Title: Beyond the Standard Model â€“ Experiment: Hidden sectors and dark photons

Date: Jul 08, 2015 11:45 AM

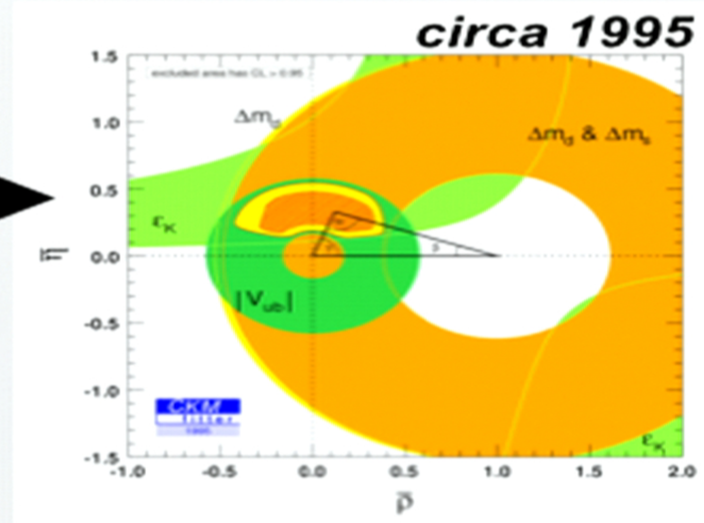
URL: http://pirsa.org/15070025

Abstract:

THE Unitarity Triangle

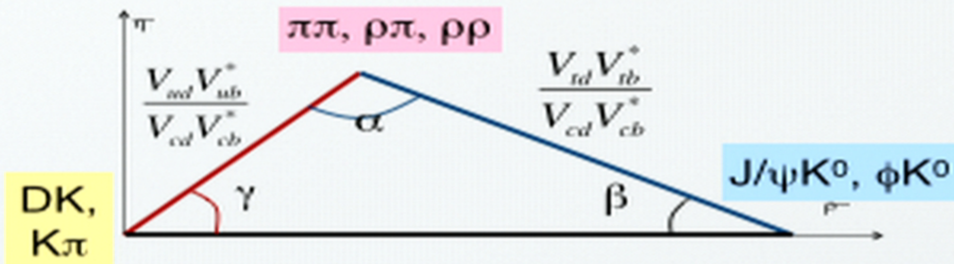
There are 6 triangle relations but most have very un-equal sides== large/small angles == small CPV effects

...EXCEPT!!!



THE UT = Column 1 (***d***) * Column 3(***b***)

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



One of the ***main goals of B-Factories is to see if this triangle closes***...if it doesn't, it would be sign of **physics beyond the Standard Model!**

CKMfitter Group (J. Charles et al.), Eur. Phys. J. C41, 1-131 (2005) [hep-ph/0406184], updated results and plots available at: http://ckmfitter.in2p3.fr

TRISEP 2015

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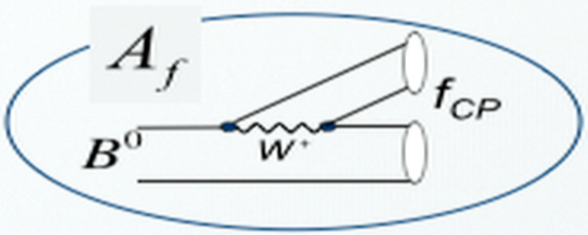
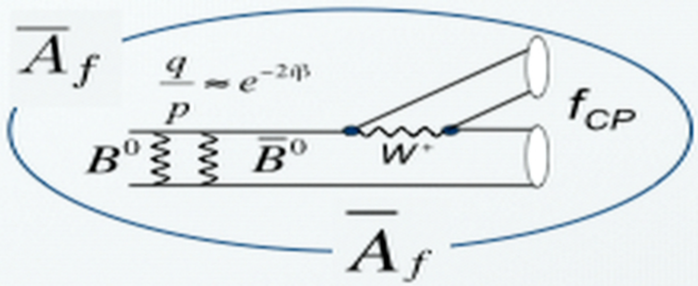
UT Angles Measurements = CPV

…measuring the angles of the UT requires measuring the phases between amplitudes

- measure *time-dependent* rates of B and $\overline{B}$ to the ***same*** final state



$$A_{CP}(\Delta t) = \frac{\Gamma(\overline{B} \to f) - \Gamma(B \to f)}{\Gamma(\overline{B} \to f) + \Gamma(B \to f)}$$

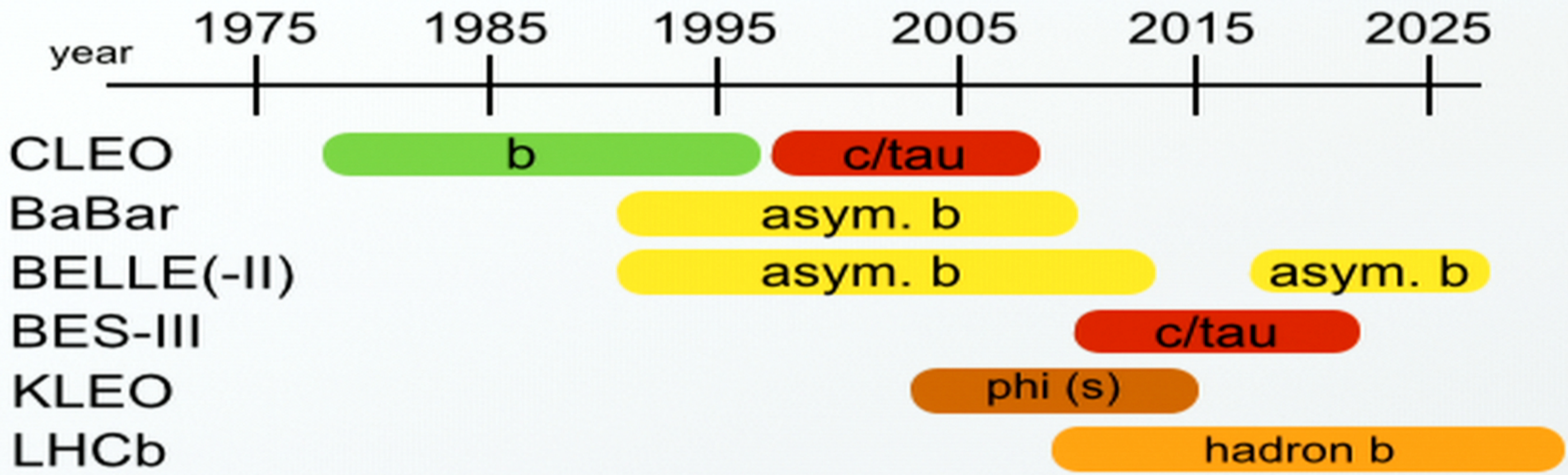


$$= \frac{2\,\mathrm{Im}\,\lambda}{1+|\lambda|^2} \sin \Delta m_d \Delta t - \frac{1-|\lambda|^2}{1+|\lambda|^2} \cos \Delta m_d \Delta t$$

"S" "C"

$$\lambda = \eta_f \left(\frac{q}{p}\right)\left(\frac{\overline{A}_f}{A_f}\right)$$

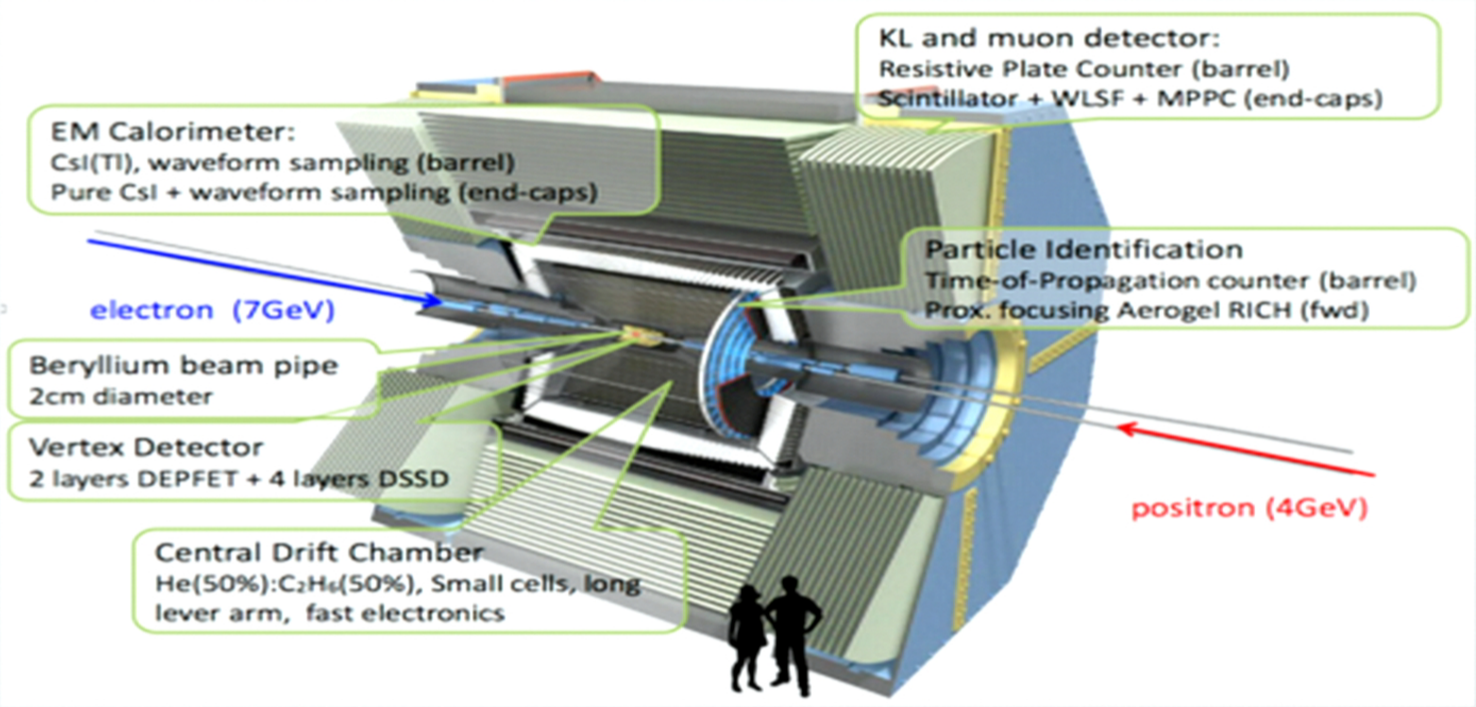
(quark) Flavor Factories



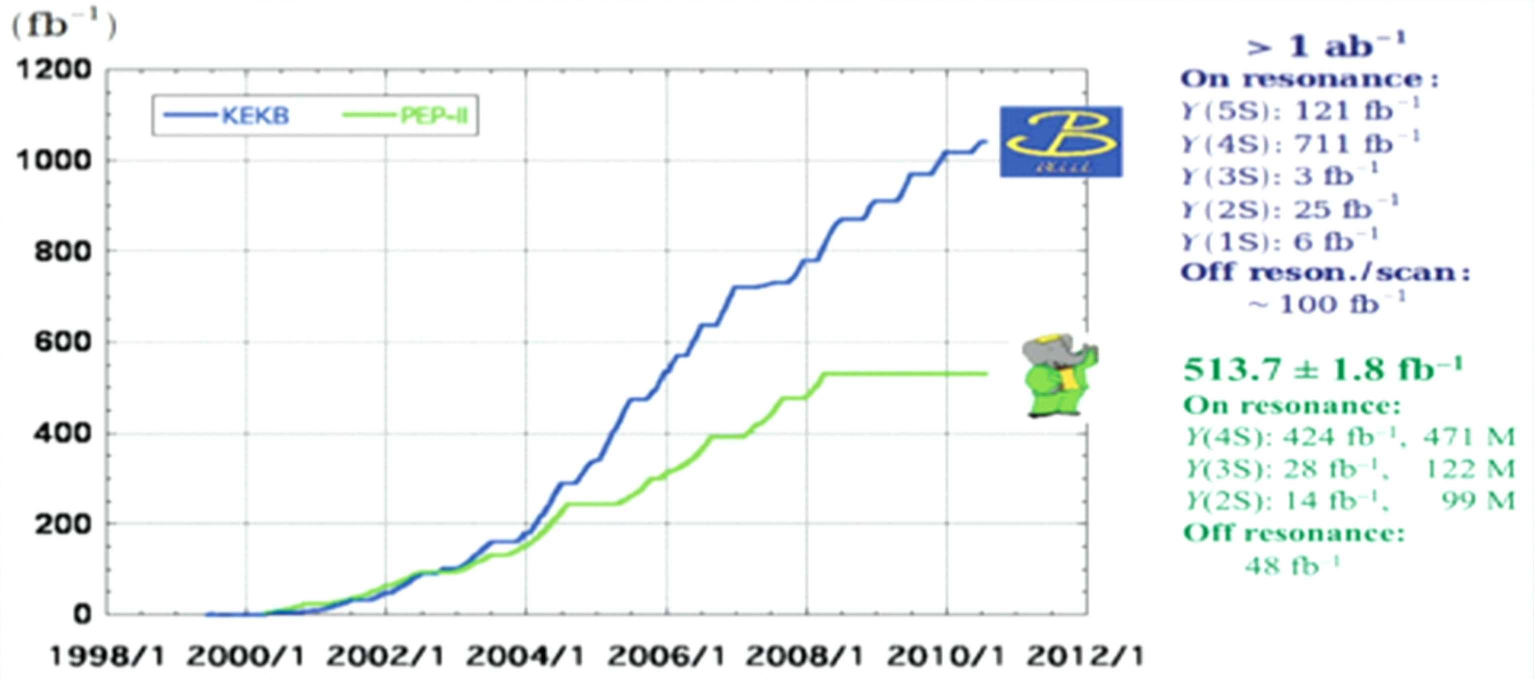
disclaimer: dates in the future are guesses

disclaimer: ...in the past may be too

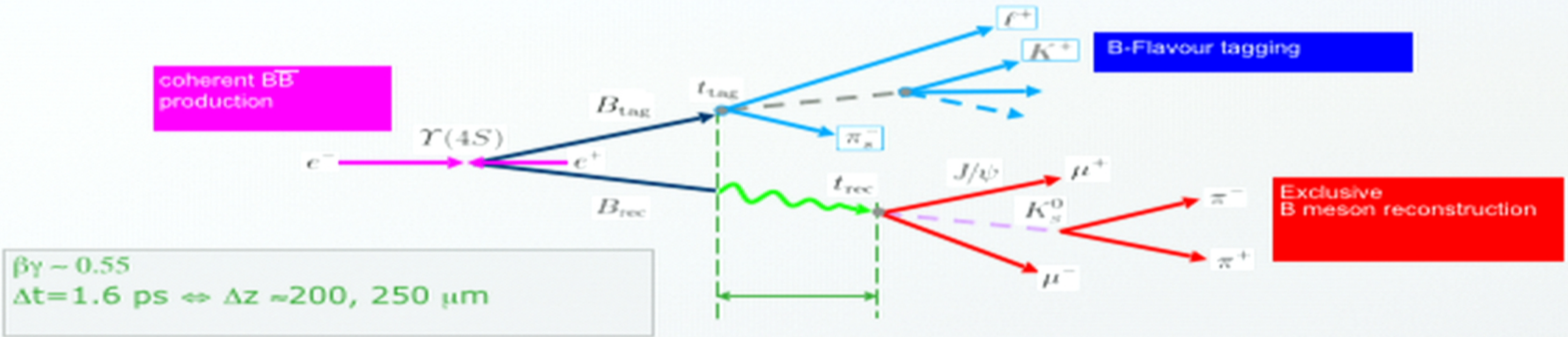
Belle-II Detector (as example)



Gen-I got a lot of data



Asymmetric B-Factories



e^+e^- B-Factories:

Typical error on Δt ~ 0.8 ps
The Δt resolution function obtained from high stat. B→DX
Events tagged using the charge of the leptons, kaons, pions
Effective tagging efficiency (including mistag-rate) ~30%

LHCb:

Typical error on Δt ~ 0.05 ps
Effective tagging efficiency (including mistag-rate) ~5%

$\sin 2\beta$ from $B^0 \rightarrow (c\bar{c})\, K^0$

The "golden mode" for the B-Factories was:

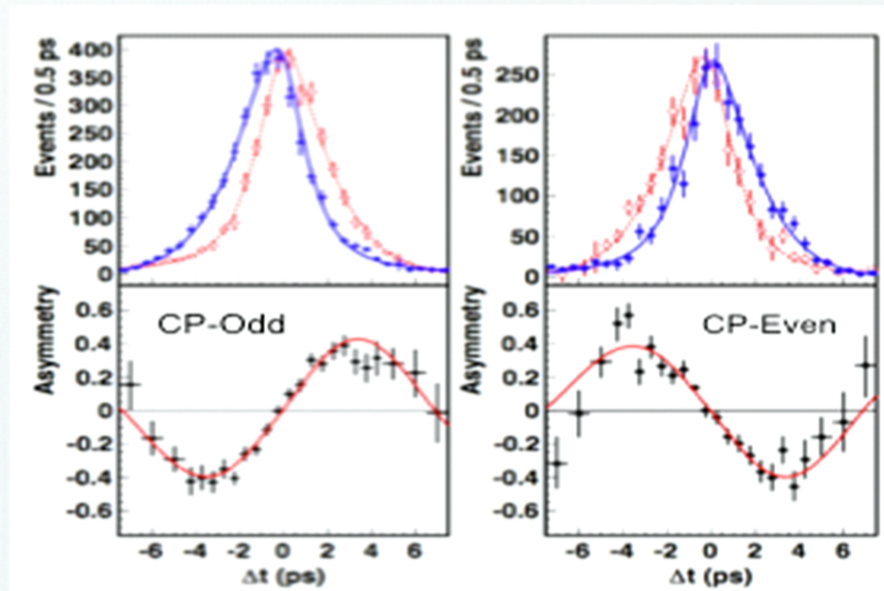
$$B^0/\bar{B}^0 \rightarrow J/\Psi\, K_s^0$$

$$-\frac{2\,\mathrm{Im}\,\lambda}{1+|\lambda|^2}\sin\Delta m_d\Delta t - \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos\Delta m_d\Delta t$$

"S" "C"

$S=\sin 2\beta$

$C=0$



BELLE, PRL, 108 (2012) 171802

- J/Ψ is narrow $\rightarrow$ very clean final state
- $J/\Psi \rightarrow \mu^+\mu^-$ or e^+e^- from B-decay vertex $\rightarrow$ precise Δt measurement
- $K_s^0 \rightarrow \pi^+\pi^-$ narrow & displaced from B-decay vertex $\rightarrow$ also very clean

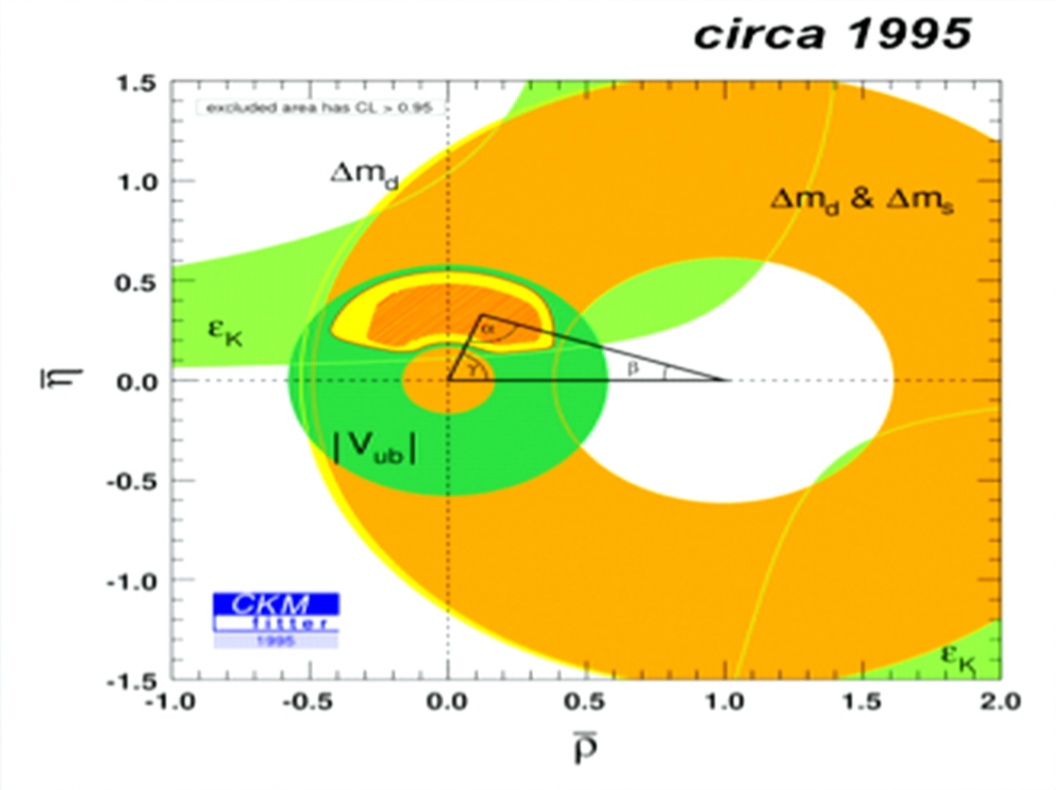
$\Rightarrow$eventually more and more charmonium & K_L^0 final states were added to the measurement…plot above has XXX final states included

Other measurements in the UT

- Tree-level:
  - $|V_{ub}|$
  - gamma: $B^0 \rightarrow DK$
- Mixing & CPV:
  - beta: $B^0 \rightarrow \bar{c}cK^0$ TD-CPV
  - alpha: $B^0 \rightarrow \pi\pi/\rho\pi/\rho\rho$ TD-CPV (and Isospin)
  - gamma: $B^0 \rightarrow DK$
  - Δm_d, Δm_s: lifetime measurements (hadron machines)
  - $\varepsilon_{K:}$ Kaon CPV

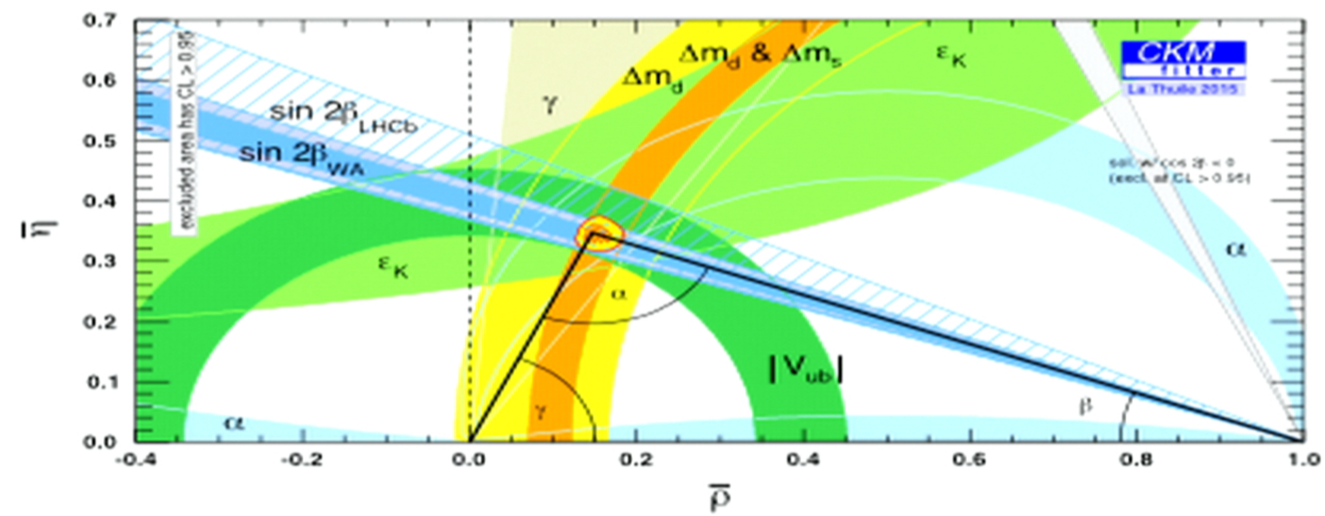
A lot of work from a lot of different folks…
besides the experiments!
<u>http://www.slac.stanford.edu/xorg/hfag/</u>
<u>http://ckmfitter.in2p3.fr/</u>
<u>https://pprc.qmul.ac.uk/research/utfit</u>

Putting the triangle together



Where we are now…

$\overline{\rho} = 0.15 \pm 0.01$
$\overline{\eta} = 0.34 \pm 0.01$

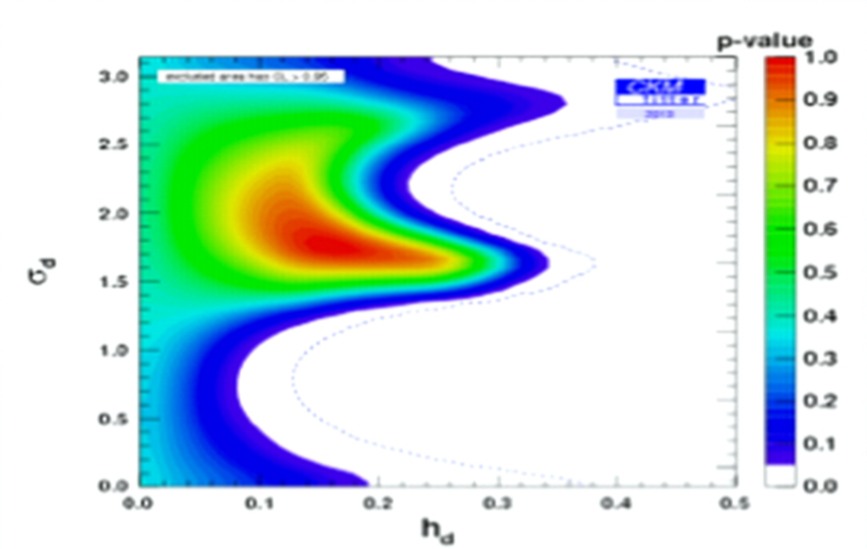


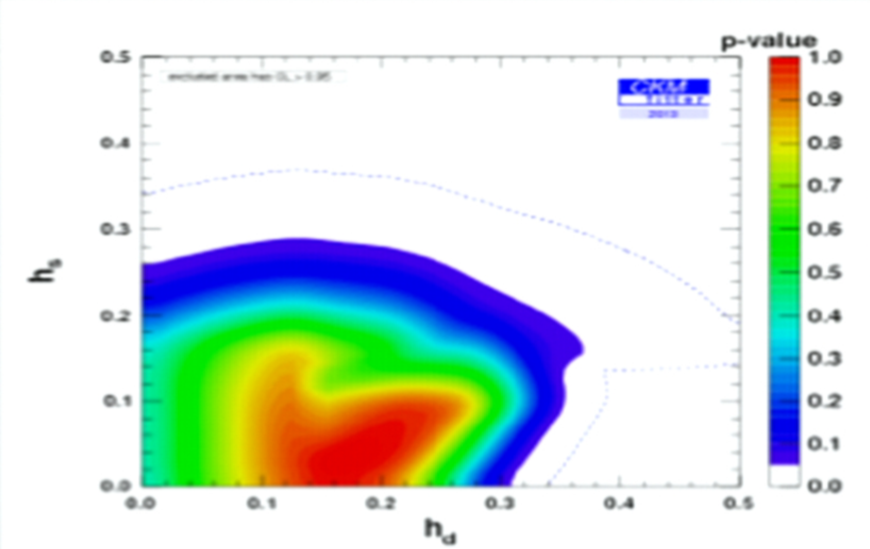
This is a triumph of the HEP community!

(on par with the Higgs IMO)

How goes the CKM Paradigm?

$$M_{12}^{d,s} = (M_{12}^{d,s})_{\rm SM} \times \left(1 + h_{d,s}\, e^{2i\sigma_{d,s}}\right)$$





Charles, Jérôme et al. Phys.Rev. D89 (2014) 3, 033016
arXiv:1309.2293 [hep-ph]

...nothing to see here...

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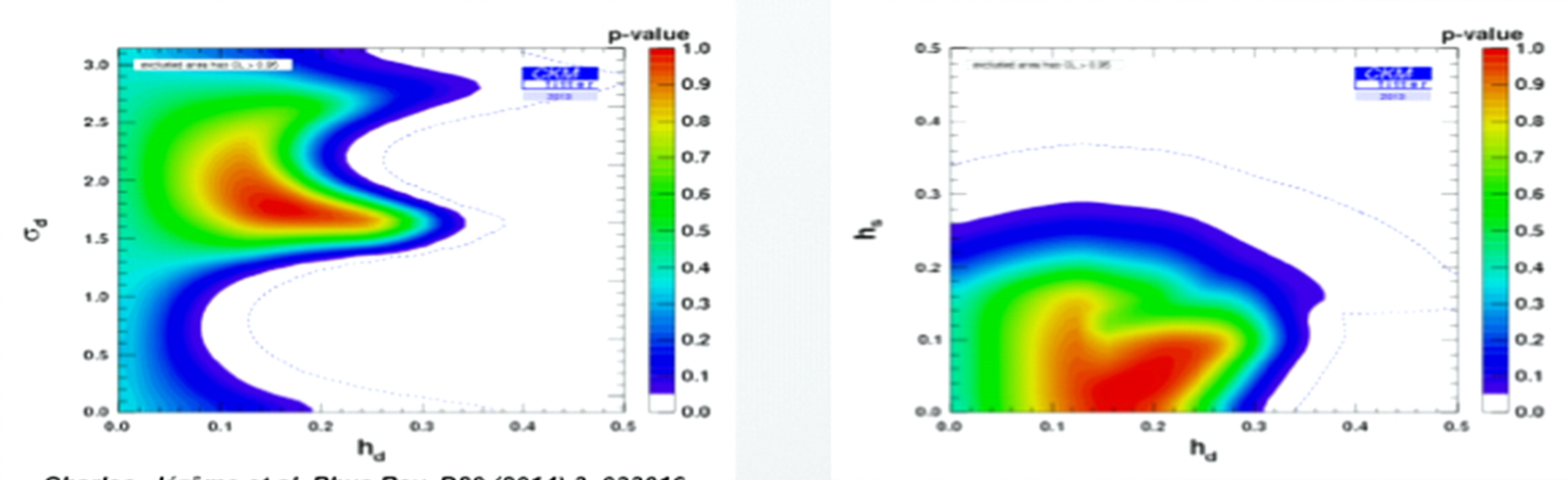

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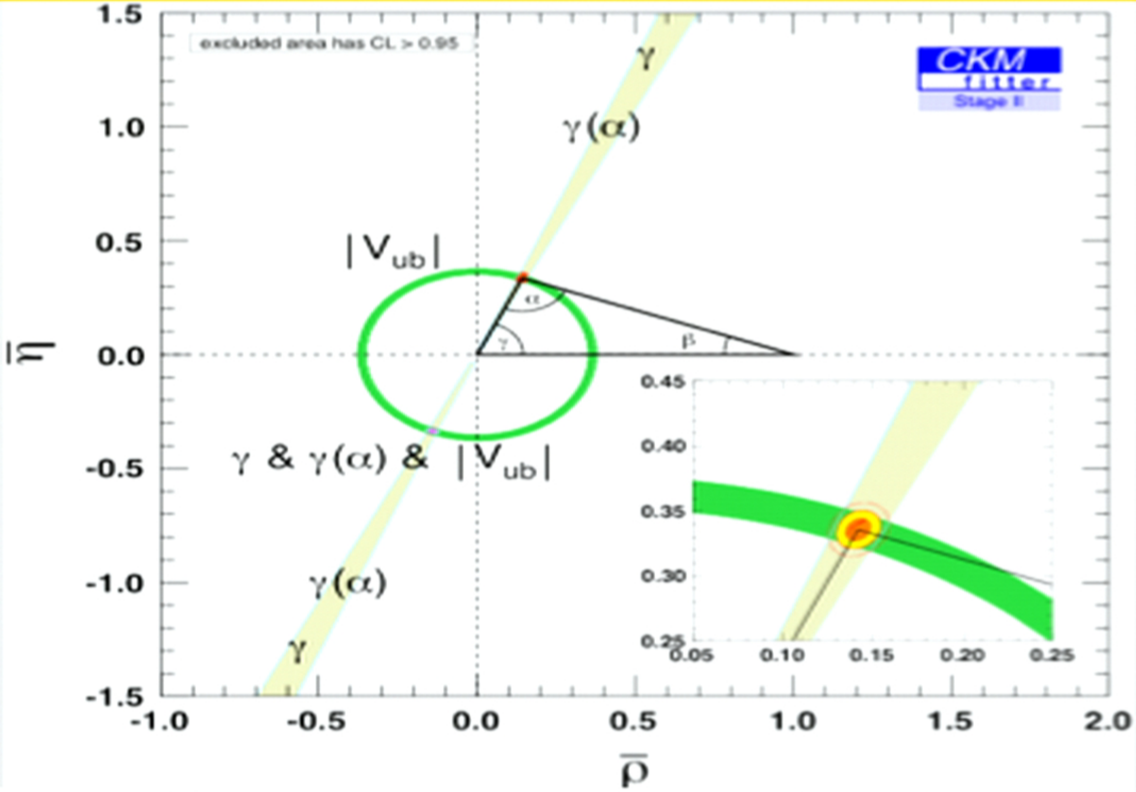
UT in 2025?



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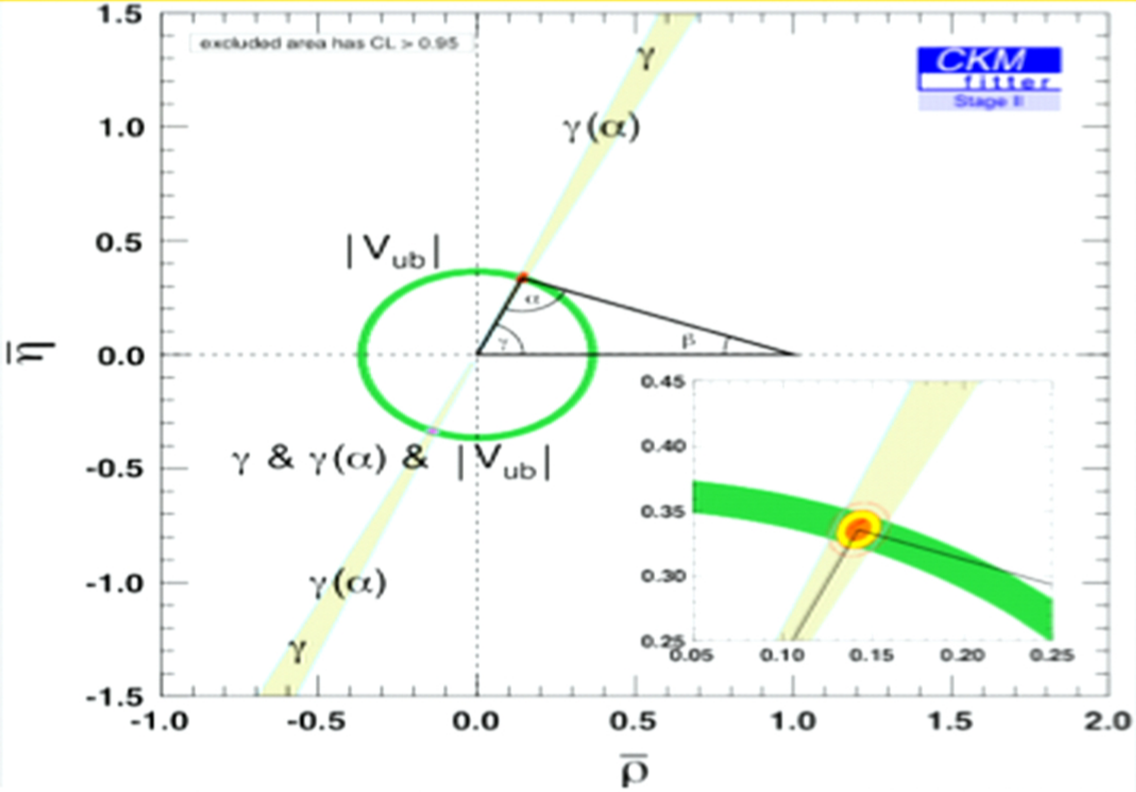

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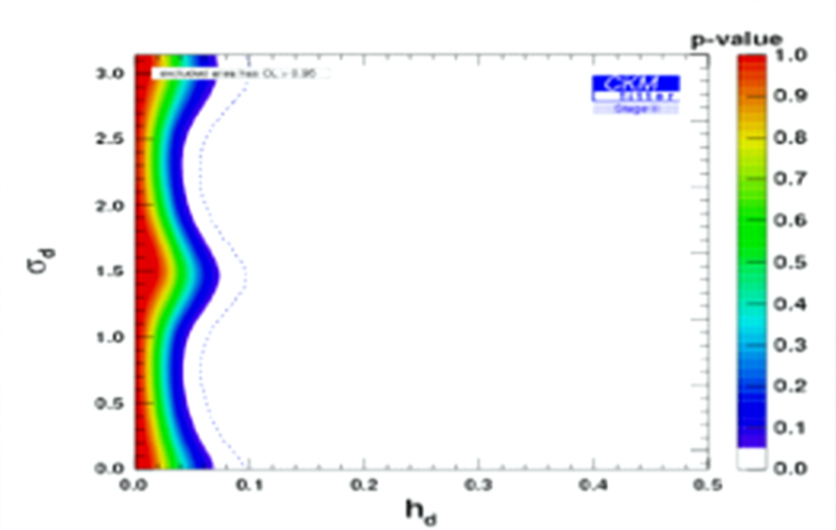
NP in 2025?

We'll see significant improvement in sensitivity to NP in the next ~10 years



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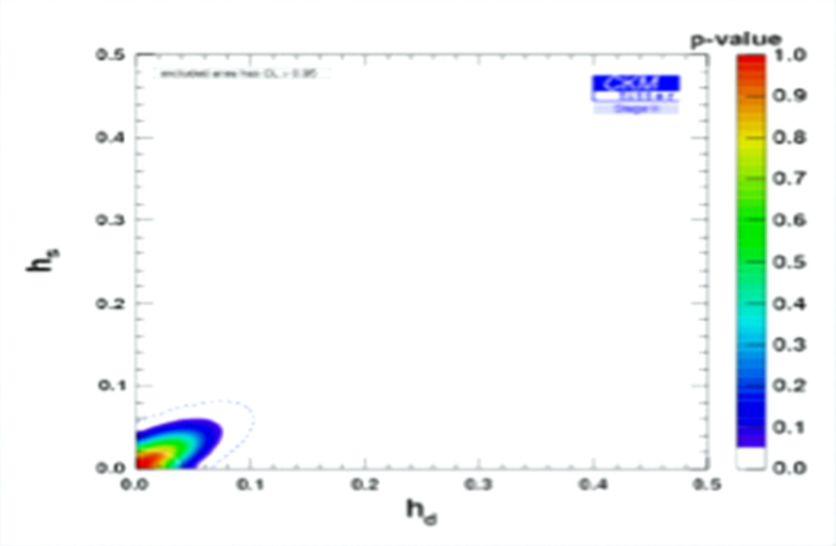
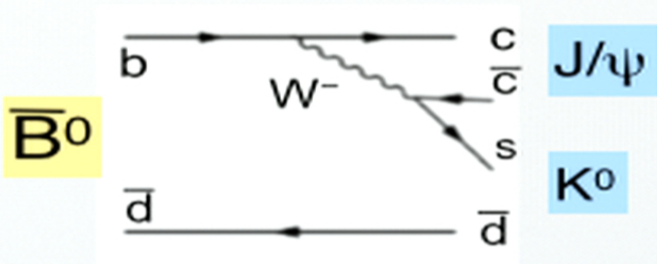
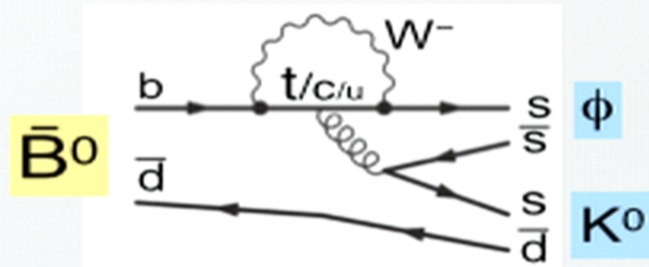


Penguinic B-Decays

$B^0 \rightarrow (\bar{q}q)K^0$ decays $\rightarrow$ gluonic penguin (+ other)



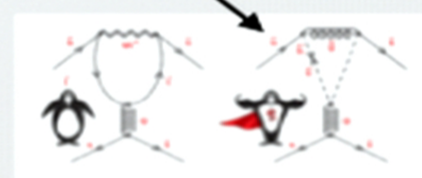


BR~ 10^{-3}

BR ~ 10^{-5}

$S=\sin 2\beta$
$C=0$

$S=\sin(2\beta+\delta_{NP})$
$C=a_{NP}$



…sensitive to NP contributions with different **weak** phases

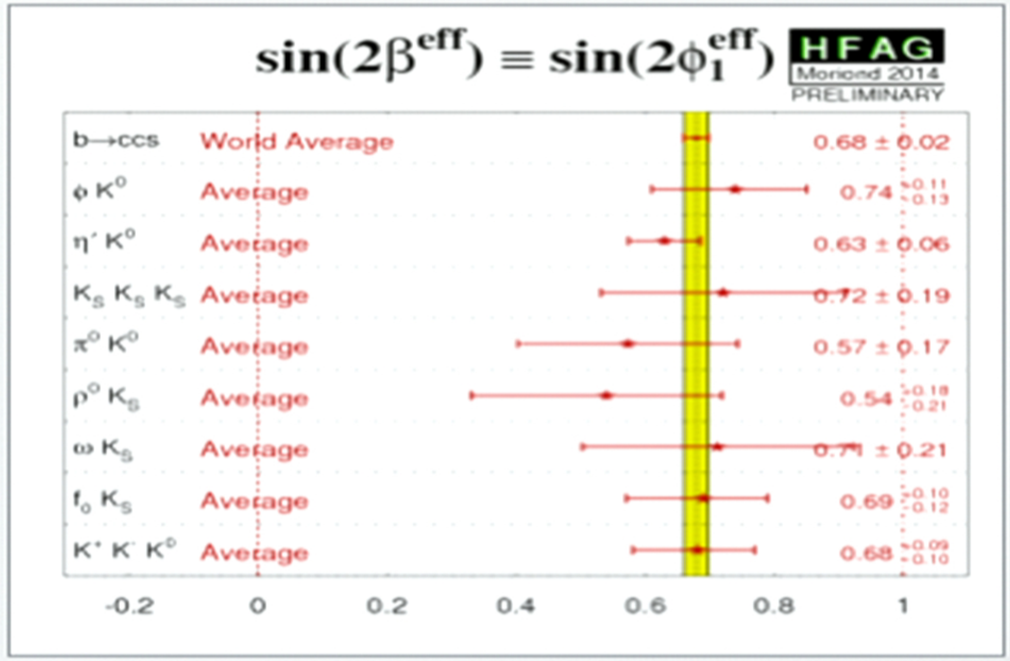
…some final states have more hadronic uncertainties than others (tree diagrams; rescattering); hard to calculate

TD-CPV From Penguins

There are a large number of final states used to probe for NP in gluonic penguins:

$B^0 \rightarrow (\bar{s}s)K^0$: ϕK_s, $\eta' K_s$
⇛ ~0 tree level pollution …
”golden modes”

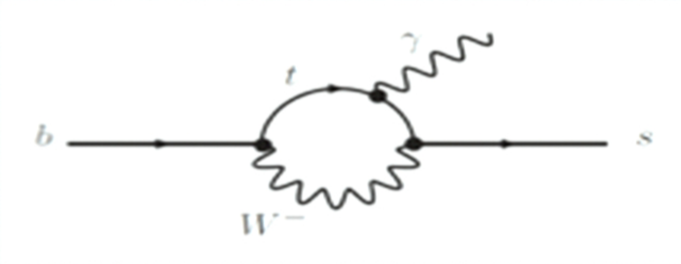
$B^0 \rightarrow (\bar{q}q)K^0$: $\pi^0 Ks$, ρKs, ωKs
⇛ some small pollution; part of the picture



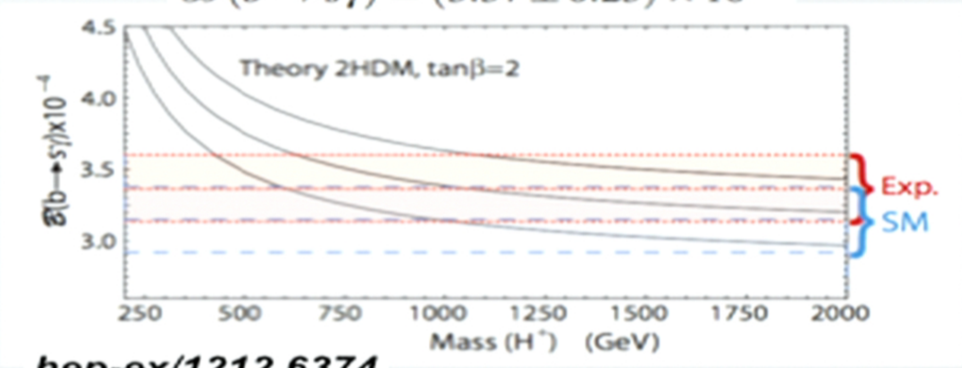
As of today, excellent agreement with sin2β
this has not always been the case…

EW Penguins: $B \rightarrow s\gamma$

electroweak penguin analog of gluonic penguin



$\mathcal{B}(b \to s\gamma) = (3.37 \pm 0.23) \times 10^{-4}$



hep-ex/1212.6374

same story as before, but EW process makes things easier to calculate

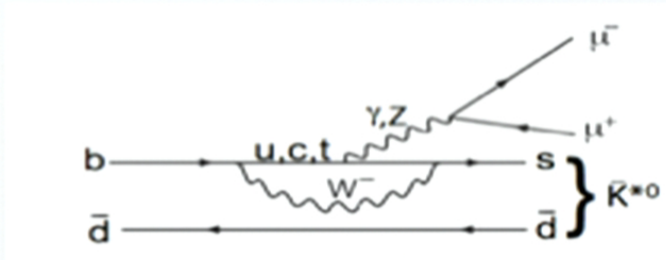
…in particular, be inclusive! The more, the less hadronic uncertainty

Measure $B \rightarrow X_s\gamma$

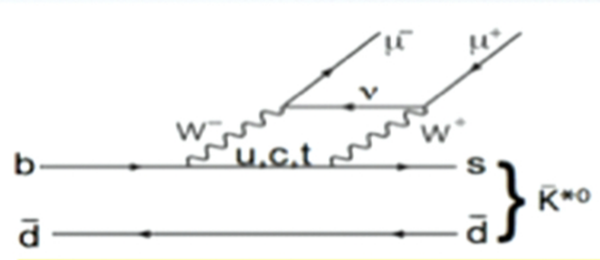
…where X_s=nK+mπ

the most recent BaBar result used 38! final states (hep-ex/1207.2520)

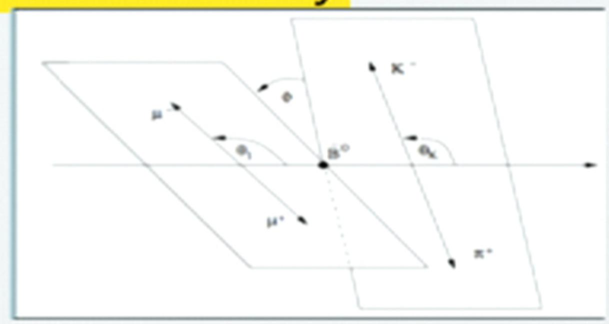
EW Penguins : B⟶K*μμ



b⟶sɣ*



ν-less double "b" decay



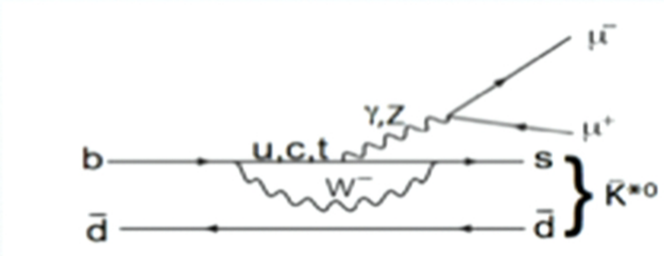
K*μμ has ***11*** angular observables that are ***calculable*** and sensitive to NP.

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\Big|_{\mathrm{P}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K + \tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos2\theta_l - F_{\mathrm{L}}\cos^2\theta_K\cos2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos2\phi + S_4\sin2\theta_K\sin2\theta_l\cos\phi + S_5\sin2\theta_K\sin\theta_l\cos\phi + \tfrac{4}{3}A_{\mathrm{FB}}\sin^2\theta_K\cos\theta_l + S_7\sin2\theta_K\sin\theta_l\sin\phi + S_8\sin2\theta_K\sin2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin2\phi\Big].$$

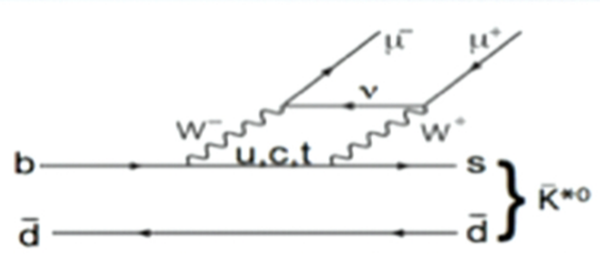
exercise:
derive this

…this is only 8.

EW Penguins : B→K*μμ



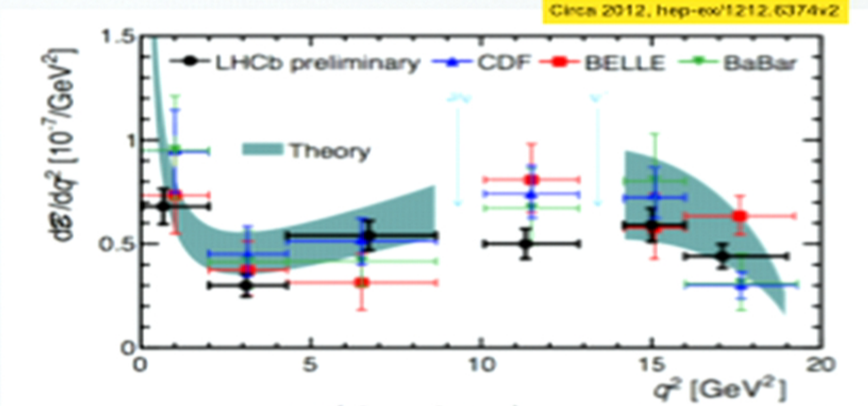
b→sɣ*



ν-less double "b" decay

in the past, measured BR & A_{FB} vs q^2…all was good

Circa 2012, hep-ex/1212.6374v2



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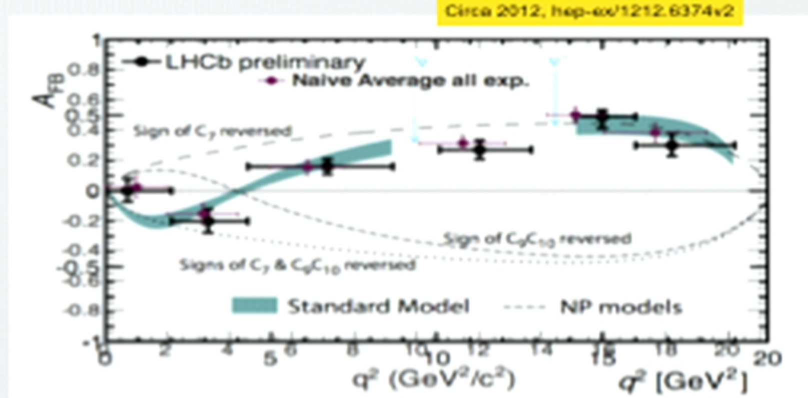


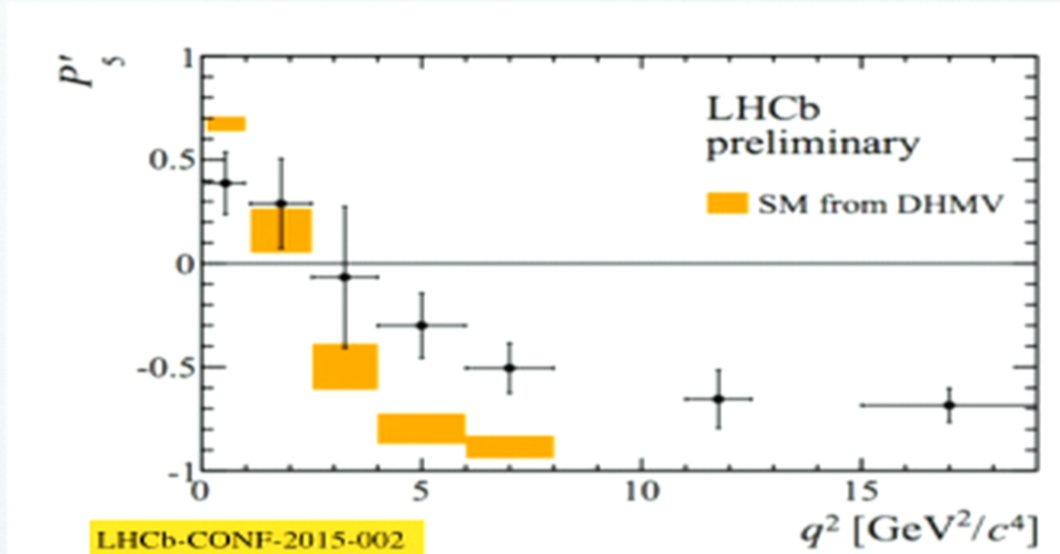
*Anomaly in B⟶K*μμ ?*

Recently (well 2013, but updated in 2015) LHCb performed full angular analysis…

mostly good agreement with SM

However, the observable P_5' exhibits a local tension with respect to the Standard Model prediction at a level of 3.7σ.

$$P_{4,5} = S_{4,5}\sqrt{F_L(1 - F_L)}$$



Do we believe it?

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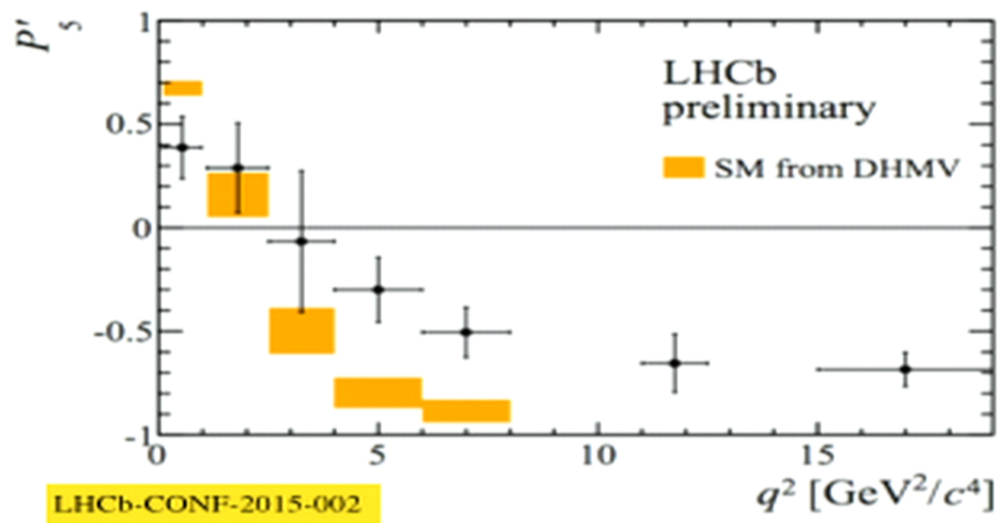
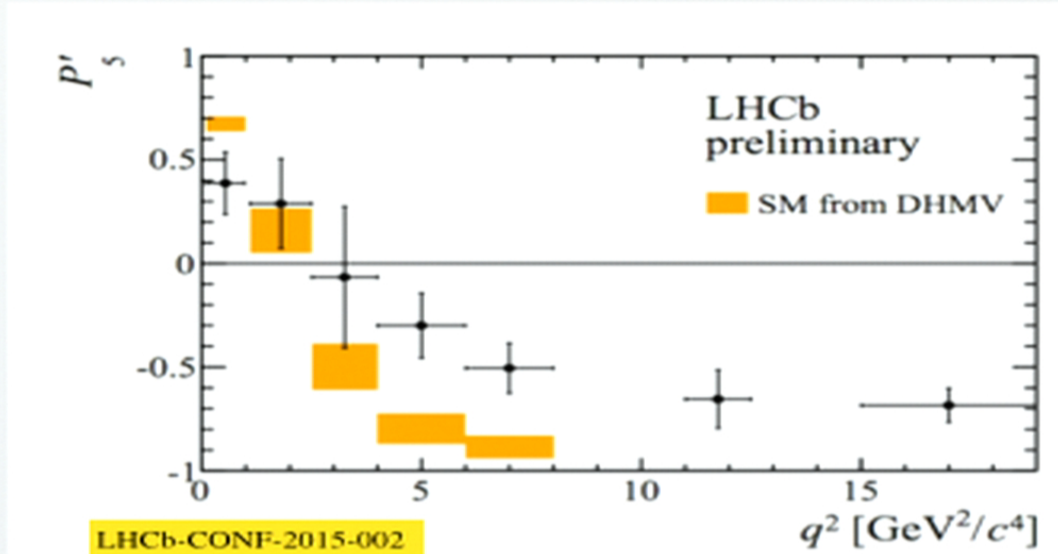


Anomaly in B⟶K*μμ ?

Recently (well 2013, but updated in 2015) LHCb performed full angular analysis…

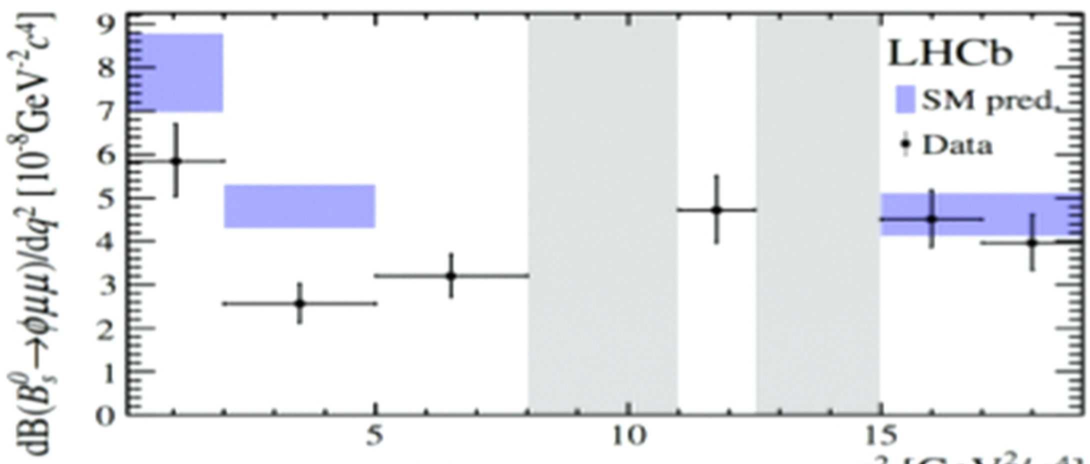
Do we believe it?
…no probably not.

- "**global**" significance <<3.7**σ**… many combinations of variables
  - why not take a ΔLkl with SM parameters?
- there is definite disagreement on the theory side … we may be starting to hit that limit



What about $B_s \rightarrow \phi\mu\mu$?

$B_s \rightarrow \phi\mu\mu$ basically same as $B \rightarrow K^*\mu\mu$
⇨ only spectator is different
⇛ $\phi\mu\mu$ **is** a CP-eigenstate
⇨the $K^*\mu\mu$ averaged over CP anyway



hep-ex/1506.08777

Another ~3(.5)**σ** discrepancy

…in the total BR this time.

Do we believe it now?

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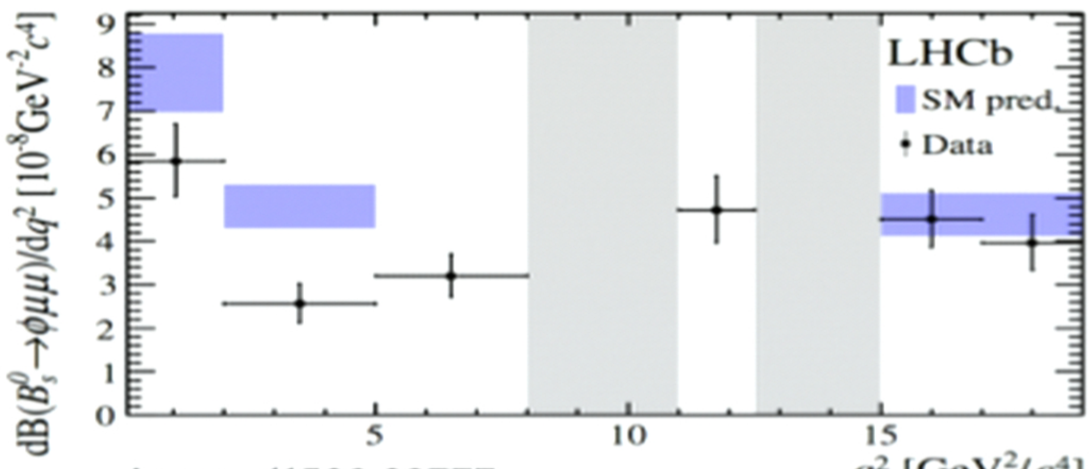

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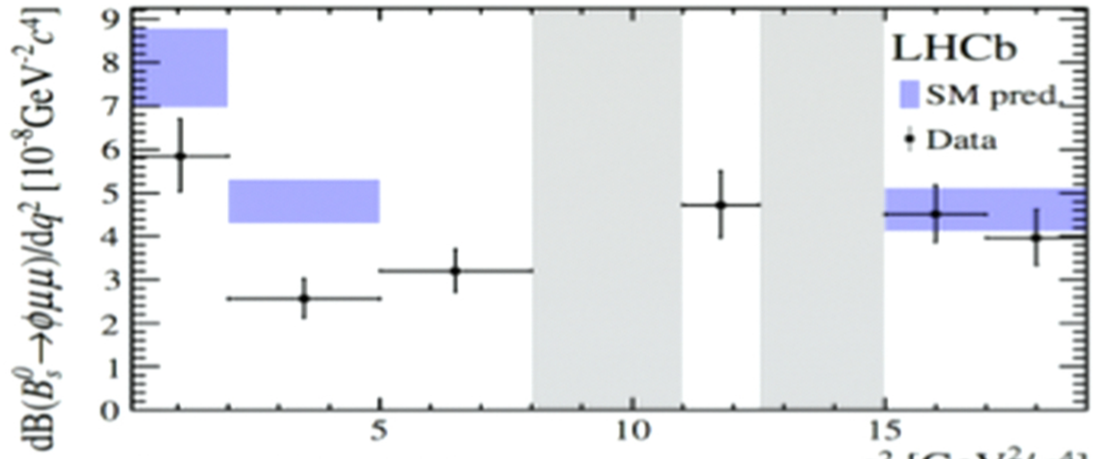

hep-ex/1506.08777

…in the total BR this time.

Do we believe it now?
…I'll leave that as an exercise for the class.

First Intermission

- Flavor physics is fun and exciting and a great place to look for physics beyond the standard model
- It can reach energy scales >> LHC
- It's not completely generic, though…e.g. can imagine NP with the same flavor structure as the SM
  - "Minimal Flavor Violation"
- Still, there are lots of places heavy NP could show up… hasn't yet…