all readout electronics, entire tracking system (Vertex locator, upstream & downstream tracking detectors) & upgrade Particle ID system



Upgrade plan

Installation in long Shutdown-2 2019-20

Tracking system:

New VELO (Si strip → Pixel)

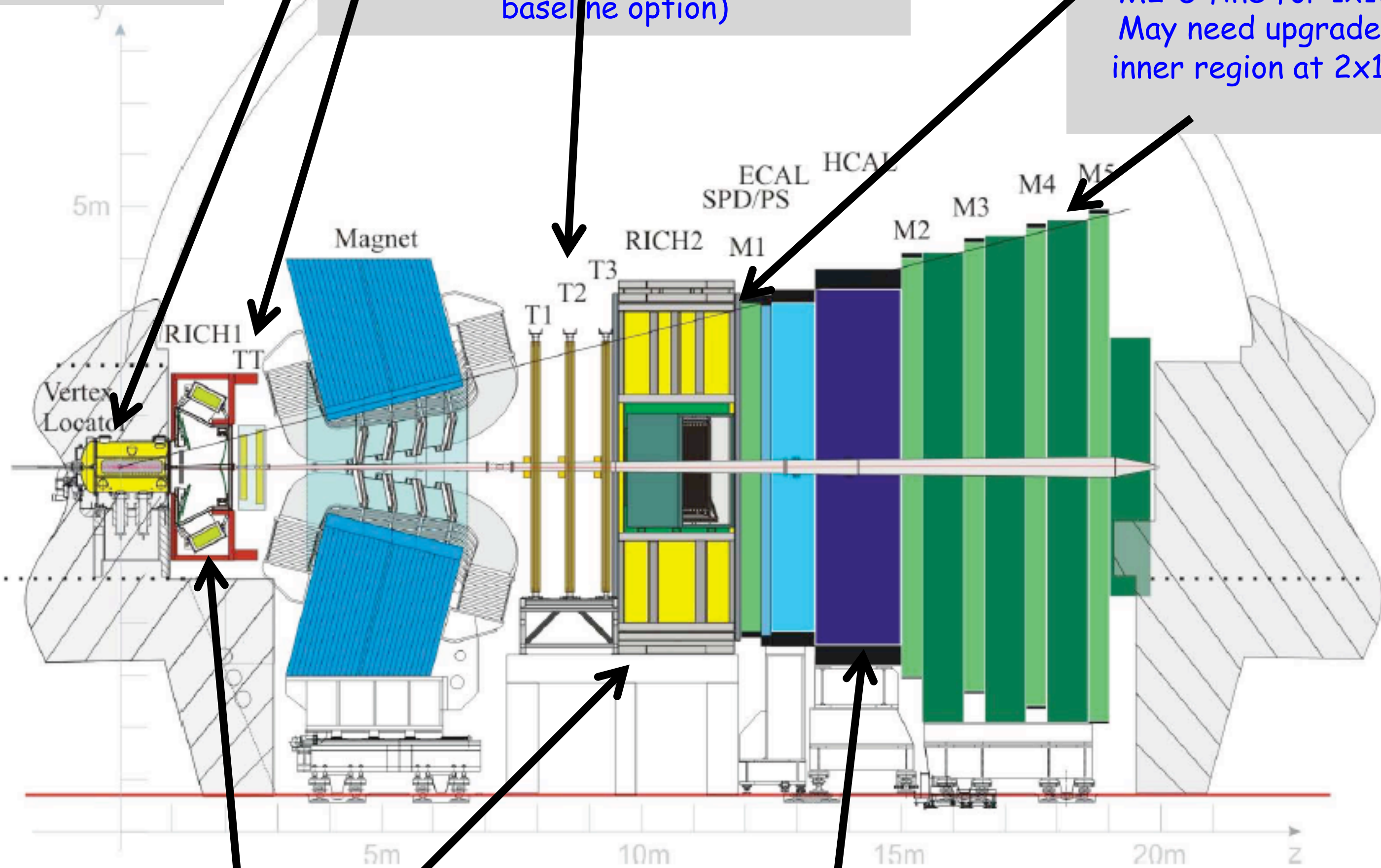
New upstream tracker (UT) (Si)

New downstream tracker (Sci Fiber – baseline option)

Muon System:

Remove M1

M2-5 fine for $1x10^{33}$
May need upgrade of inner region at $2x10^{33}$



RICH 1 & RICH 2

HPD→ MaPMT

New 40 MHz R/O

RICH1: new optics
remove aerogel

Calorimeter:

New 40 MHz R/O

Lower PMT gain to reduce anode current

Remove SPD & PS

Physics sensitivity in Key Channels

From Snowmass report

Belle-II

Will dominate inclusive channels, e.g. b->s γ… unique access to $B \to K\nu\nu$, $B \to \tau\nu$, modes with many π^0 or γ, LFV in $\tau^+ \to \mu^+\gamma$,…Also access to Charm CPV.

Observable	SM theory	Current measurement (early 2013)	Belle II ($50\,\mathrm{ab}^{-1}$)
$S(B \to \phi K^0)$	0.68	0.56 ± 0.17	± 0.03
$S(B \to \eta' K^0)$	0.68	0.59 ± 0.07	± 0.02
α from $B \to \pi\pi$, $\rho\rho$		$\pm 5.4°$	$\pm 1.5°$
γ from $B \to DK$		$\pm 11°$	$\pm 1.5°$
$S(B \to K_S \pi^0 \gamma)$	< 0.05	-0.15 ± 0.20	± 0.03
$S(B \to \rho\gamma)$	< 0.05	-0.83 ± 0.65	± 0.15
$A_{\mathrm{CP}}(B \to X_{s+d}\,\gamma)$	< 0.005	0.06 ± 0.06	± 0.02
A^d_{SL}	-5×10^{-4}	-0.0049 ± 0.0038	± 0.001
$\mathcal{B}(B \to \tau\nu)$	1.1×10^{-4}	$(1.64 \pm 0.34) \times 10^{-4}$	$\pm 0.05 \times 10^{-4}$
$\mathcal{B}(B \to \mu\nu)$	4.7×10^{-7}	$< 1.0 \times 10^{-6}$	$\pm 0.2 \times 10^{-7}$
$\mathcal{B}(B \to X_s\gamma)$	3.15×10^{-4}	$(3.55 \pm 0.26) \times 10^{-4}$	$\pm 0.13 \times 10^{-4}$
$\mathcal{B}(B \to K\nu\overline{\nu})$	3.6×10^{-6}	$< 1.3 \times 10^{-5}$	$\pm 1.0 \times 10^{-6}$
$\mathcal{B}(B \to X_s \ell^+\ell^-)$ $(1 < q^2 < 6\,\mathrm{GeV}^2)$	1.6×10^{-6}	$(4.5 \pm 1.0) \times 10^{-6}$	$\pm 0.10 \times 10^{-6}$
$A_{\mathrm{FB}}(B^0 \to K^{*0}\ell^+\ell^-)$ zero crossing	7%	18%	5%
$\lvert V_{ub} \rvert$ from $B \to \pi\ell^+\nu$ $(q^2 > 16\,\mathrm{GeV}^2)$	9% → 2%	11%	2.1%

LHCb

Will dominate the B^0_s sector, and exclusive decays with charged particles, e.g $B \to K\mu+\mu-$… Unique access to B_c & B-baryons & rare charmed decays, LFV in $\tau^+ \to \mu^+\mu^+\mu^-$

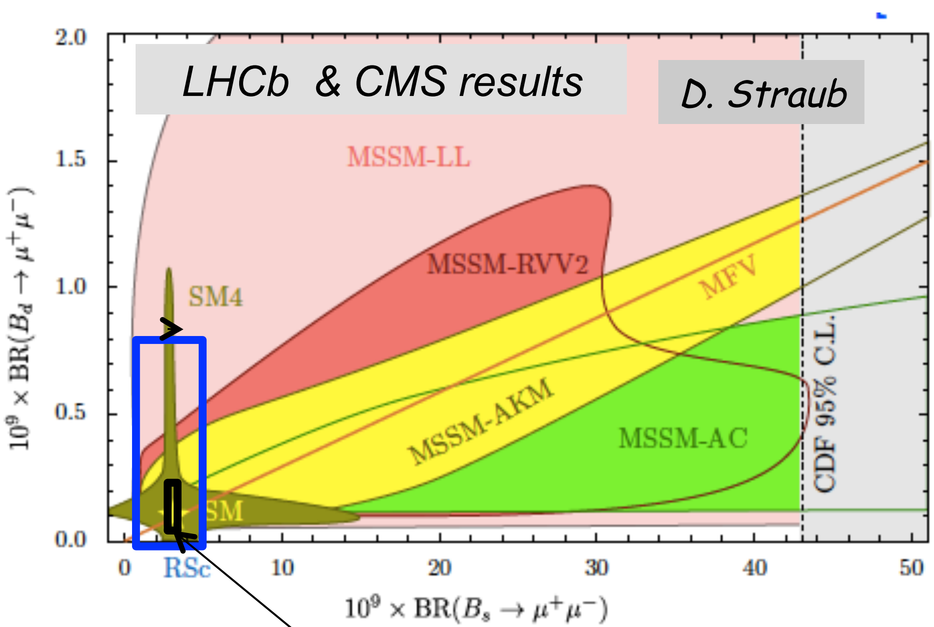
Observable	Current SM theory uncertainty	Precision as of 2013	LHCb (6.5 fb^{-1})	LHCb Upgrade (50 fb^{-1})
$2\beta_s(B_s \to J/\psi\phi)$	~ 0.003	0.09	0.025	0.008
$\gamma(B \to D^{(*)}K^{(*)})$	$< 1°$	8°	4°	0.9°
$\gamma(B_s \to D_s K)$	$< 1°$	—	$\sim 11°$	2°
$\beta(B^0 \to J/\psi K^0_S)$	small	0.8°	0.6°	0.2°
$2\beta_s^{\mathrm{eff}}(B_s \to \phi\phi)$	0.02	1.6	0.17	0.03
$2\beta_s^{\mathrm{eff}}(B_s \to K^{*0}\bar{K}^{*0})$	< 0.02	—	0.13	0.02
$2\beta_s^{\mathrm{eff}}(B_s \to \phi\gamma)$	0.2%	—	0.09	0.02
$2\beta^{\mathrm{eff}}(B^0 \to \phi K^0_S)$	0.02	0.17	0.30	0.05
A^s_{SL}	0.03×10^{-3}	6×10^{-3}	1×10^{-3}	0.25×10^{-3}
$\mathcal{B}(B_s \to \mu^+\mu^-)$	8%	36%	15%	5%
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s \to \mu^+\mu^-)$	5%	—	~100%	~35%
$A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$ zero crossing	7%	18%	6%	2%

Expected future NP sensitivity

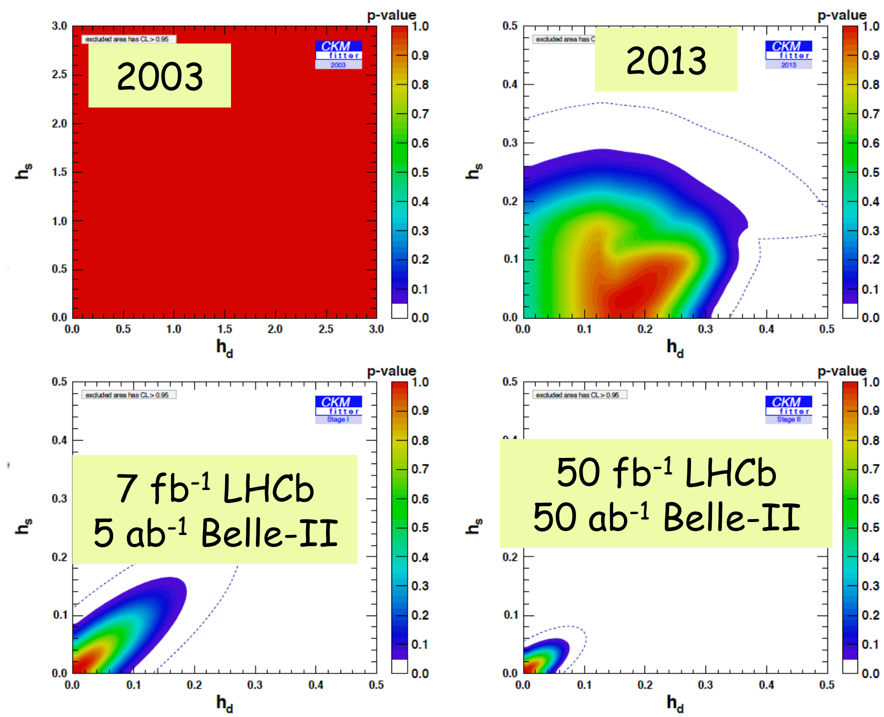
Charles et al (arXiv: 1309.2293).

Assumes also major improvements to the accuracy of the theoretical inputs

$$M_{12} = M_{12}^{\rm SM} \times \left(1 + h\, e^{2i\sigma}\right)$$



50 fb^{-1} At LHCb upgrade



Summary:

- Flavor physics remains one of the primary drivers of the search for New Physics beyond SM.
  - The current data is consistent with the Standard Model, setting severe constrains on scenarios of New Physics Beyond SM, but many stones remain unturned.
    - There are some areas of tensions with SM, waiting for more precise measurements and theoretical calculations.

- Future: The planned experimental program for next decade or more together with advances on the theory front will challenge the SM with tremendous precision.