CKM elements and CP violation

Jonas Rademacker, University of Bristol

PPAP community review of particle physics science programme
Birmingham University Physics Department: July 13,14,15 2009.

Credits

- Thanks to

  Adrian Bevan, Diego Bettoni, Ulrik Egede, Bostjan Golob, Ikaros Bigi, George Hou, Robert Fleischer, Tim Gershon, Patrick Koppenburg, Cristina Lazzaroni, Jim Libby, Franz Muheim, Klaus Peters, Maria Smizanska, Patrick Spradlin, Guy Wilkinson, ...

Flavour Physics

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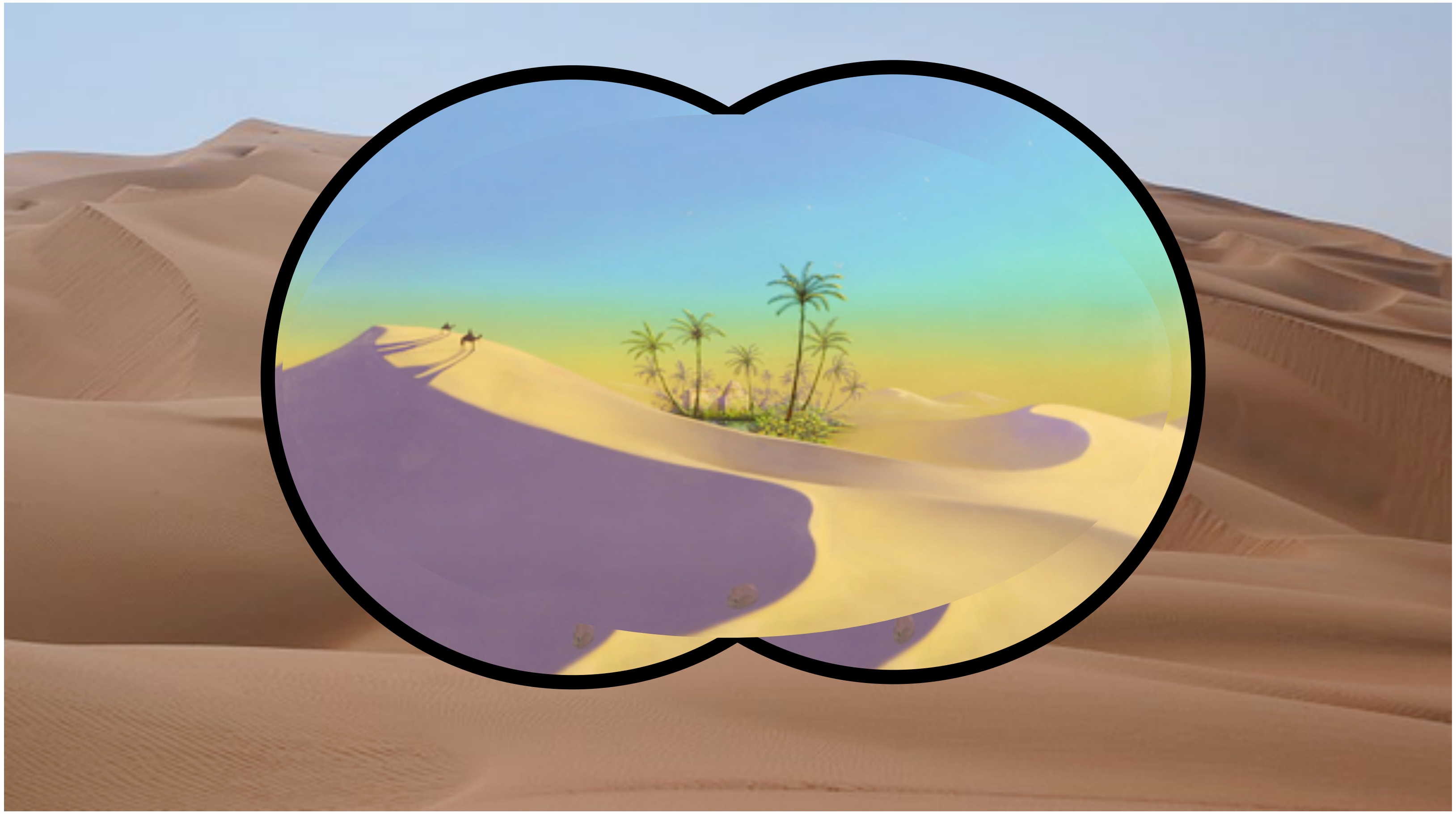

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The cost of clear vision

Strategy for this talk

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- The question - as I understand it - is: What can be done after 2014? and: What needs to be done in 2014 and beyond?
- So much is clear: Flavour Physics will measure coupling constants and phases where “New Physics” and “old physics” interact. We’ll see beyond the energy frontier. It will provide essential input to model building.
- Because we expect nothing less than a revolution from the LHC, it is impossible to know the specific measurements that will be the most important in 2014.
- To provide specific examples, we’ll look at “Hot Topics in CKM/CPV now”, make an educated guess where they could be in 2014, and evaluate whether a significant increase in statistical precision is likely to have high impact.

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- We need to identify theoretically clean measurements with high sensitivity and discriminating power for New Physics models.

How Precise is Precise enough

- Estimated Lattice QCD precision on important flavour physics parameters (made 2006 - up-to-date numbers in Jonathan's talk):

	Now 2006	2010 40 TFlop Yr	2014 1 PFlop Yr
B_k	11%	4%	2%
$f_{Bs}\sqrt{B_{Bs}}$	13%	4%	2%
ξ	5%	2.5%	1.5%
V_{ub} excl.	11%	5%	3%
V_{cb}-excl.	4%	1.5%	1%

V. Lubicz, Super-B IV Workshop (2006)

Current Flavour Experiments

- BaBar & BELLE: ca 1.5 ab^{-1}, 1.2M BB pairs. Far, far beyond anybody's dreams in 1999. Flagship measurement: sin(2β) - but achieved much more than that.

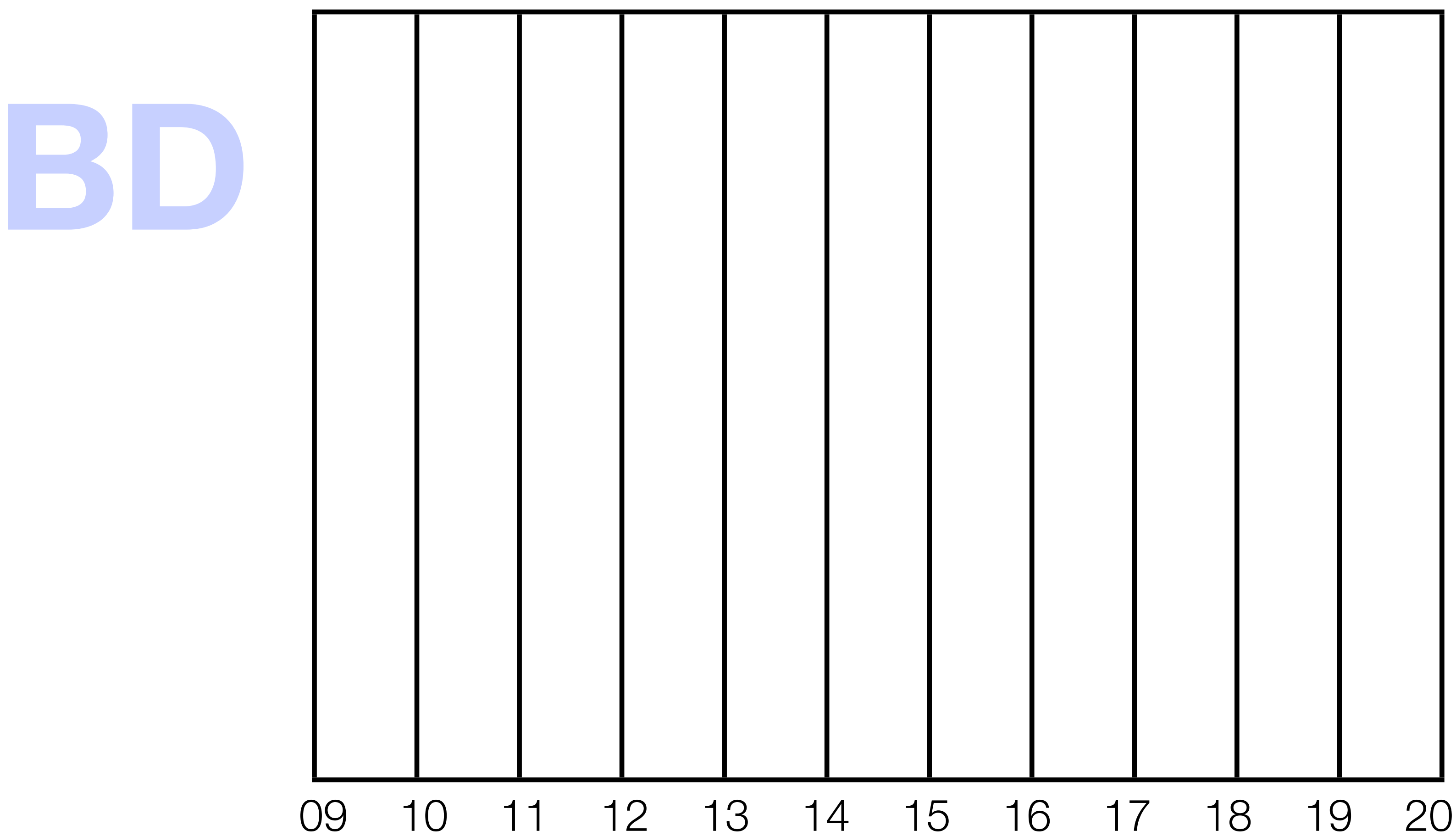
- CDF/D0: Not dedicated flavour experiments, yet a very successful ones. Flagship measurement: Bs mixing. Analysed only a fraction of their final data set.

- Charm: All of the above produce more charm than B - and together discovered charm mixing at 9 sigma.

- CLEO-c: Charm at threshold - D mesons with "special properties" - provides irreplaceable input to precision B physics, D mixing, decay constants, ...

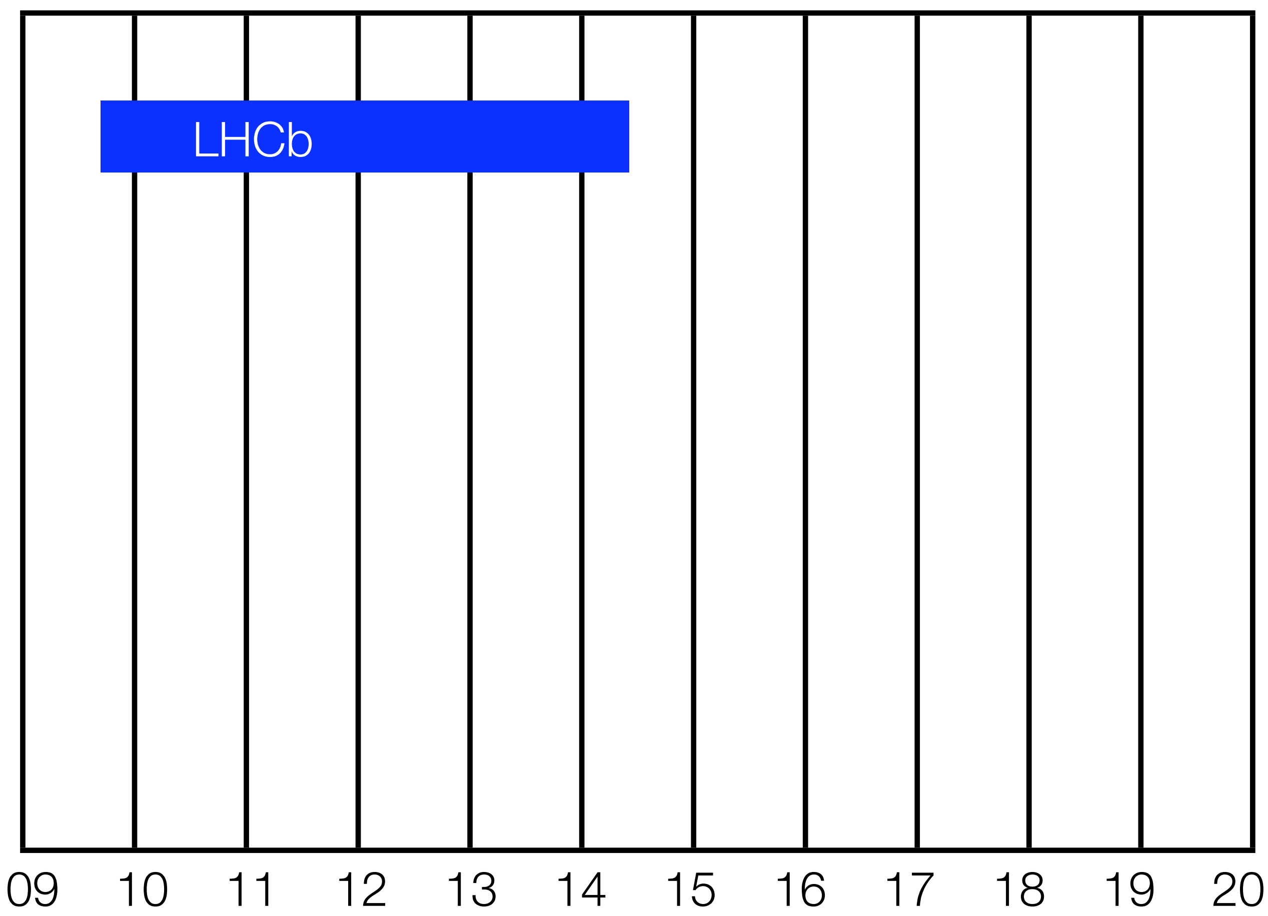
- Kaons: NA48, KTeV, KLOE ... : ε, ε', unitarity tests (|Vus|) at sub-per-mil level, rare decays.

Data taking periods of future Flavour Experiments



Data taking periods of future Flavour Experiments

BD



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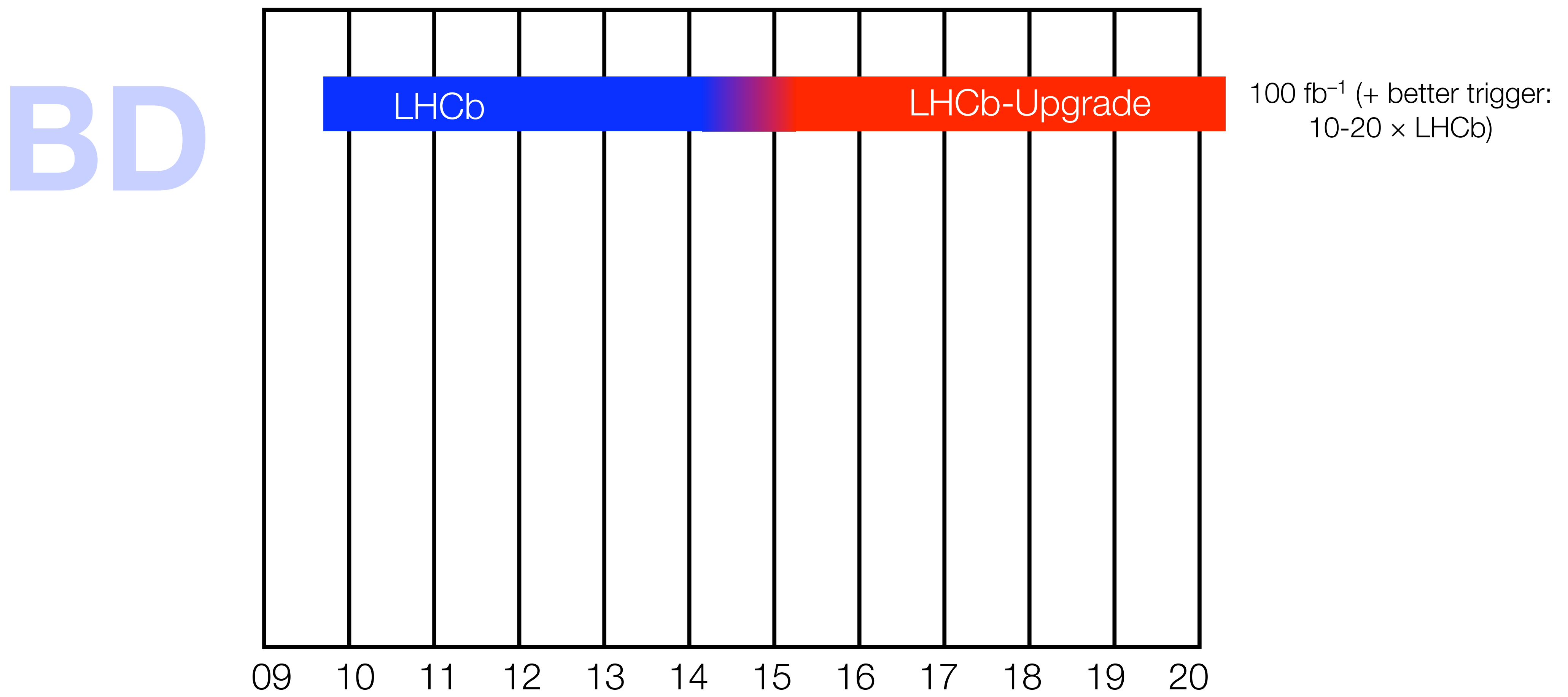

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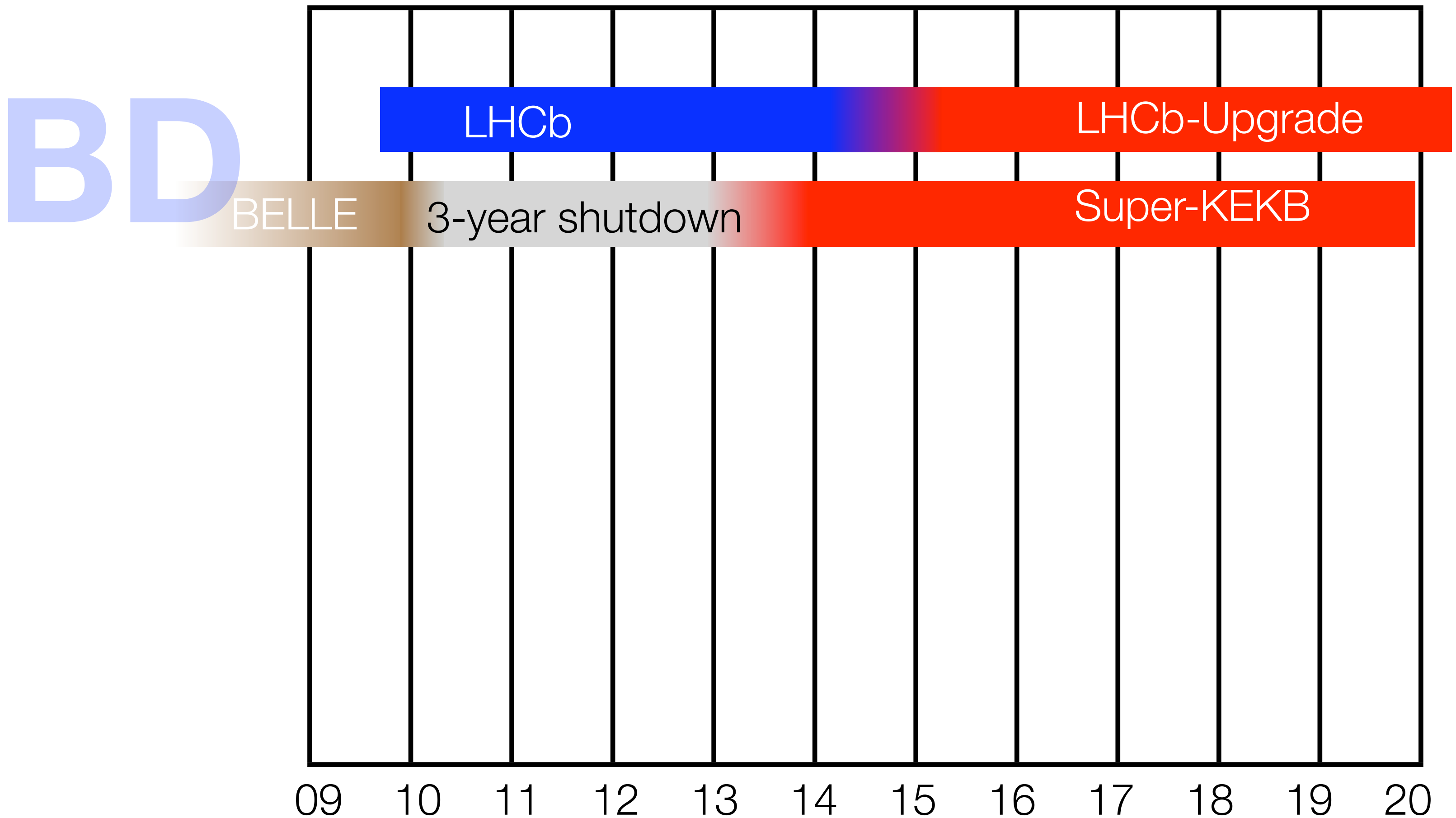

100 fb^{-1} (+ better trigger: 10-20 × LHCb)

50 ab^{-1} (30 × B-fact)

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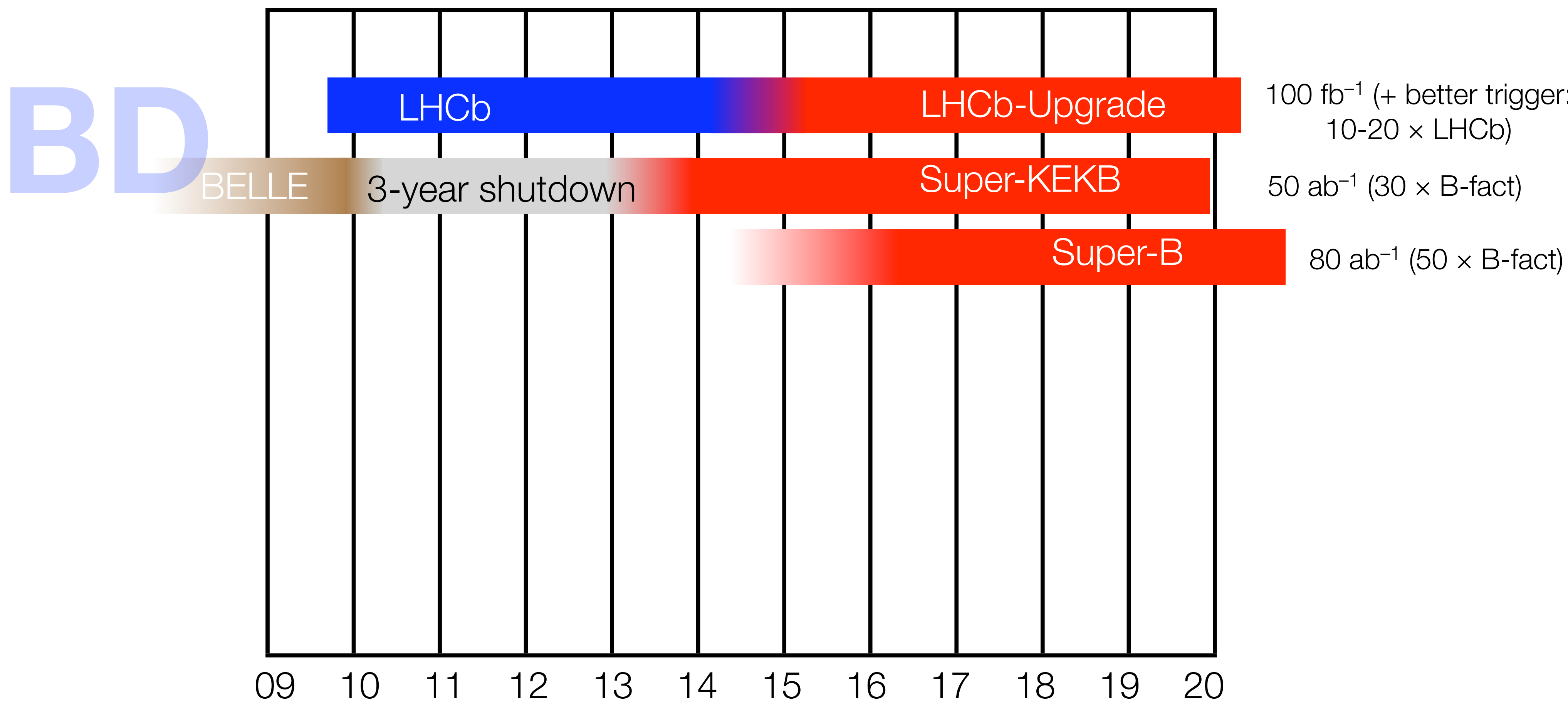

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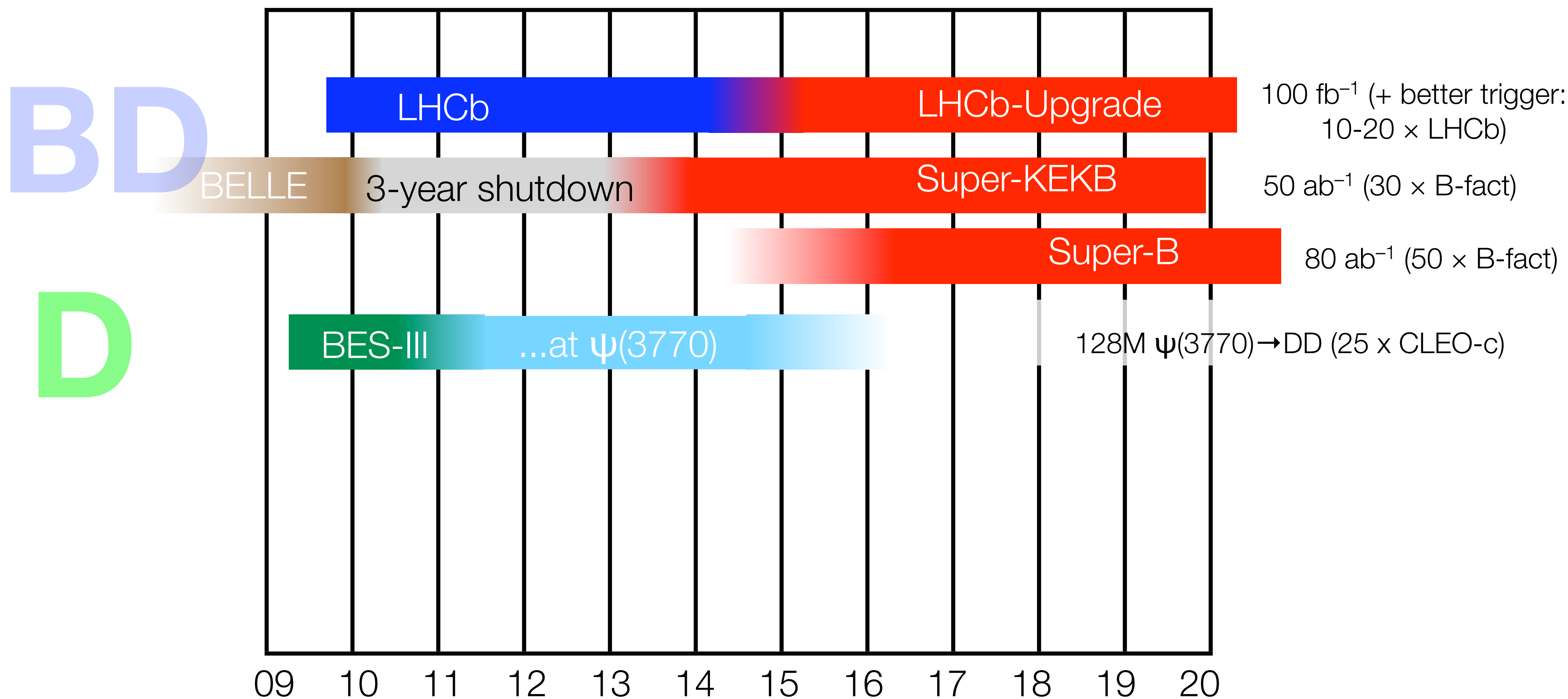

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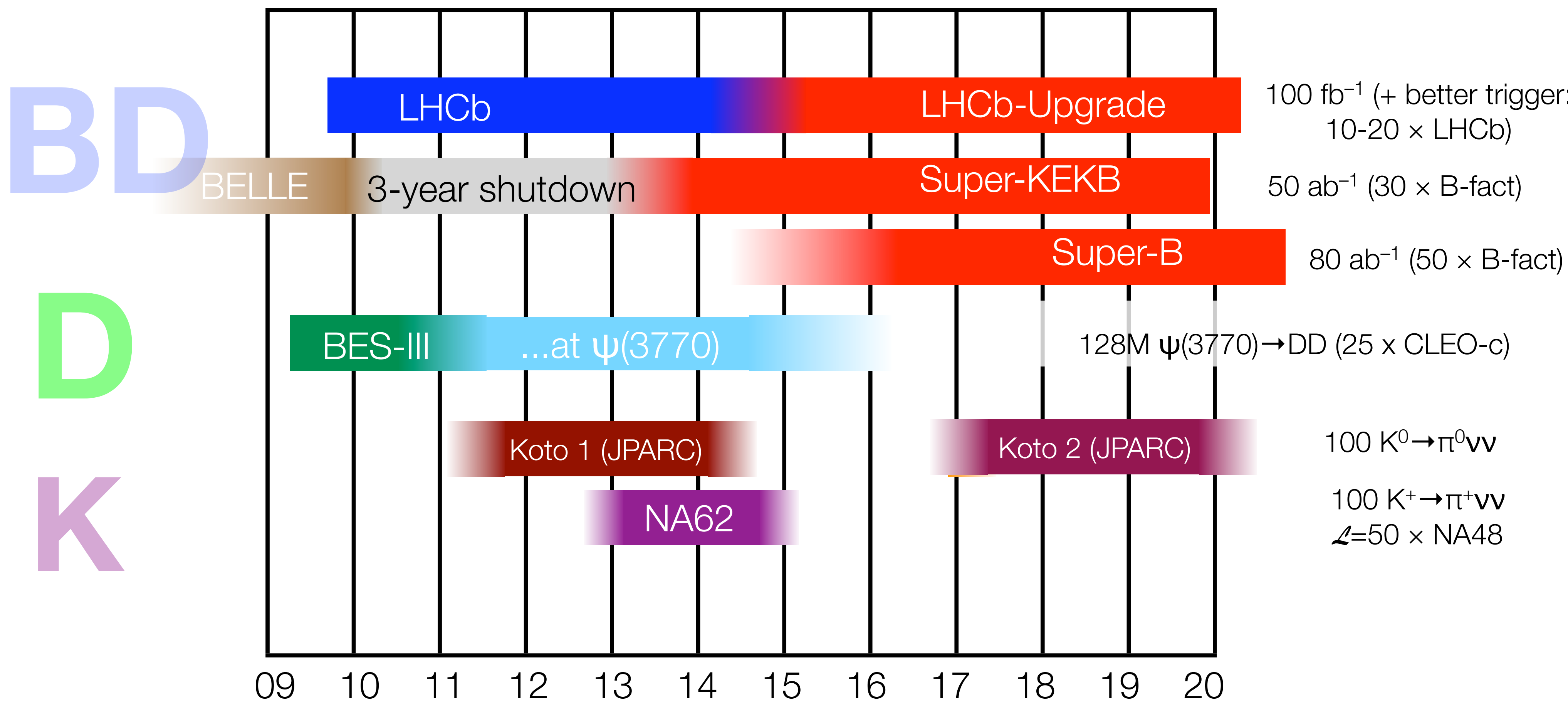

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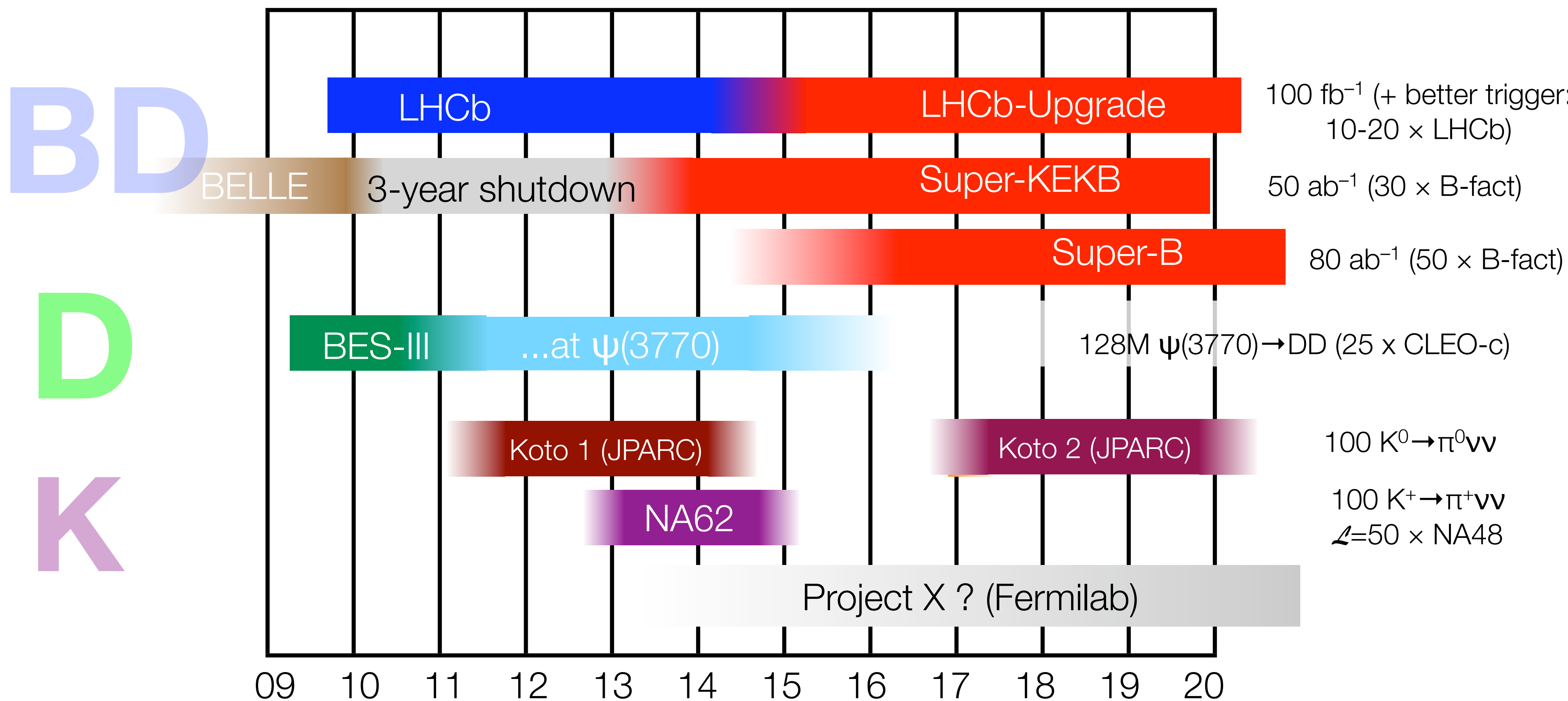


Super Flavour Factory / LHCb upgrade on one slide

- SFF: Based on the same principles as B-factories (e+ e- colliders), but much higher luminosity (~30-50 times combined BaBar+BELLE luminosity)
    - Strengths: Clean environment, good at neutrals.
    - Weaknesses: Fewer B mesons than LHCb upgrade. Only B_d, $B^{\pm}$ when running a $\Upsilon(4S)$. Could run at $\Upsilon(5S)$ to get B_s, but: smaller x- section, and insufficient time-resolution to resolve fast B_s oscillations.
- LHCb-upgrade: Uses, like LHCb, large b-x section at LHC. Higher luminosity (×10) and improved trigger (×2 efficiency for hadronic modes).
    - Strength: Enormous event yields, b-hadrons of all types (B_d, B_s, B_c, baryons, etc). Excellent time resolution.
    - Weaknesses: More background, no beam-constraints, not good at neutrals.

Numbers & Assumptions

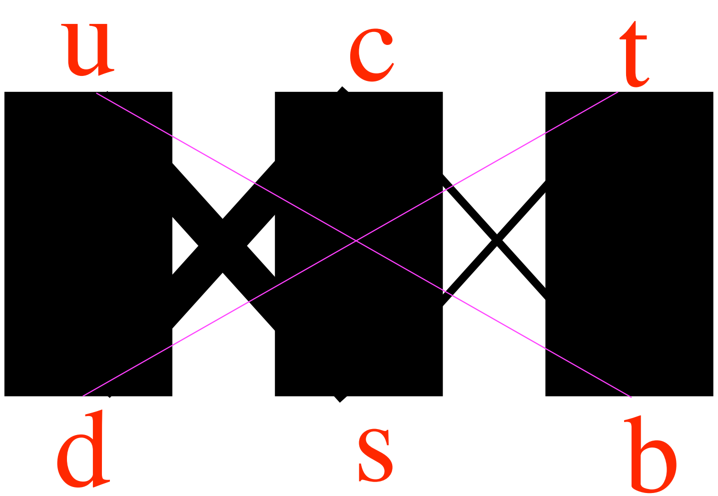
- 2014: Precision will be dominated by LHCb (except for modes that LHCb cannot do). Assume 10fb^{-1} of data by 2014.

- 2020:

  - LHCb-Upgrade: 10×LHCb for modes with leptons, 20×LHCb for hadronic modes. Statistics only.

  - Super Flavour Factory: Based on SuperB CDR for 75 ab^{-1} (50× combined current B-factory). This in turn is based on scaling BaBar & BELLE numbers. Considers systematics, but usually assumes that they can be improved in line with statistics.

CKM matrix

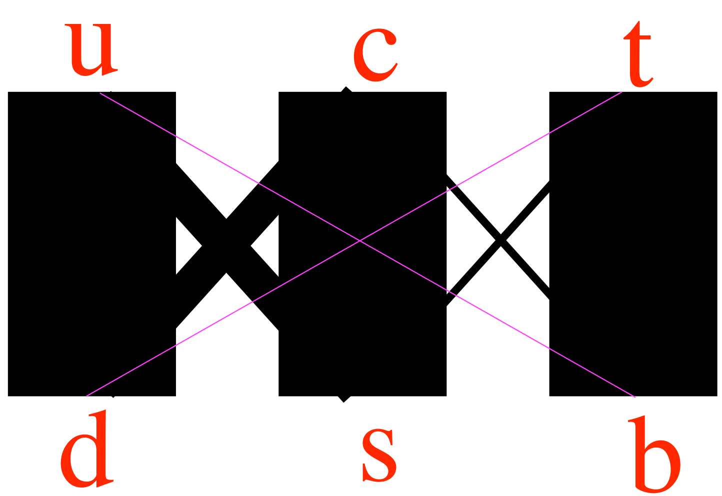


$$V_{CKM} \approx \begin{array}{c} \\ d \\ s \\ b \end{array} \begin{array}{c} \begin{array}{ccc} u & c & t \end{array} \\ \begin{pmatrix} 1 & \lambda & \lambda^3 e^{-i\beta} \\ -\lambda & 1 & \lambda^2 \\ \lambda^3 e^{-i\gamma} & -\lambda^2 & 1 \end{pmatrix} \end{array}$$

where λ=0.22

structure of the quark mixing matrix

CKM matrix



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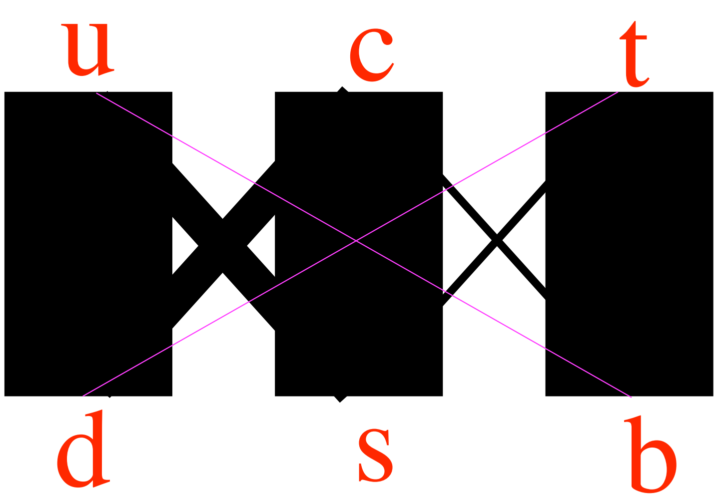

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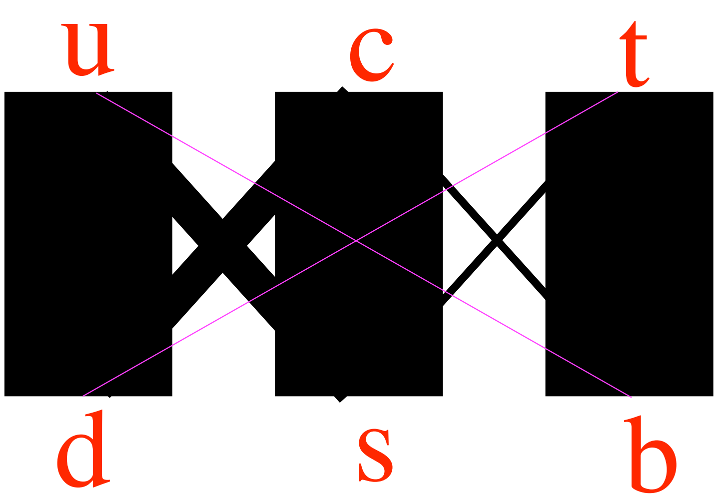

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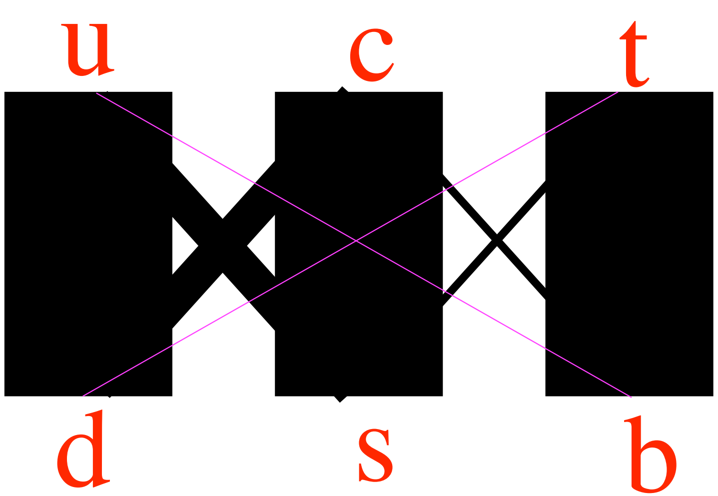
$$V^\dagger V = \begin{pmatrix} V_{ud}^* & V_{cd}^* & V_{td}^* \\ V_{us}^* & V_{cs}^* & V_{ts}^* \\ V_{ub}^* & V_{cb}^* & V_{tb}^* \end{pmatrix} \cdot \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

CKM matrix



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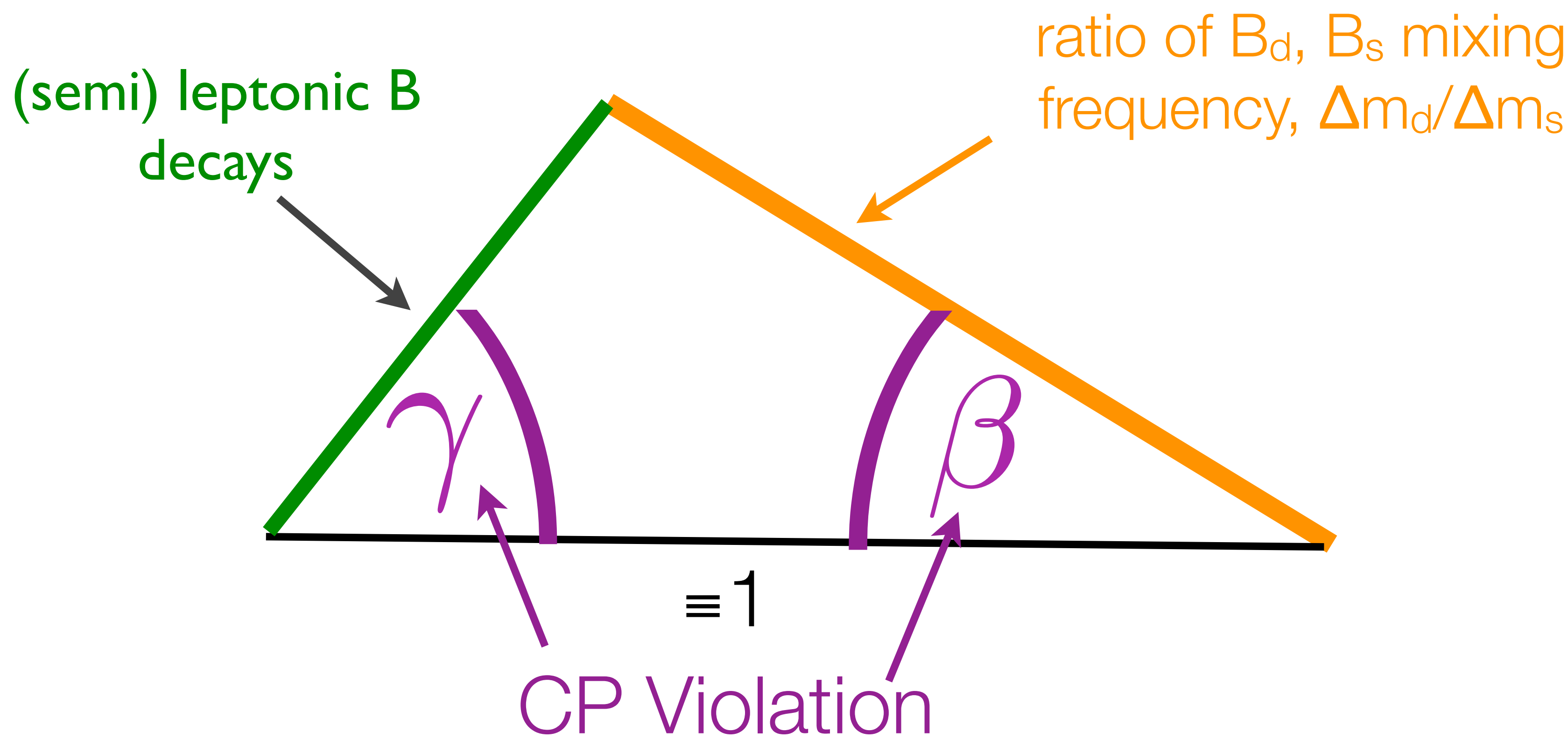
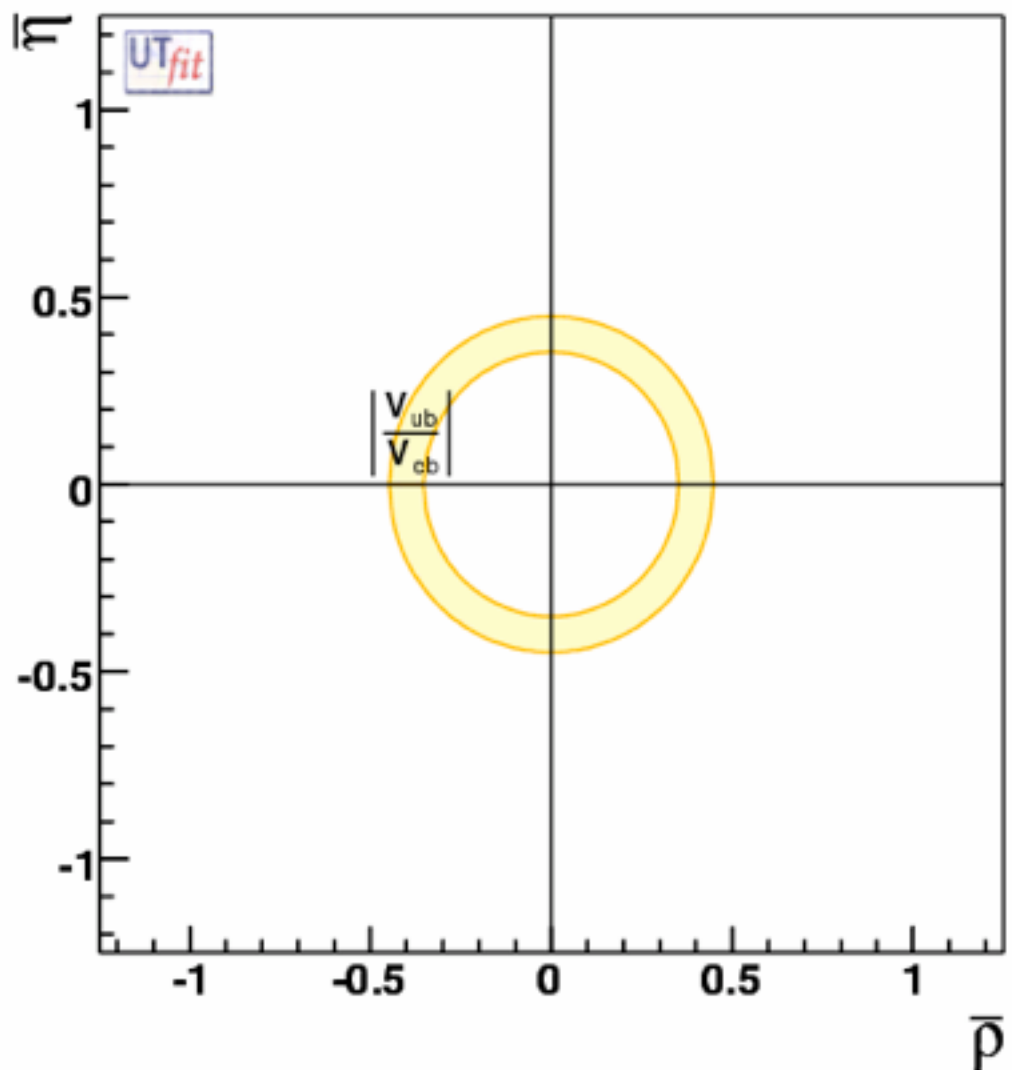
$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

Unitarity Triangle

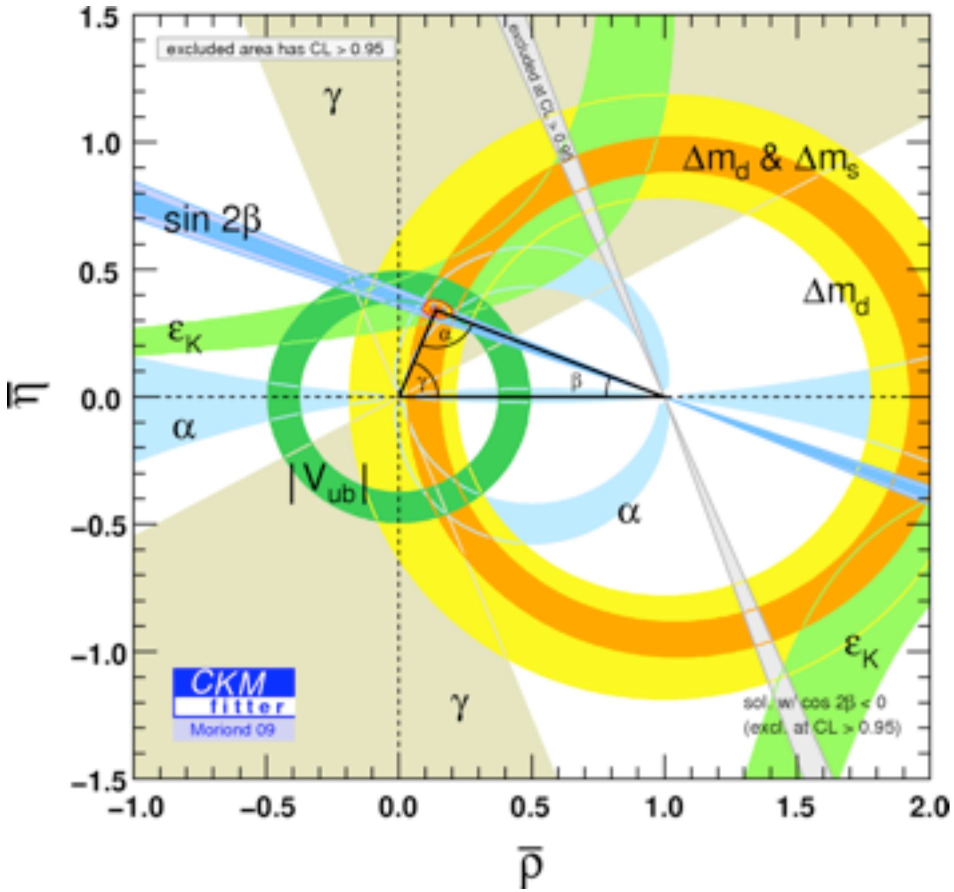


Current constraints on the apex of the UT now



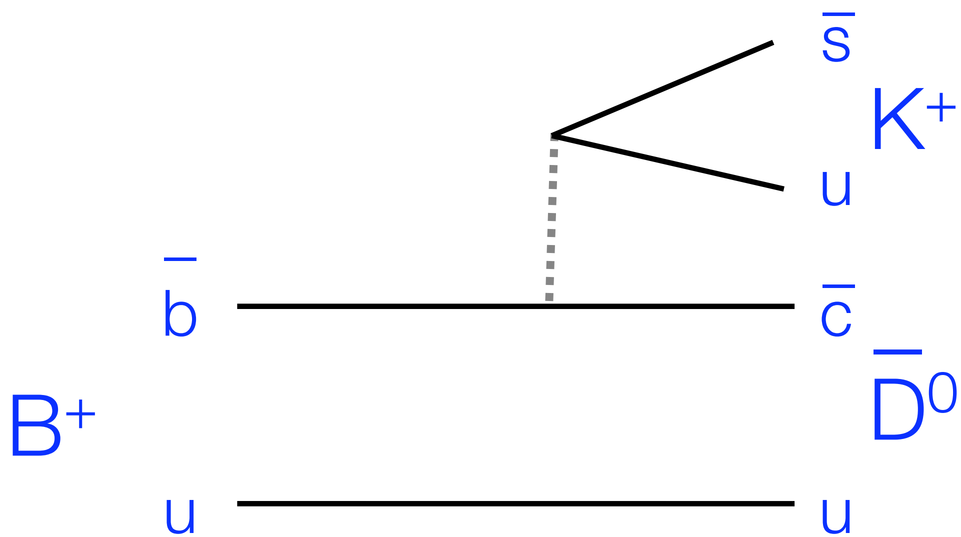
Now & Next

- Now: CKM picture of quark mixing and CPV in the Standard Model impressively confirmed at a precision of ~10%.
- Next: Exploit CKM relationships to compare new-physics sensitive loop processes with SM-dominated tree processes. Hope for mis-matches.
- Higher precision will directly translate into increased New Physics reach (see Gino's talk).

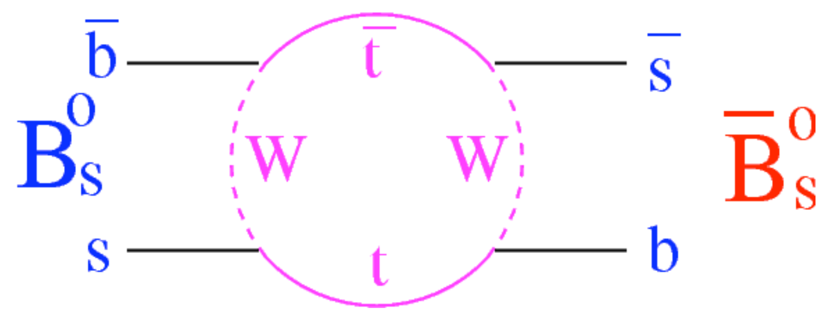


Loops vs Trees

- Expect no New Physics in Trees

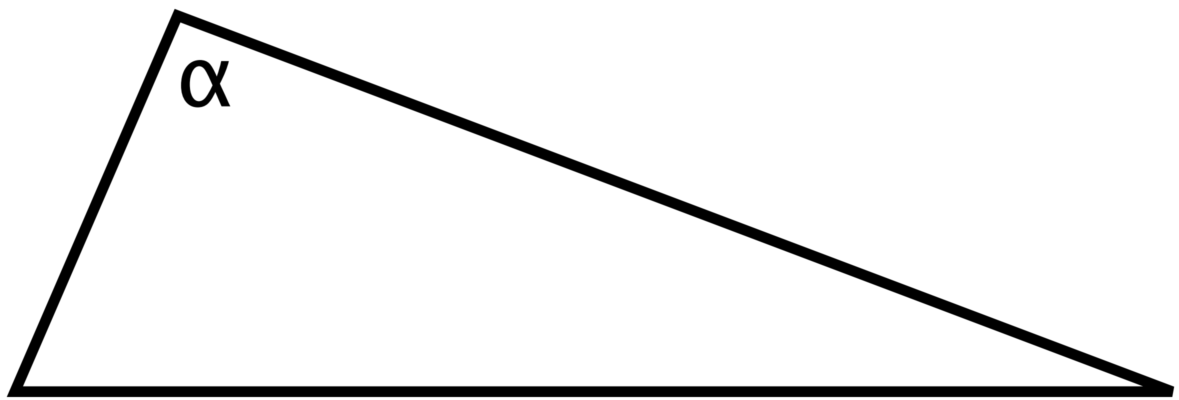


- New Physics in loops?



Loops vs Trees

- The co-incidence (?) that α≈90º gives two pairs of nearly de-coupled tree vs loop measurements.



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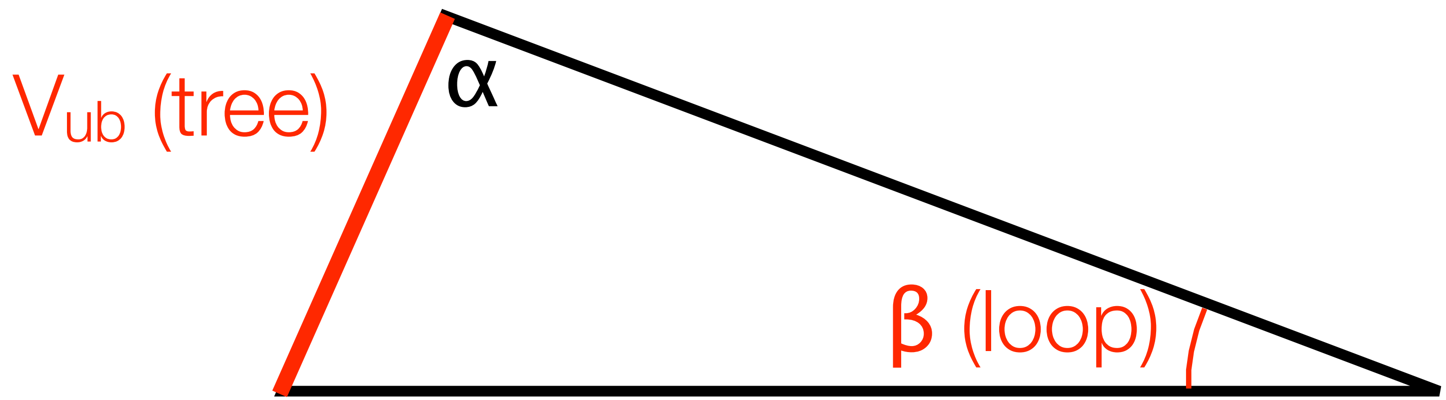

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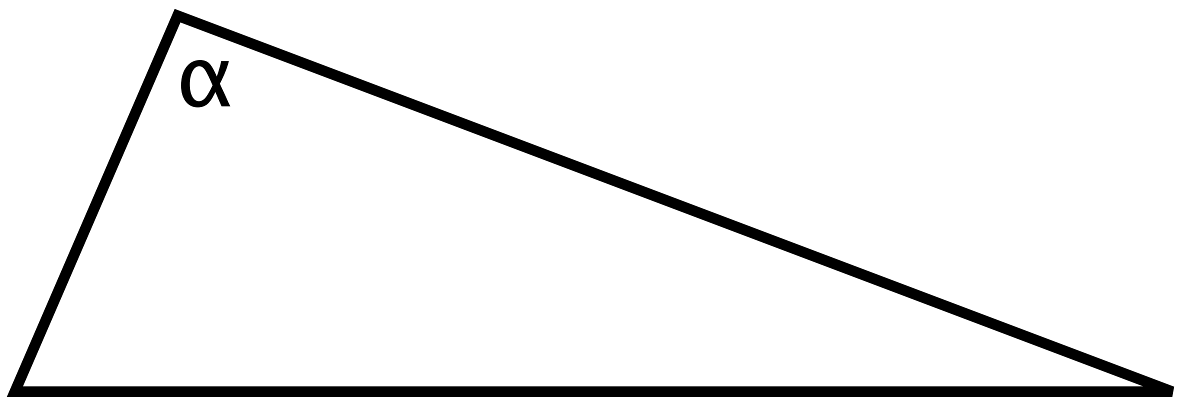

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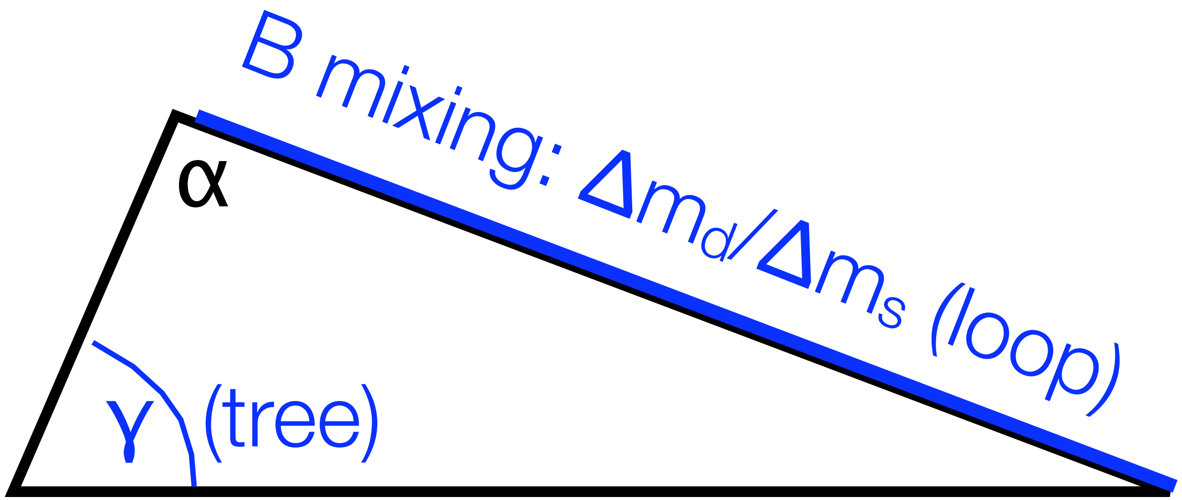

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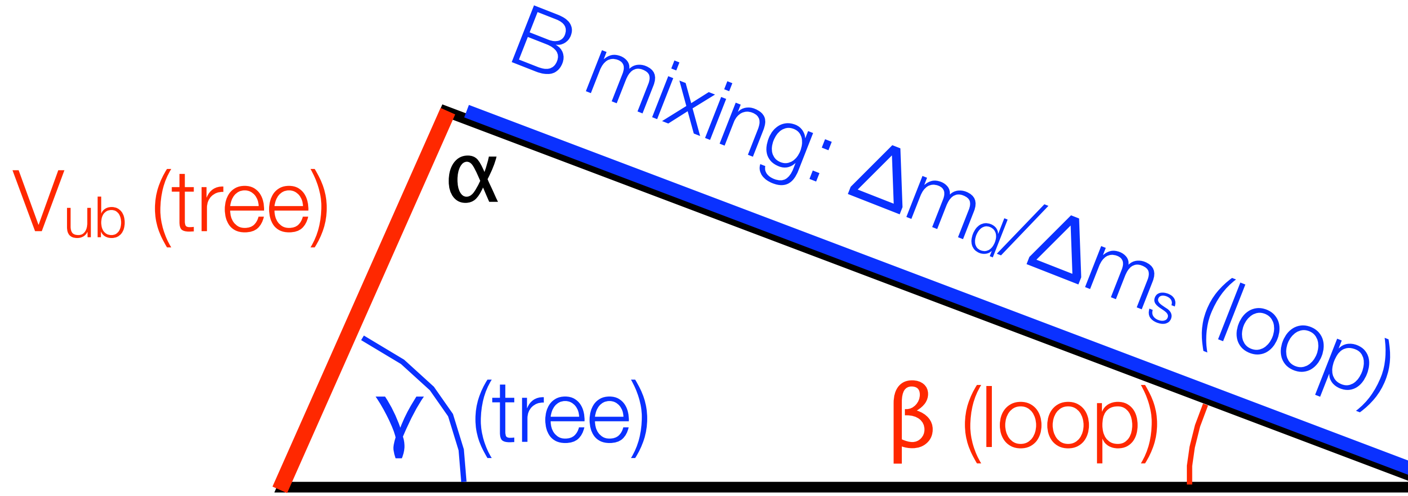
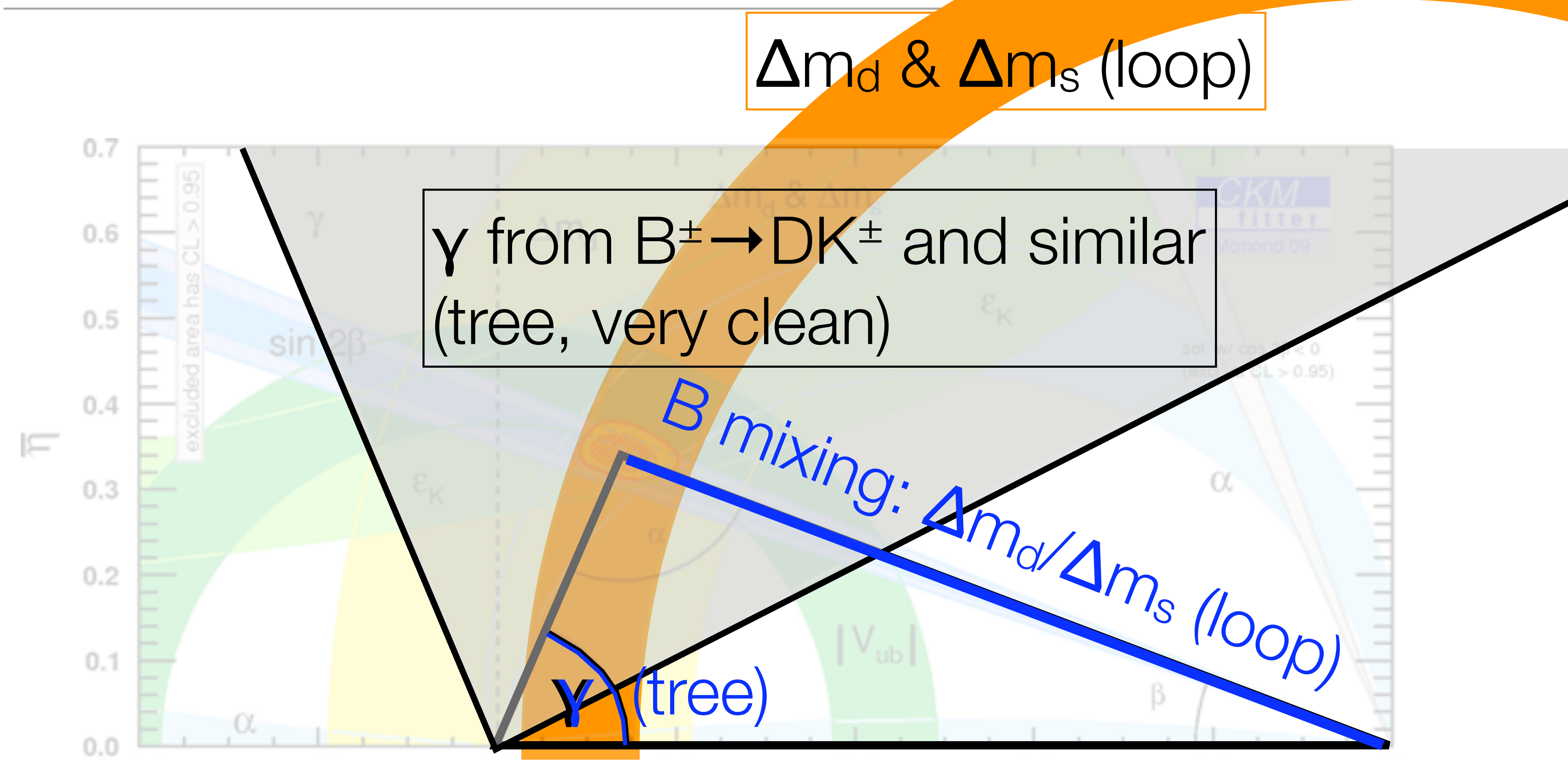


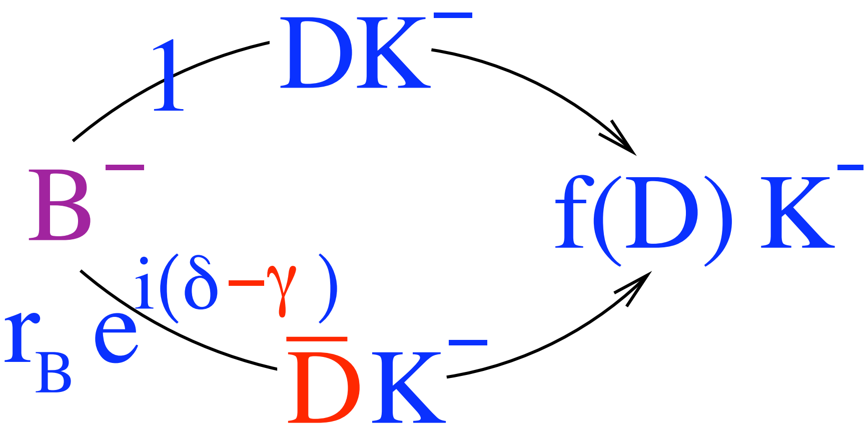
γ and Δm now

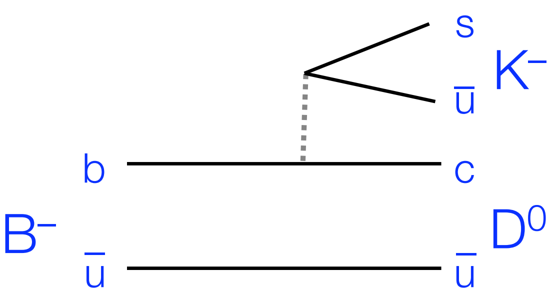


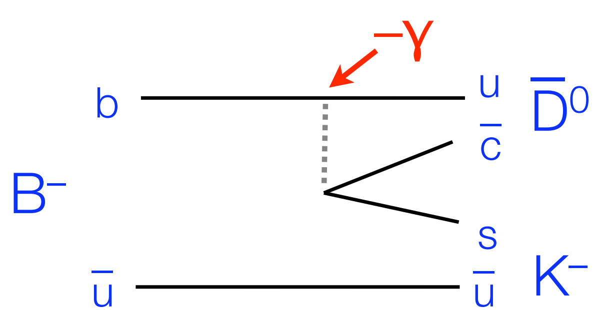
Currently: γ(direct) =70° ± 30°, dominant error: statistics

γ(from side) = 68° ± 4°, dominant error: Lattice QCD

γ from B±→DK± in 2014







- Very clean, only proceeds via trees. Pioneered by B-factories.
- Many different final states f(D) accessible at LHCb.
- Input from CLEO-c (later also BES-III) controls systematics associated to the D→f(D) part of the decay chain.
- **Precision in 2014: σ_γ=2°-3°**

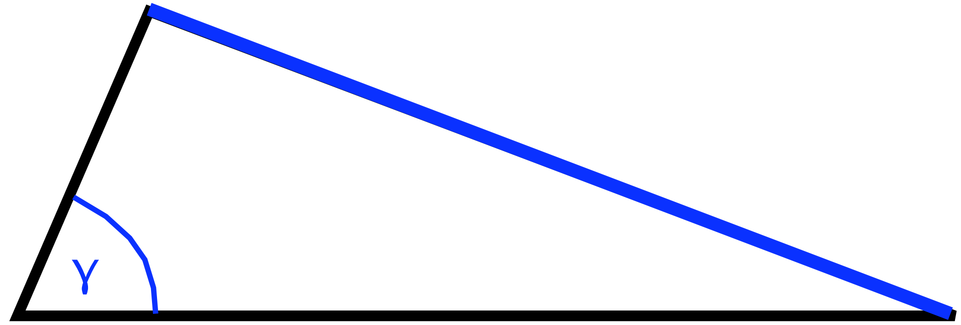
Gronau, Wyler Phys.Lett.B265:172-176,1991, (GLW), Gronau, London Phys.Lett.B253:483-488,1991 (GLW) Atwood, Dunietz and Soni Phys.Rev.Lett. 78 (1997) 3257-3260 (ADS) Giri, Grossman, Soffer and Zupan Phys.Rev. D68 (2003) 054018 Belle Collaboration Phys.Rev. D70 (2004) 072003

Progress on side

- Best experimental constraints from B_s and B_d mixing frequencies, Δm_d and Δm_s. Known very precisely. Error on UT parameters dominated by LQCD, expect significant progress by 2014 (σ_ξ from ~3% to 1.5%).

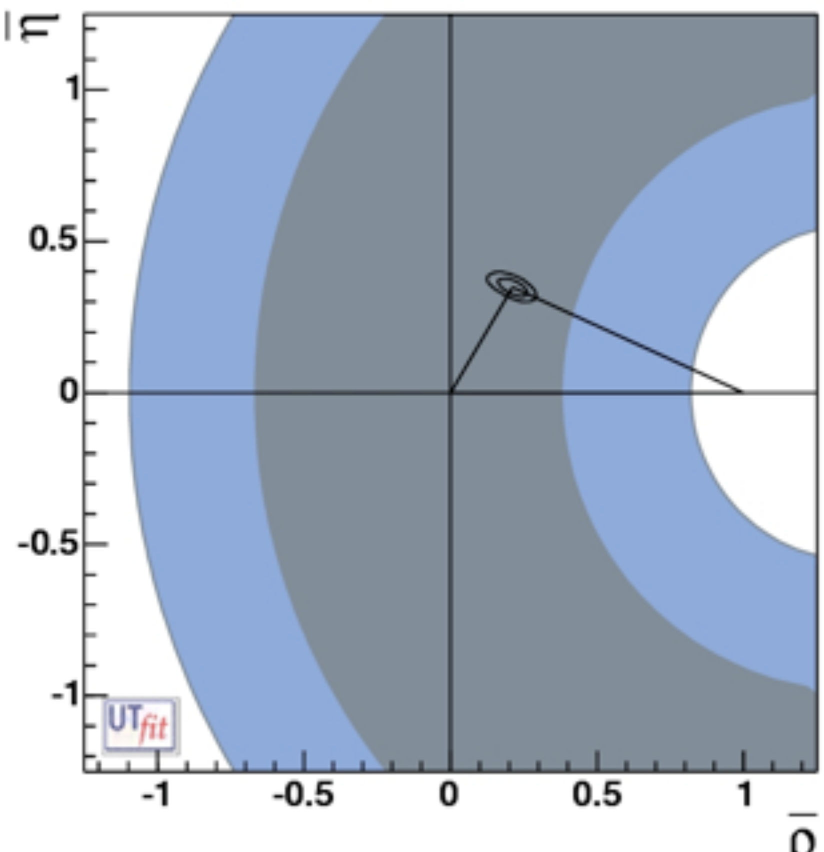
- Alternative constraints: $B \rightarrow \rho\gamma$, $B \rightarrow K^*\gamma$. Currently, from this, $\sigma(|V_{td}|/|V_{ts}|)$~20% with similar theoretical and experimental error. Assuming improvements in theory, significant improvements could be made by SuperB and/or LHCb-Upgrade.

- An independent, theoretically clean measurement is possible through $K^+ \rightarrow \pi^+ \nu\nu$ - not with the current 5 events, but NA62 set to increase this to ~100.

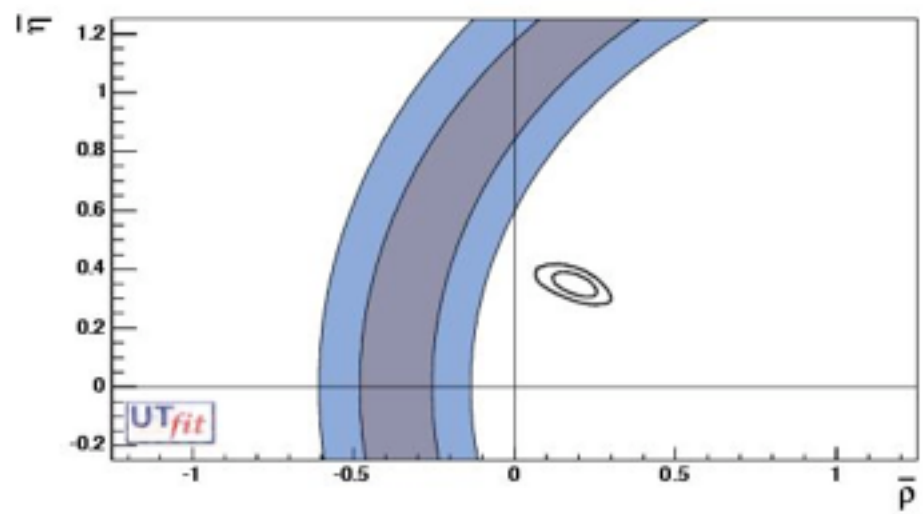


Side measurements using $K^+ \to \pi^+ \nu\nu$

Current Constraints (5 events)

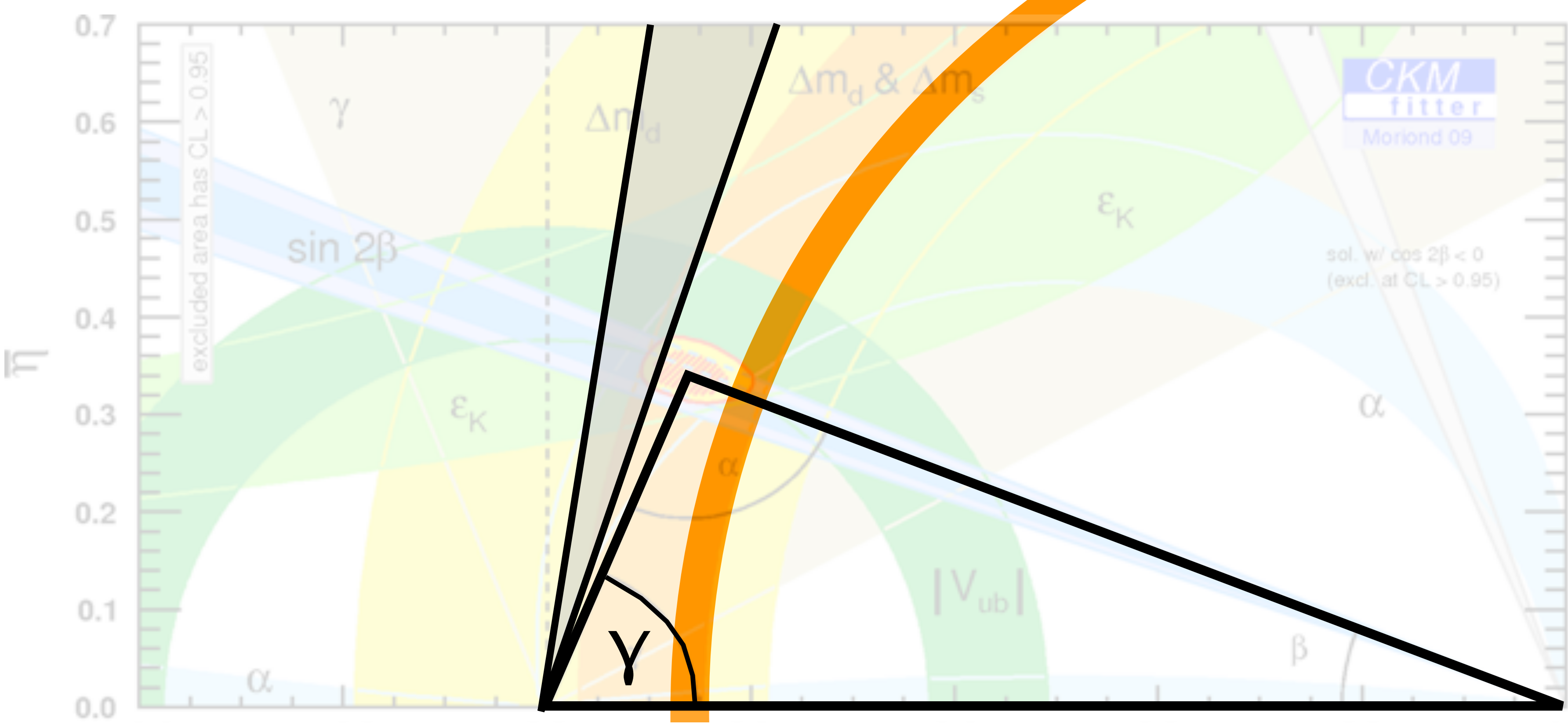


Constraints with NA62's 100 events:



(assuming current central values)

γ and Δm projections for 2014

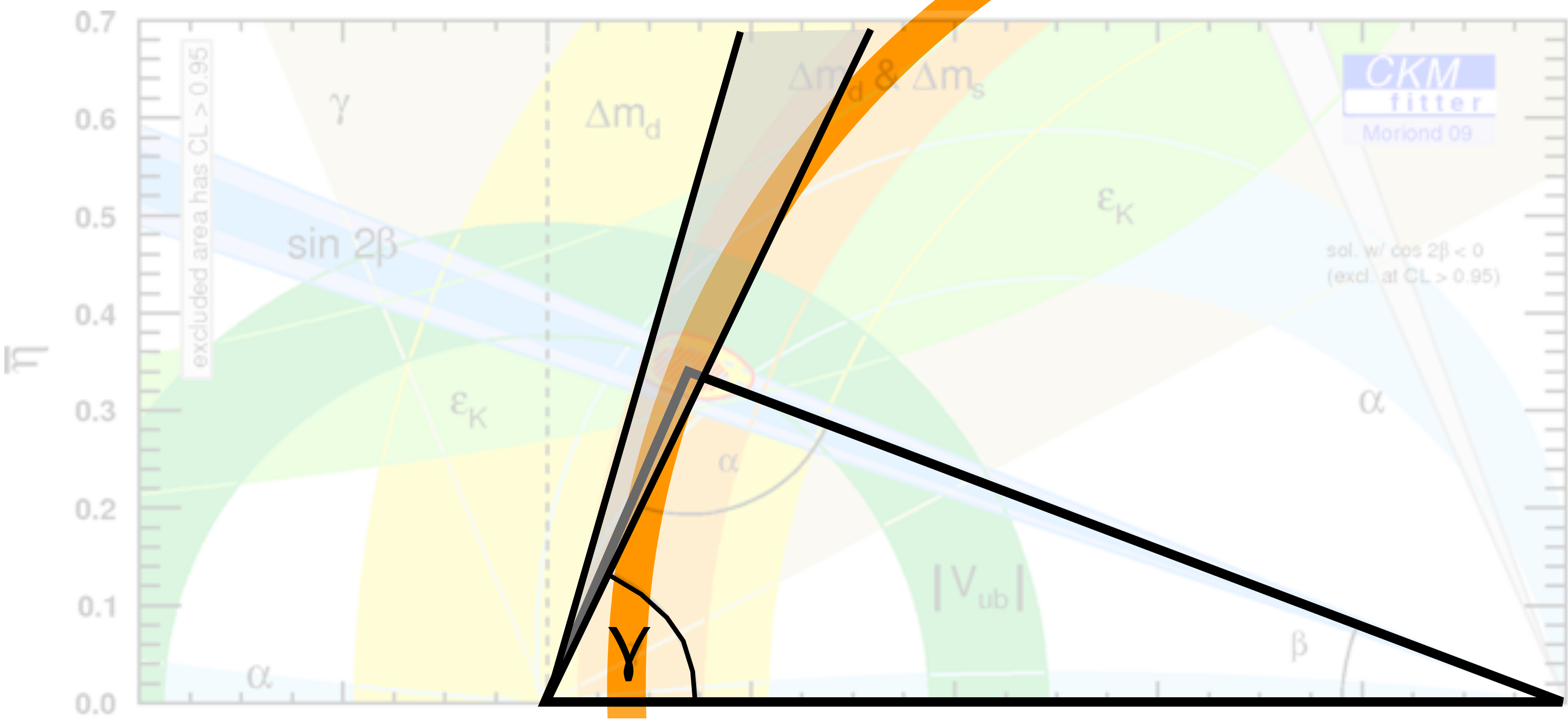


2014: σ_γ(direct, tree) $\approx$ 2°-3°

σ_γ(from side, loop) $\approx$ 1°-2°

γ and Δm projections for 2014

Or, if we are unlucky

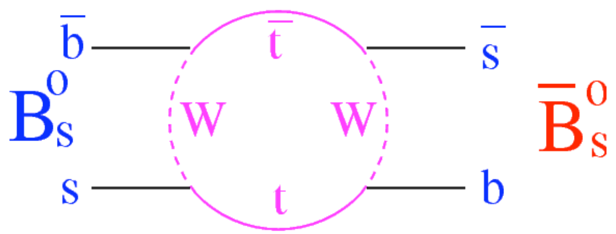


2014: σ_γ(direct, tree) ≈ 2°-3°

σ_γ(from side, loop) ≈ 1°-2°

γ and Δm: Why we need sub-1° precision on γ

- We have a very precise measurement of the B_d and B_s mixing frequencies (<1%) - we could already be staring at NP in B mixing without seeing it.



$$M\left(B_s \to \bar{B}_s\right) \sim \frac{\left(y_t V_{tb}^* V_{ts}\right)^2}{16\pi^2 M_W^2} + \frac{c_{NP}}{\Lambda^2}$$

- Our interpretation of these measurements is (and in 2014 still will be) limited by lattice and SM γ. Increased precision will directly translate into NP reach.

- Expect the lattice will do its bit: Expect precision for the indirect, loop-sensitive γ constraint from B-mixing < 1°.
  (Note to LQCD friends: to catch MFV, it would be nice not to have to rely on the ratio $\Delta m_d/\Delta m_s$, only (which could remain unaffected), but relate Δm_d and Δm_s separately to SM parameters)

- We experimentalists need to do ours: To exploit this for NP sensitivity, we need sub-1° level precision on γ.

γ reach from theoretically clean tree modes

	σ Now	σ 2014	LHCb-Upgrade/ SuperB
$B_s \to D_s K$		~5°	1°/ -
$B^+ \to DK^+$, $B^0 \to DK^*$ combination of various D decay modes*	12°(UTFit) 28°(CKM-Fitter)	2°-3°	<1°/ 1°-2° (starting from UTFit)

Many leading systematics (e.g. detection asymmetries) measured in data.

additional modes should reduce error further

- Essentially no theory error.
- Requires input from $\psi(3770) \to DD$. CLEO-c data make significant impact. Those statistics will be increased by ×25 by BES III - or even ×100 should SuperB run at $\psi(3770)$ for 1 months.

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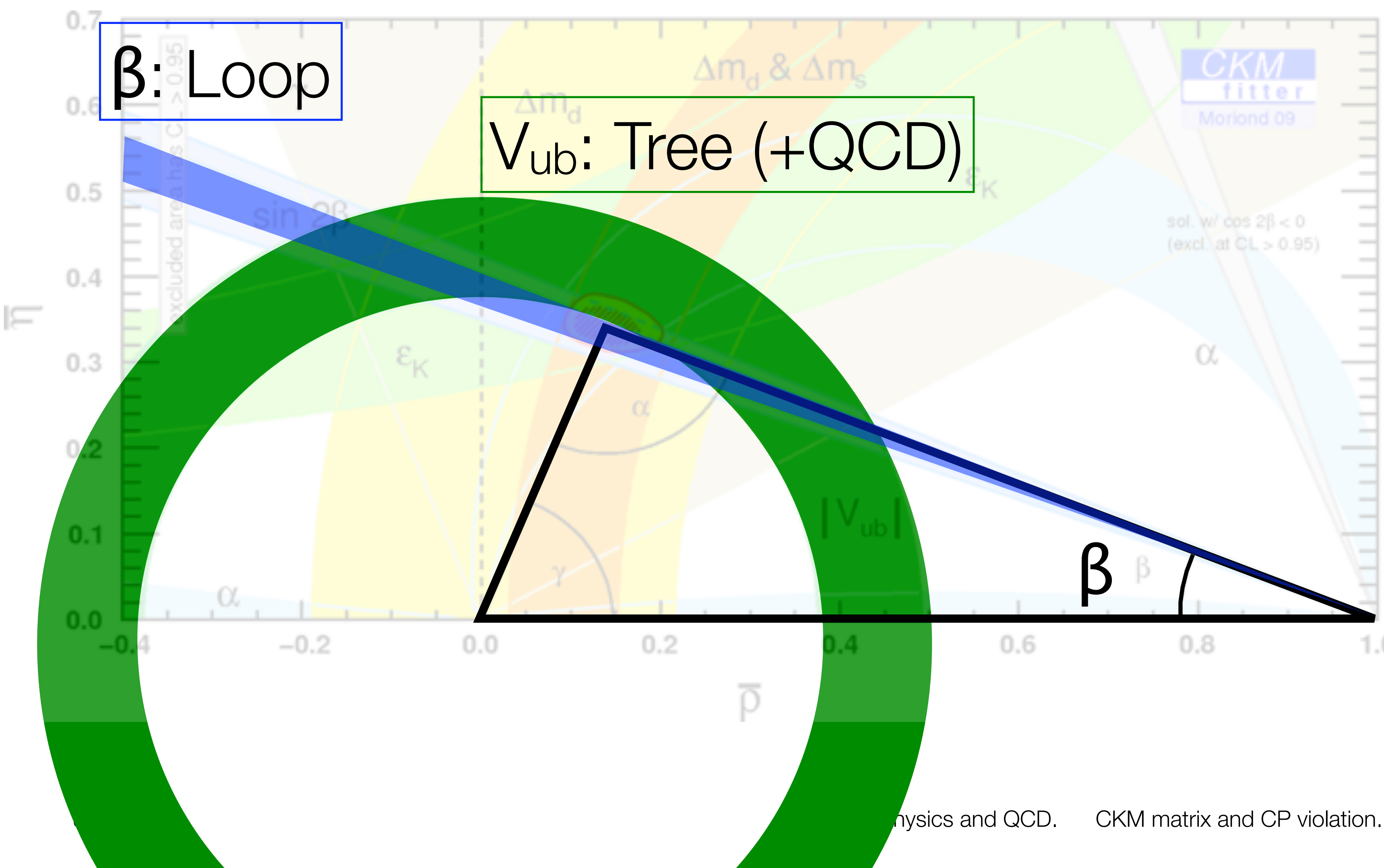
additional modes should reduce error further

• E

• R t. T uld S

Sub-1° γ is achievable, and highly desirable. It increases our sensitivity to NP in one of the places where it is most likely to show up, B meson mixing.

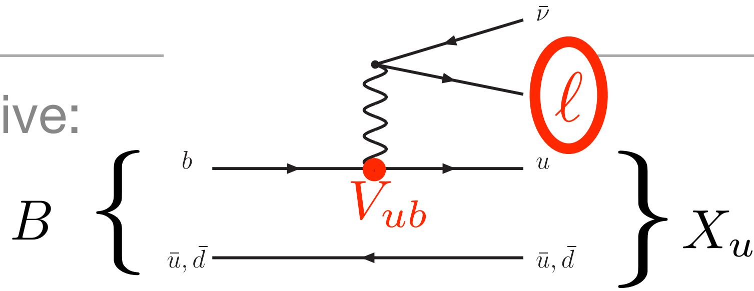
$|V_{ub}|$ and β now



β: Loop
V_{ub}: Tree (+QCD)
β
Δm_d & Δm_s
Δm_d
ε_K
sin 2β
$|V_{ub}|$
α
γ
CKM fitter
Moriond 09
sol. w/ cos 2β < 0
(excl. at CL > 0.95)
$\bar{\eta}$
$\bar{\rho}$

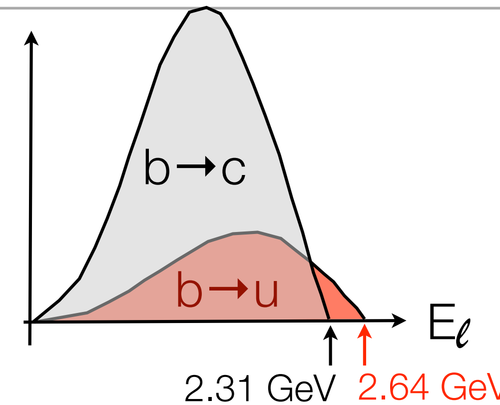
$|V_{ub}|$

- Inclusive:

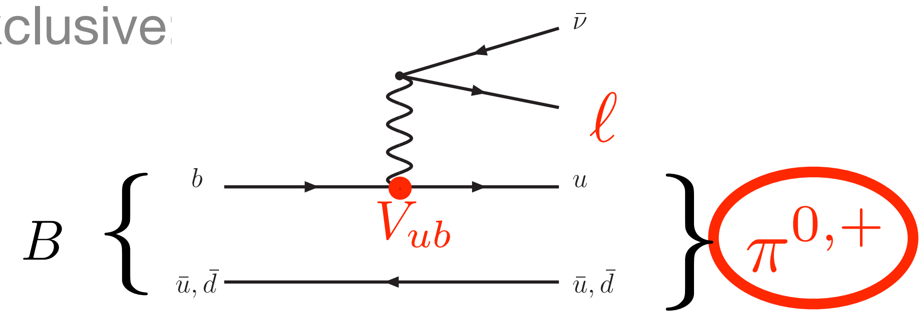


$$|V_{ub}| = \left(4.23 \pm 0.15^{+0.30}_{-0.25}\right) \times 10^{-3}$$

Theory required to predict signal shape



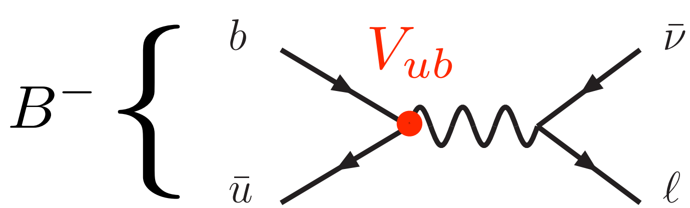
- Exclusive:



$$|V_{ub}| = \left(4.34 \pm 0.12^{+0.55}_{-0.37}\right) \times 10^{-3}$$

Theory to predict form factor.

- Leptonic:

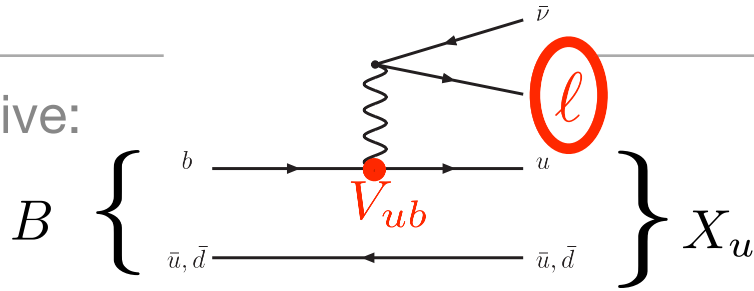


$$|V_{ub}| = (5.2 \pm 0.5(\text{exp}) \pm 0.05(\text{theo})) \times 10^{-3}$$

Theory input: Decay constant (~probability that u,b meet inside B meson).

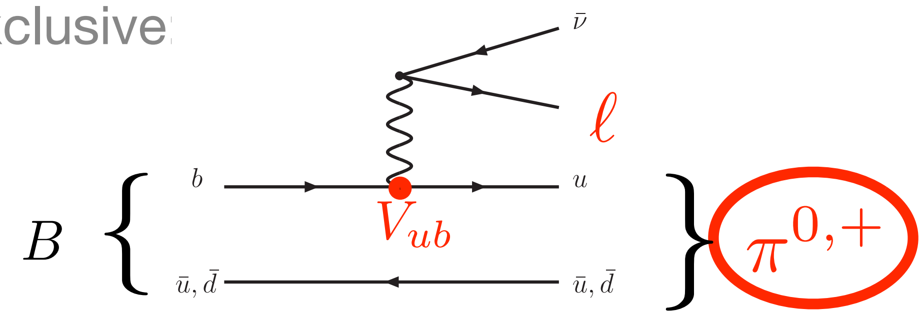
$|V_{ub}|$

- Inclusive:



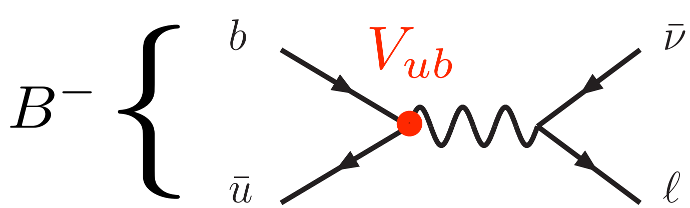
$$|V_{ub}| = \left(4.23 \pm 0.15^{+0.30}_{-0.25}\right) \times 10^{-3}$$

- Exclusive:



$$|V_{ub}| = \left(4.34 \pm 0.12^{+0.55}_{-0.37}\right) \times 10^{-3}$$

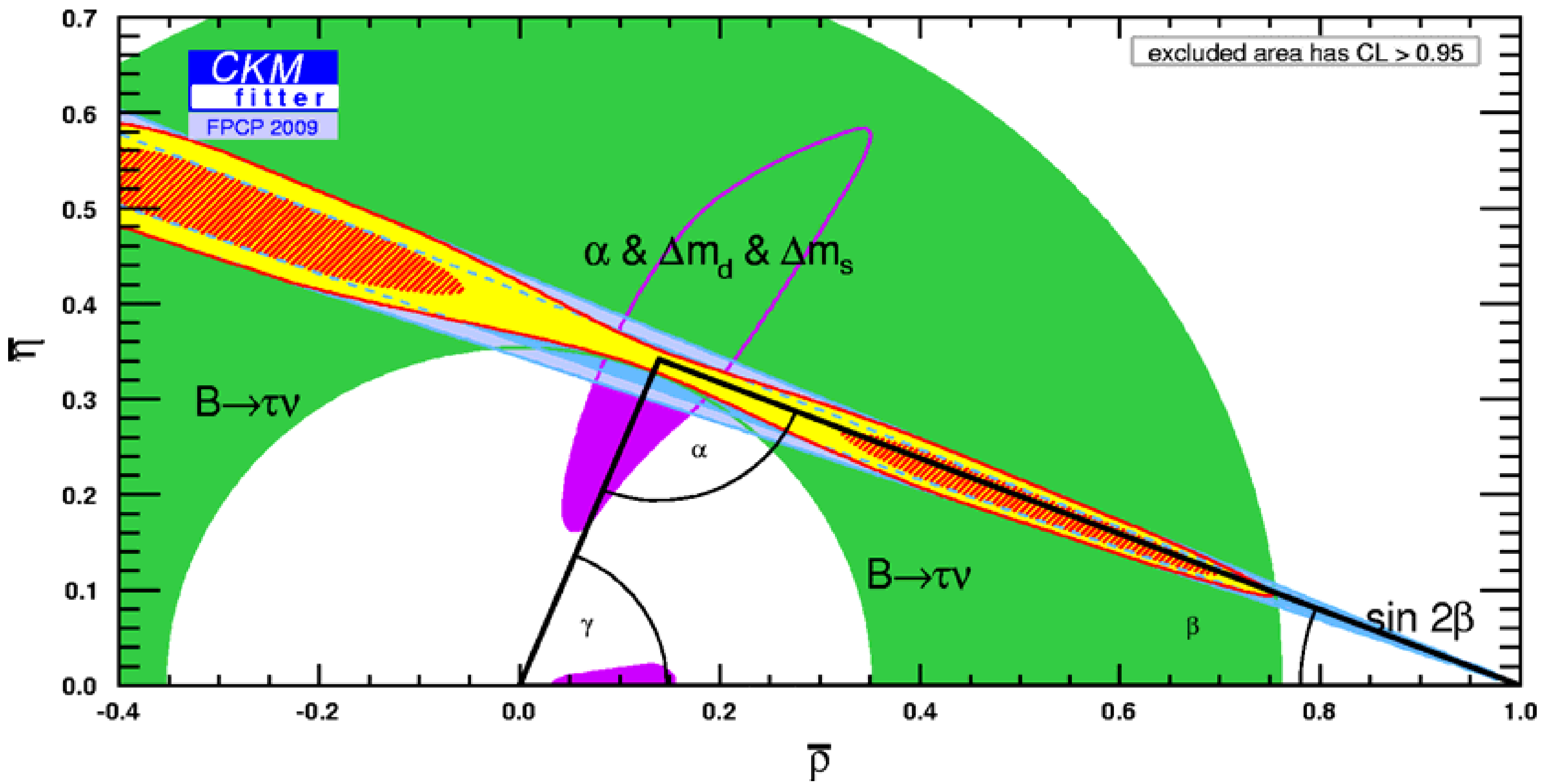
- Leptonic:



$$|V_{ub}| = (5.2 \pm 0.5(\text{exp}) \pm 0.05(\text{theo})) \times 10^{-3}$$

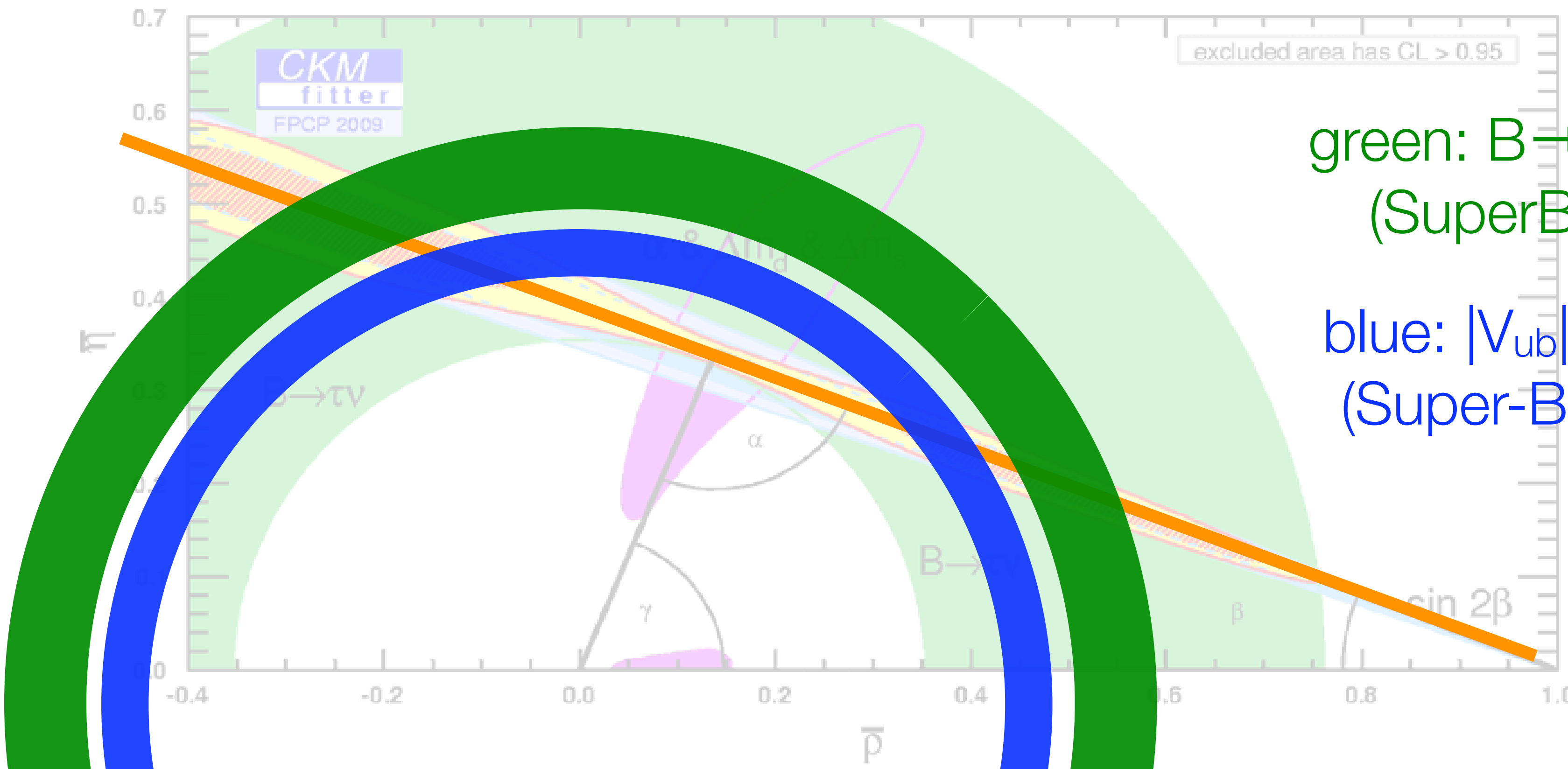
- By 2014: No improvement of experimental errors from LHCb
- Inclusive will remain theory-limited.
- Exclusive: $\sigma^{\text{LQCD}} \sim$ 3% in 2014 = current experimental error. And lattice will continue to improve. Worth measuring at SuperB.
- B→τν: Theoretically clean - and currently a “hot topic”. Super-B could improve this dramatically (~2% error). Interesting sensitivity to NP (charged Higgs) - see Fergus’ talk.

"Tension" between B→τν and sin 2β (now)



Yellow area: 95% CL for combined fit with $\sin(2\beta_{cc})$ and $B \rightarrow \tau\nu$. The orange dashed area indicates the 1 σ confidence level.

What a Super-B factory + Lattice could do to $|V_{ub}|$



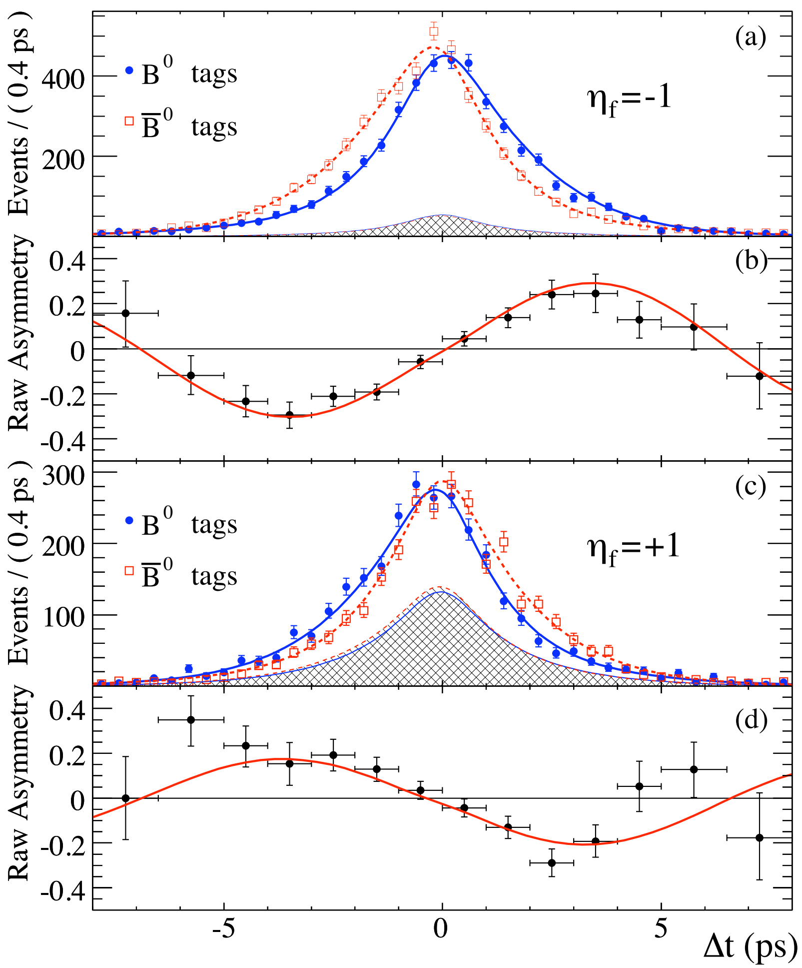
green: B→τν (SuperB)

blue: $|V_{ub}|$ exclusive (Super-B + lattice)

Yellow area: 95% CL for combined fit with $\sin(2\beta_{cc})$ and $B \to \tau\nu$. The orange dashed area indicates the 1 σ confidence level.

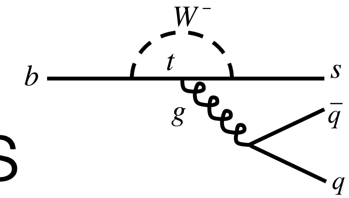
sin 2β from B→J/ψ K_S (and similar)

Plots from BaBar

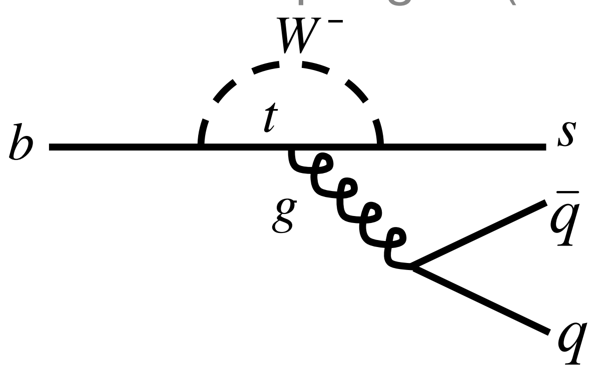


- Current: $\sin 2\beta = 0.655 \pm 0.0244$
- Interesting tension to CKM-constraints from other measurements: $\sin 2\beta^{CKM} = 0.817^{+0.026}_{-0.040}$
- LHCb 10/fb, 2014: σ(stat) ~ 0.01
- SuperB: σ ~ 0.005
- LHCb-Upgrade: σ(stat) ~ 0.003 (systematics biggest challenge - high importance of control channels such as B_s→J/ψ K_S. (see Eur. Phys. J. C 10 (1999) 299)

sin(2β) and b→s gluonic penguins

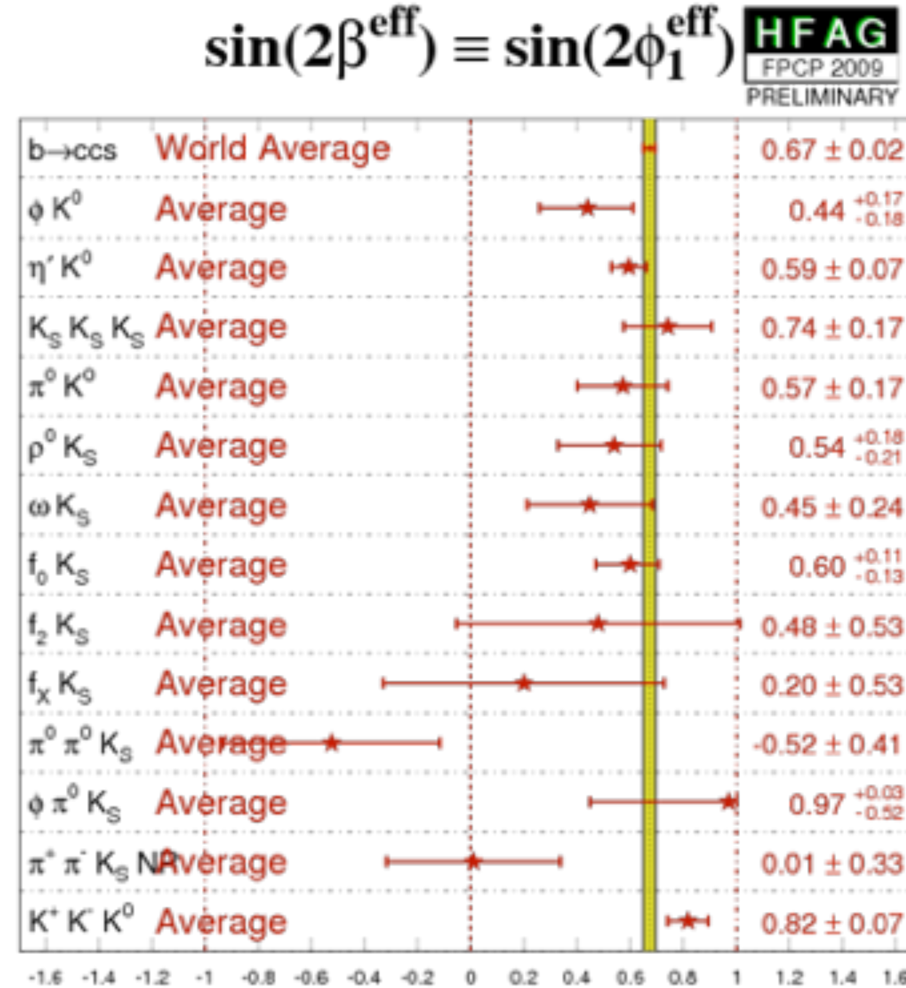


- Decays such as B→φK° decay solely via the b→s penguin (NP-sensitive!):

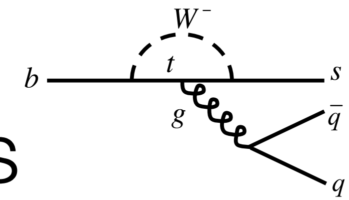


- In SM, the measured $\sin 2\beta^{eff}$ should be the same as for $J/\psi K_S$, with small corrections (theory tends to predict slightly larger measured values)

- These results tend to come out low. Not significant, but suggestive.



sin(2β) and b→s gluonic penguins



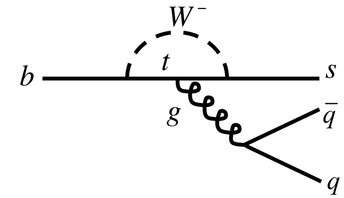
- Whether these hints are due to NP or not - this approach is sensitive to NP and we should look for it. Concentrate on theoretically cleanest channels.

Channel	σ Now	σ 2014	σ theor. (now) arXiv: 0802.3201	LHCb Upgrade (stat)/ SuperB
$B_d \to \varphi K^o$	0.18	0.10	~0.01	0.02/ 0.02
$B_d \to \eta' K^o$	0.07	0.07	~0.01	0.01
$B_d \to K^o K^o K^o$	0.17	0.17	~0.02	0.02
$B_s \to \varphi\varphi$	∞	0.05	~0.01	0.01

- In terms of today's central values:
  ~1σ consistency (now)
  ~2σ effect in 2014
  >10σ effect after LHCb upgrade/SuperB

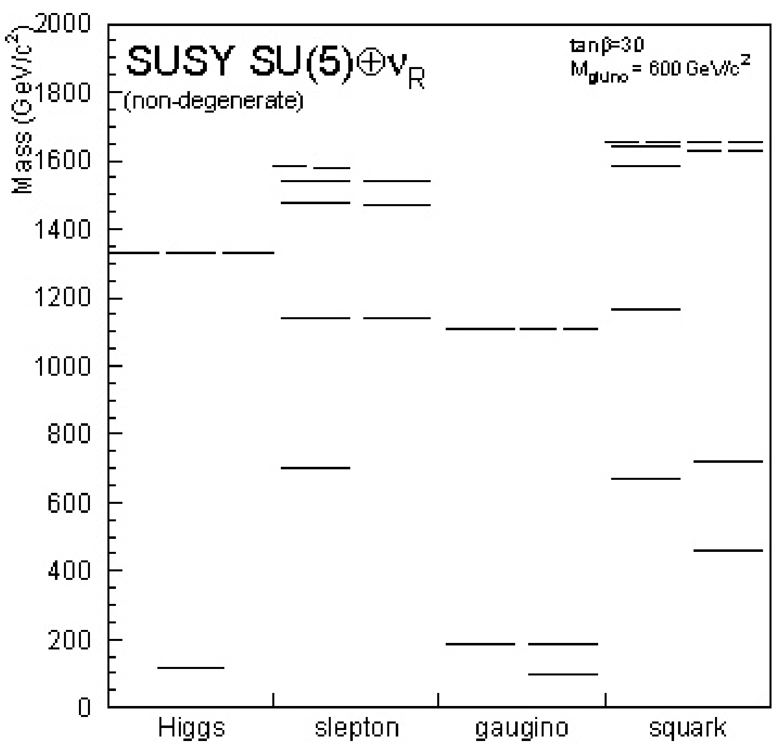
- More channels accessible, esp. at SuperB, but usually (now) with larger theor. error. Could be reduced from better theory + control channels.

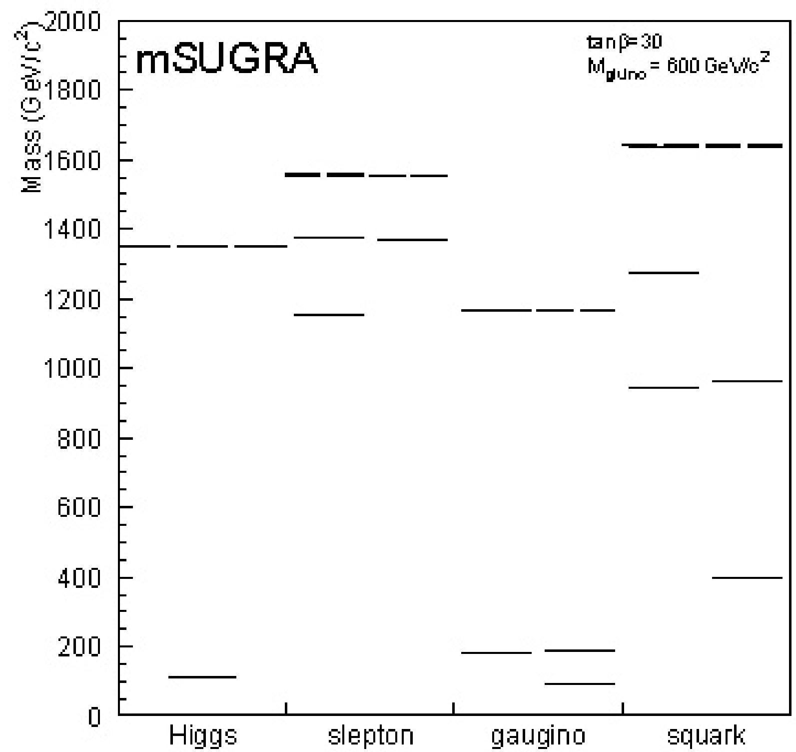
sin(2β^{eff}) as model discriminator



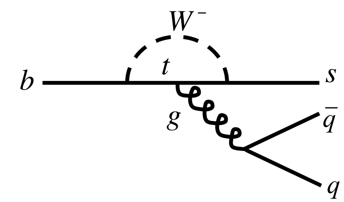
Mass spectra of two popular SUSY models

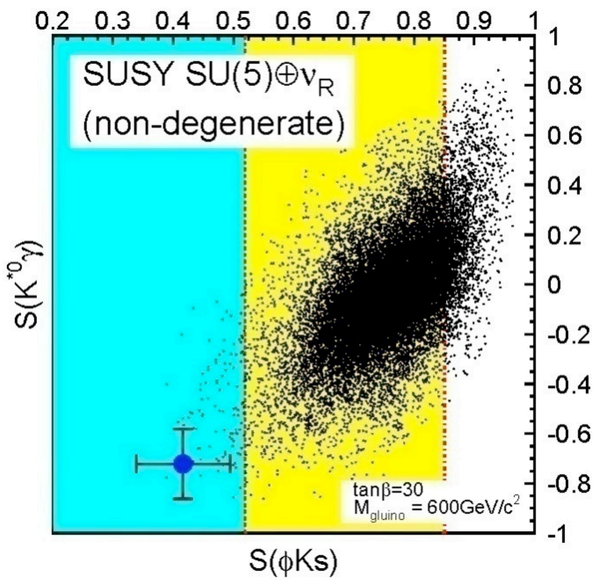
quite similar - difficult to distinguish models

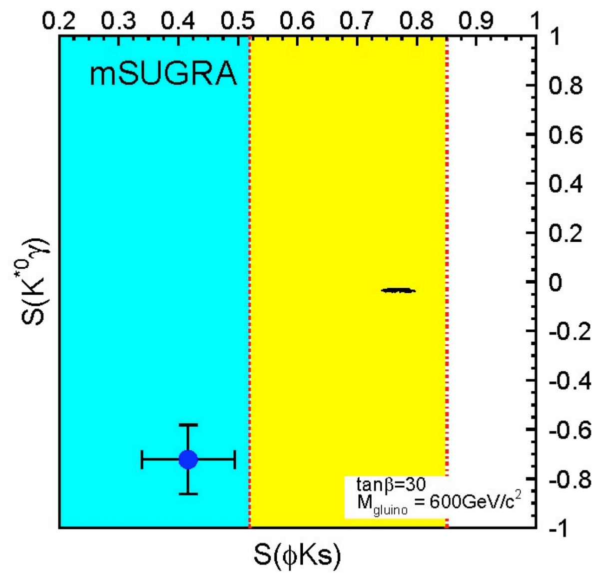


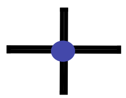


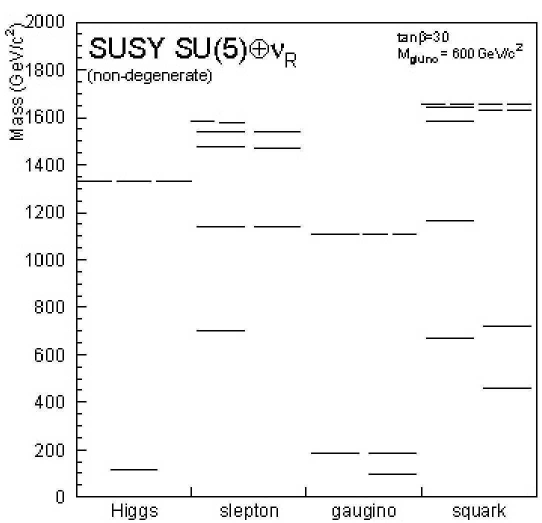
sin(2β^{eff}) as model discriminator

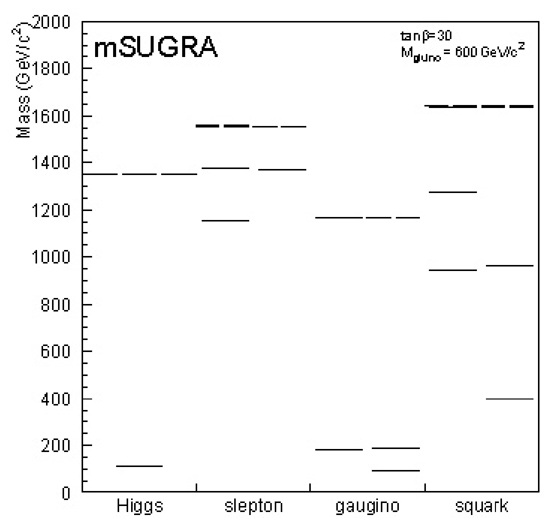






 = expected sensitivity at SuperBelle (50 ab^{-1}) (similar at Super-B or LHCb-Upgrade)





particle/ sparticle mass spectra similar

Nobel Mixing

Nobel Mixing

- For neutral meson systems:

  Mixing → CP violation → Nobel Prize (~20 years)

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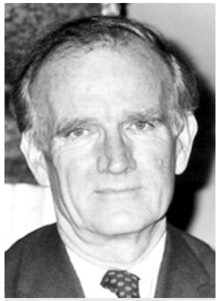
The Nobel Prize in Physics 1980

"for the discovery of violations of fundamental symmetry principles in the decay of neutral K-mesons"

James Watson Cronin



Val Logsdon Fitch

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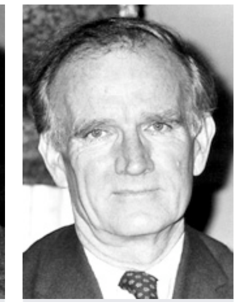

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½ Nobel Prize in Physics 2008

"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"

Makoto Kobayashi

Toshihide Maskawa

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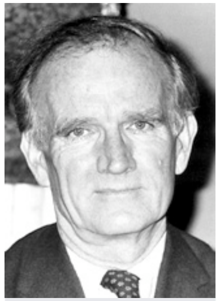

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© The Nobel Foundation
Photo: U. Montan

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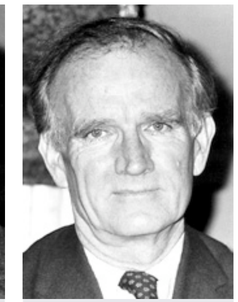

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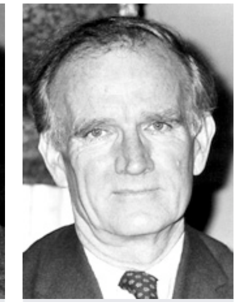

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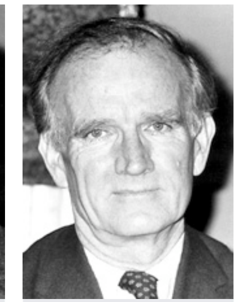
- For 2 out of 4 mixing meson systems, we only just got started:
  - B_s: Mixing discovered in 2006, no CPV, yet.
  - D^0: Mixing discovered in 2007, no CPV, yet.
  - In both systems, the prize is in finding non-SM CP violation (in the case of D°, this is any CPV)

The Nobel Prize in Physics 1980

"for the discovery of violations of fundamental symmetry principles in the decay of neutral K-mesons"

James Watson Cronin



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Makoto Kobayashi

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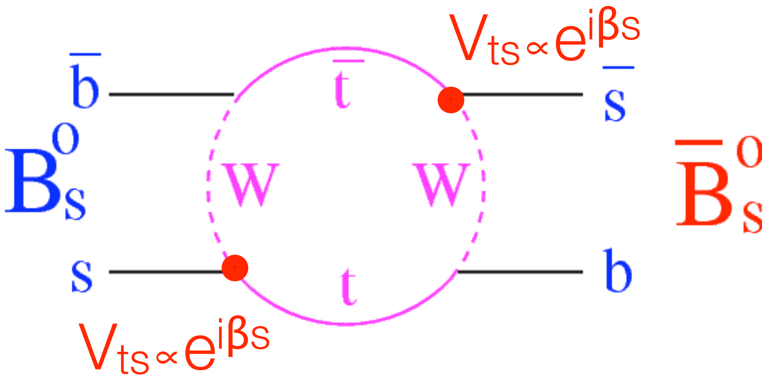
Toshihide Maskawa

Bs mixing and sin 2β_s

- The B_s system is characterised by
  - **Δm** - the mass difference between B-mass eigenstates (~oscillation frequency)
  - **ΔΓ** - the width (lifetime) difference between B_H and B_L
  - **A_{SL}** - CP violation in mixing, equivalent to ε in K° system. 0 in SM
- **sin2β_s** - the CKM phase that is the equivalent of sin2β in the Bd system. In the SM, β_s ~0.



$$M\left(B_s \to \bar{B}_s\right) \sim \frac{\left(y_t V_{tb}^* V_{ts}\right)^2}{16\pi^2 M_W^2} + \frac{c_{NP}}{\Lambda^2}$$

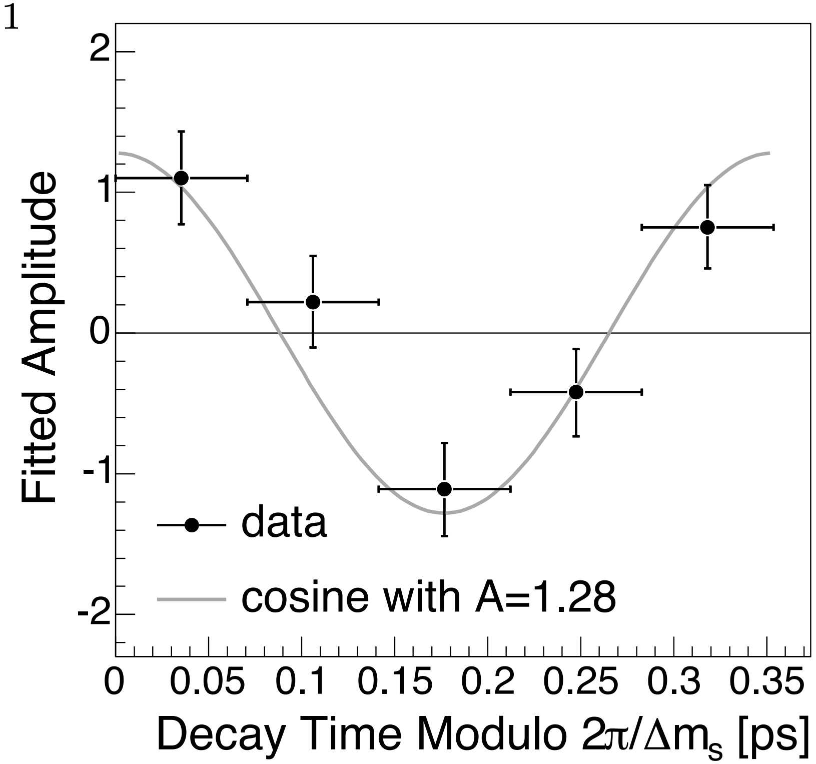
Bs mixing

$$\Delta m_s, \Delta\Gamma_s, A^s_{SL}, \sin(2\beta_s)$$

- Δm is the only parameter from this list that has been measured precisely:

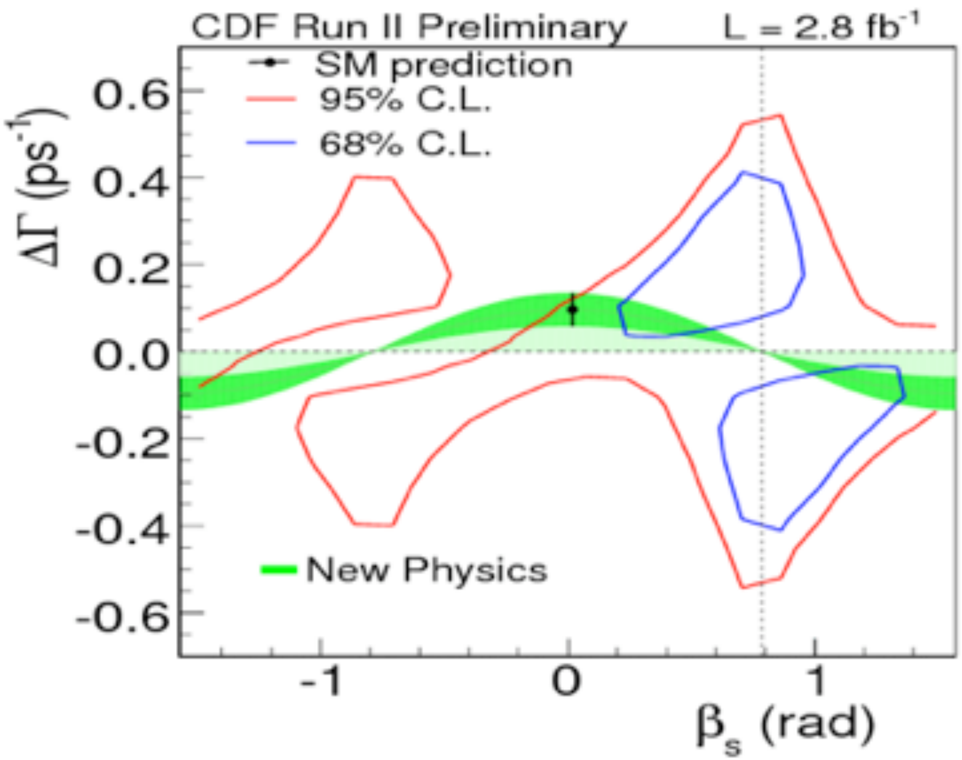
$$\Delta m_s = 17.77 \ \pm 0.10 \ (\mathrm{stat}) \ \pm 0.07 \ (\mathrm{syst})\, \mathrm{ps}^{-1}$$

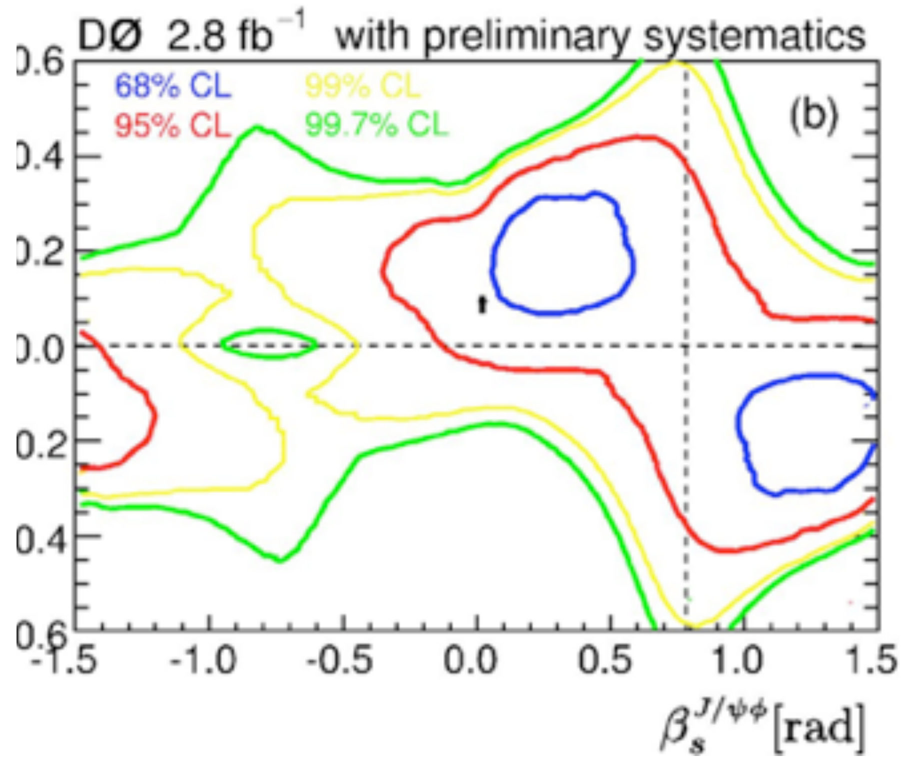
Bs oscillations at CDF



- To translate this amazingly precise result into a precision test of the SM, we need:
  - A precise measurement of γ
  - Precise LQCD calculations to interprete $\Delta m_d/\Delta m_s$ in terms of CKM parameters.

$B_s \to J/\psi\varphi$ at DØ and CDF





$$\Delta\Gamma_s(\text{meas}) = \Delta\Gamma_s^{SM}\cos\phi_s^{NP} \qquad \Delta\Gamma = 0.15^{+0.05}_{-0.07}$$

$$\sin(2\beta_s)(\text{meas}) = \sin(2\beta_s - \phi_s^{NP}) \qquad \phi_s^{NP} = -0.77^{+0.29}_{-0.37}$$

plots: 2009 - combined numbers: HFAG, 2008 (1/2 CDF data)

$B_s \rightarrow J/\psi\varphi$ in 2014 and beyond

- Current indirect SM constraints (now, CKM fitter): $\beta_s = 0.0181 \pm 0.0008$
- Theory uncertainty in relating measurement to SM parameter negligible ("golden mode"). Sensitivity to New Physics high, and unexplored.
- Now: σ(TeV) ~ 0.3, result ca 2σ from SM.
- LHCb (10 fb^{-1}): σ(stat) ~ 0.007 (SM at 2.5σ, current central value at 100σ)
- LHCb Upgrade (100 fb^{-1}): σ(stat) ~ 0.002 (SM at 9σ)

Charm's many ways of increasing NP sensitivity:

- Charm results crucial for a high-precision measurement of CKM angle γ in B decays.
- Test LQCD through form factor / decay constant measurements - which is in turn input to B physics.
- Input to kaons: Precise $|V_{cd}|$ measurement in charm needed to translate excellent precision on ε_K into precise UT constraints
- Mixing (recently discovered) and CP violation. CP violation in charm would be a clear signal of NP.
- Understanding properties of light meson resonances.
  Although this could become important input to high-precision Dalitz analyses to study otherwise inaccessible aspects of CP violation, we'll skip it here.

$$B \downarrow D \downarrow$$

$K^* \rho a_1 \; f(980)\ldots$

$\sigma(?) \kappa(?)\ldots$

Charm

<table>
<tr><th></th><th></th><th>In publications 07/08/09</th><th>On tape</th><th>2014</th><th>2020</th></tr>
<tr><td rowspan="3">“Normal” flavour-specific $D \to K\pi$ (events seen, i.e. reconstructed, passed cuts)</td><td>(Super) B factories</td><td>2.3M</td><td>4.3M</td><td>5.7M</td><td>200M</td></tr>
<tr><td>CDF</td><td>3M</td><td>12M</td><td>16M</td><td></td></tr>
<tr><td>(upgraded) LHCb</td><td></td><td></td><td>500M</td><td>10G</td></tr>
<tr><td rowspan="2">$D \to K\pi$ from $\psi(3770) \to DD$</td><td>CLEO-c/ BES-III</td><td colspan="2">150k</td><td>3.5M</td><td></td></tr>
<tr><td>Super B?</td><td colspan="3">running 1 month at $\psi(3770)$</td><td>20M</td></tr>
</table>

Most numbers estimated by naive scaling (esp for CDF, trigger efficiency could be an issue). Published numbers are: Babar: 1.229 M for 384/fb in 2007. BELLE: 1.1M in 400/fb [Phys.Rev.Lett.98:211803,2007], CDF: 3.04 M in 1.5/fb CLEO: 50k in 281/fb

Quantum correlated charm pairs at CLEO-c, BESIII

$e^+e^- \rightarrow \psi(3770) \rightarrow D\overline{D}$

$m^2(K_S\pi^+)/GeV^2$

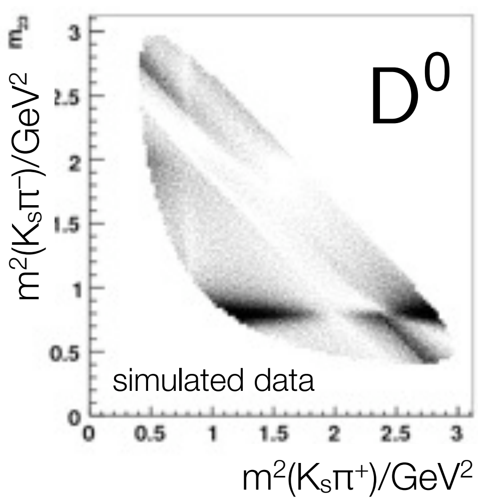
Quantum correlated charm pairs at CLEO-c, BESIII

$e^+e^- \rightarrow \psi(3770) \rightarrow D\overline{D}$

ψ'' → $\overline{D}_{\text{flavour}} \rightarrow K^+e^- \nu_e$

ψ'' → $D_{\text{flavour}} \rightarrow K_S\pi^+\pi^-$

Everybody (B-factory, LHCb) can do that:



$m^2(K_S\pi^+)/GeV^2$

Quantum correlated charm pairs at CLEO-c, BESIII

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$\psi'' \rightarrow \overline{D}_{\text{flavour}} \rightarrow K^+ e^- \nu_e$

$\psi'' \rightarrow D_{\text{flavour}} \rightarrow K_S \pi^+ \pi^-$

$\psi'' \rightarrow D_{CP+} \rightarrow KK$

$\psi'' \rightarrow D_{CP-} \rightarrow K_S \pi^+ \pi^-$

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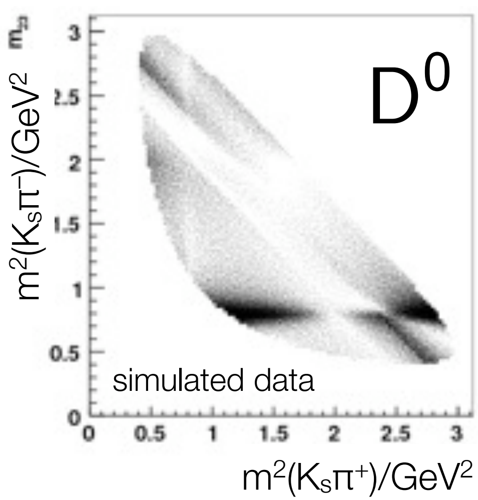
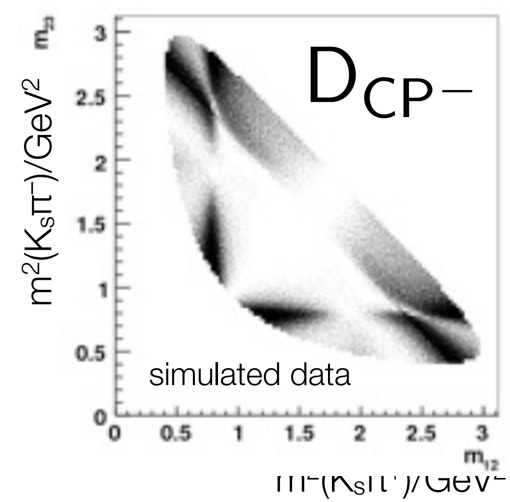


Only $\psi(3770) \rightarrow DD$ can also do that:



Quantum correlated charm pairs at CLEO-c, BESIII

$e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}$

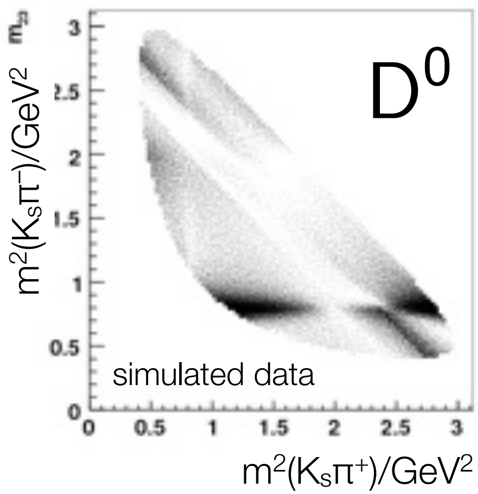
$\psi'' \rightarrow \bar{D}_{flavour} \rightarrow K^+ e^- \nu_e$

$\psi'' \rightarrow D_{flavour} \rightarrow K_S \pi^+ \pi^-$

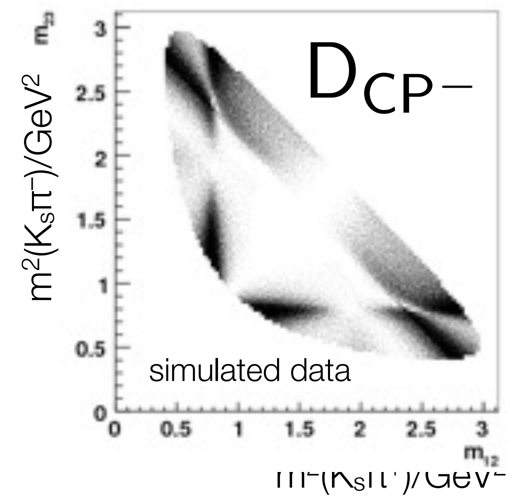
$\psi'' \rightarrow D_{CP+} \rightarrow KK$

$\psi'' \rightarrow D_{CP-} \rightarrow K_S \pi^+ \pi^-$

Everybody (B-factory, LHCb) can do that:



Only $\psi(3770) \rightarrow$ DD can also do that:



Two measurements for each point in Dalitz space: can extract magnitude AND phase. Replaces 7° model systematic in γ from $B^\pm \rightarrow D(K_S\pi\pi)K^\pm$ with < 2° stat. error.

$\psi(3770) \to DD$

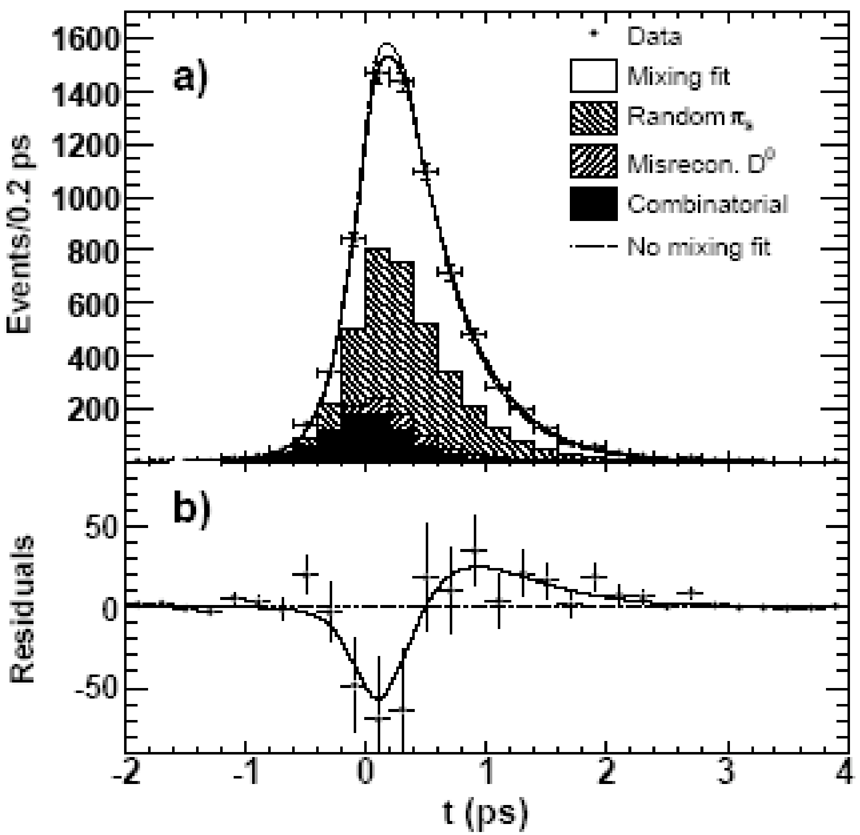
	CLEO-c stat ⊕ sys	BES-III stat	Super-B at $\psi(3770)$, 1 month, stat only	Input for...
$\sigma(f_{D+})$	4.1% ⊕1.2%	1%	0.4%	|Vub| (check LQCD)
$\sigma(f(q^2=0))$	5.3% ⊕ 0.7%	1%	0.5%	|Vub|excl. (check LQCD)
$\cos(\delta^{Kpi})$	0.24 ⊕ 0.06	0.06	0.03	D mixing, and γ
phases of other channels	add channels			D mixing, and γ
Coherence factor in $K3\pi$	0.22 ⊕ 0.01	0.04	0.02	γ
further γ input	increase precision, add channels.			γ

Refernces: PhysRevD.78.012001

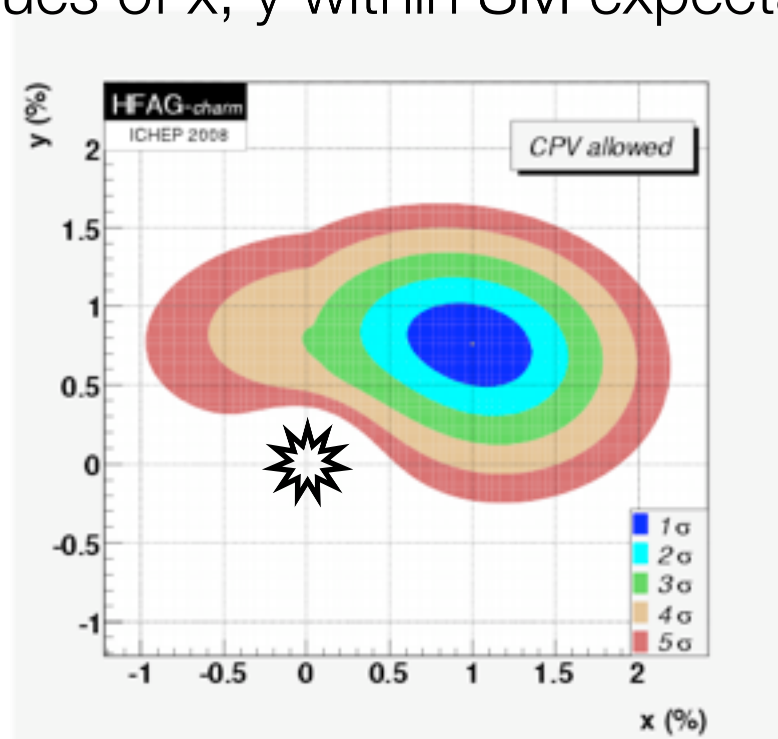
Charm Mixing

- Parameters: x ~ Δm (mass difference), y ~ ΔΓ (width difference) between CP eigenstates of the D° system.

BaBar, March 2007



Status now: Mixing established at >9**σ**, values of x, y within SM expectations.



Charm mixing

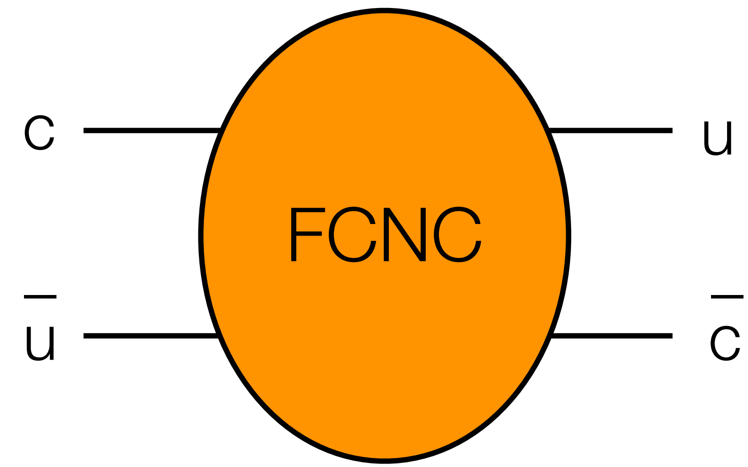
- Mixing recently discovered (BaBar/BELLE/CDF). Need to turn evidence to precision. Systematics will be crucial for SuperB and LHCb-Upgrade.

	BaBar(%)	BELLE(%)	CDF(%)	σ combined*	LHCb (2014) stat only	SuperB/ LHCb Upgr.(stat)
$(x\cos\delta)^2$ $D\to K\pi$	−0.02 ±0.03(stat) ±0.02(sys)	0.02±0.02	0.01±0.04	$1.5\cdot10^{-4}$	$6\cdot10^{-5}$	$3\cdot10^{-5}$/ $1\cdot10^{-5}$
$y\cos\delta$ $D\to K\pi$	0.97 ±0.44(stat) ±0.31(sys)	0.06±0.40	0.85±0.76	$3\cdot10^{-3}$	$9\cdot10^{-4}$	$7\cdot10^{-4}$/ $2\cdot10^{-4}$
y_{CP} $D\to KK$	1.0 ±0.2(stat) ±0.2(sys)	0.2 ±0.6(stat) ±0.8(sys)		$3\cdot10^{-3}$	$4\cdot10^{-4}$	$5\cdot10^{-4}$/ $1\cdot10^{-4}$

*) published values, corresponds to ca ½ of B-factory data, 1/5 of CDF data

CPV in charm

- Unique window on FCNC affecting up-type quarks (all other mixing meson systems are made from down-type quarks). Quite possible that up-type quarks are affected by NP significantly different from down-type quarks.
- Precise SM prediction $\varphi^{\text{CP-charm}} = 0 \pm 10^{-3}$
- Potential for large NP enhancements
- Experimentally unexplored territory.
- My bet: Could be *the* hot topic in 2014 and beyond.



CPV in charm: A_Γ

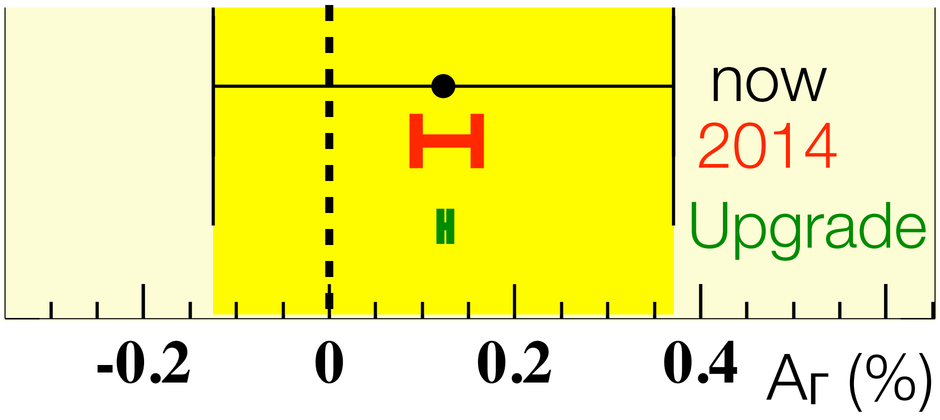
- Measured as a lifetime asymmetry, detector effects cancel:

$$A_\Gamma = \frac{\tau(\bar{D}^0 \to K^+K^-) - \tau(D^0 \to K^+K^-)}{\tau(\bar{D}^0 \to K^+K^-) + \tau(D^0 \to K^+K^-)}$$

- Approaching SM sensitivity in 2014 (~3σ for $A_\Gamma \sim 10^{-3}$).

- LHCb-Upgrade and SuperB will for the first time be able to make a significant measurement of CPV at SM level.

	BaBar BELLE (920/fb)	LHCb 2014	LHCb-Upgrade/ SuperB
D→KK	0.2 M	16 M	320M/ 14M
σ_{A_Γ}	$25 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$0.7 \cdot 10^{-4}$/ $3 \cdot 10^{-4}$



BaBar: PhysRevD.78.011105 , BELLE: Phys. Rev. Lett. 98, 211803 (2007). LHCb-2007-049

Prospects for direct CPV

- Example: $D^o \to K^+K^-$, SM expectation < 10^{-3}
  - BaBar 2008: (+0.00 ± 0.34 ± 0.13)% (386/fb, 66k events)
  - BELLE 2008: (-0.43 ± 0.30 ± 0.11)% (540/fb, 120k events)
  - World average (HFAG): (+0.22 ± 0.37)%
- CDF has obtained its result of (+2.0 ± 1.2 ± 0.6)% with only 2% of its current data set. CDF could beat world stat precision now.
- LHCb in 2014: σ(stat) = 0.03% in 10/fb
- LHCb Upgrade: σ(stat) = 0.01%
- SuperB: σ(stat) = 0.02%

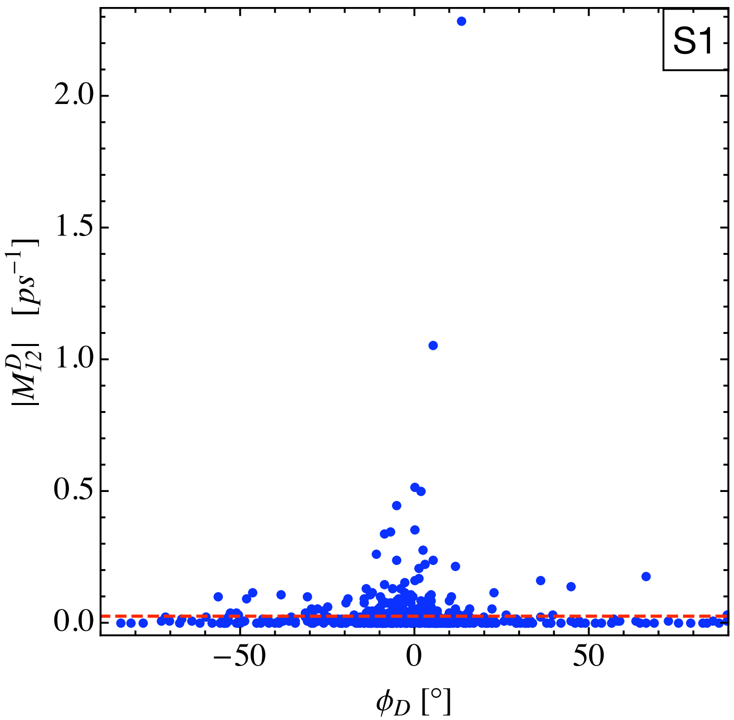
Dawn of precision era in charm CPV

BELLE: Phys. Lett. B 670 (2008) 190

CP Violation in Charm

- From a slide by M. Neubert at FPCP 09 on the signature of RS-models with warped extra dimensions.

- Very large effects possible in $D - \bar{D}$ mixing, including large CP violation. Prediction might be testable at LHCb



$$(M_{12}^D)^* = \langle \bar{D} | \mathcal{H}_{\mathrm{eff,RS}}^{\Delta C=2} | D \rangle$$
$$= |M_{12}^D| \, e^{2i\phi_D}$$

- - maximal allowed SM effect with no significant CP phase

● consistent with quark masses, CKM parameters, and 95% CL limit $|\varepsilon_K| \in [1.3, 3.3] \cdot 10^{-3}$

Kaons

- A historical note (from L. B. Okun: "Spacetime and vacuum as seen from Moscow", Int.J.Mod.Phys. A17S1 (2002) 105-118):

> A special search at Dubna was carried out by E. Okonov and his group. They have not found a single $K_L^0 \to \pi^+\pi^-$ event among 600 decays of K_L^0 into charged particles [13] (Anikina et al., JETP, 1962). At that stage the search was terminated by administration of the Lab. The group was unlucky.
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> Approximately at the level 1/350 the effect was discovered by J.Christensen, J.Cronin, V.Fitch and R.Turlay [14] at Brookhaven in 1964 in an experiment[...]

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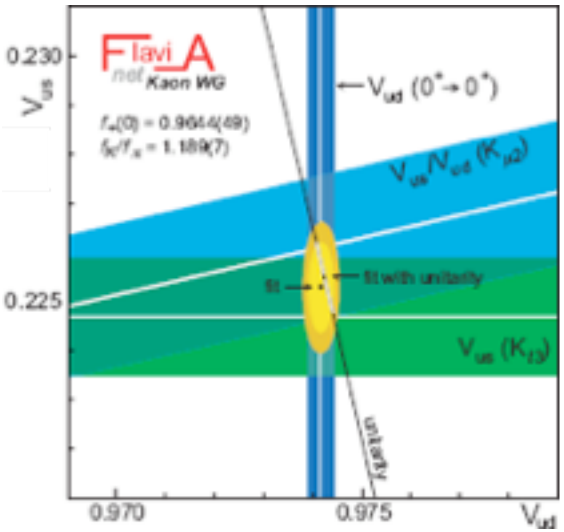
- Don't give up once you've excluded New Physics at the few% level.

- A glorious past is no impediment to a glorious future.

- Global symmetries are usually broken (C, P, CP,... MFV?)

Kaons: $|V_{us}|$

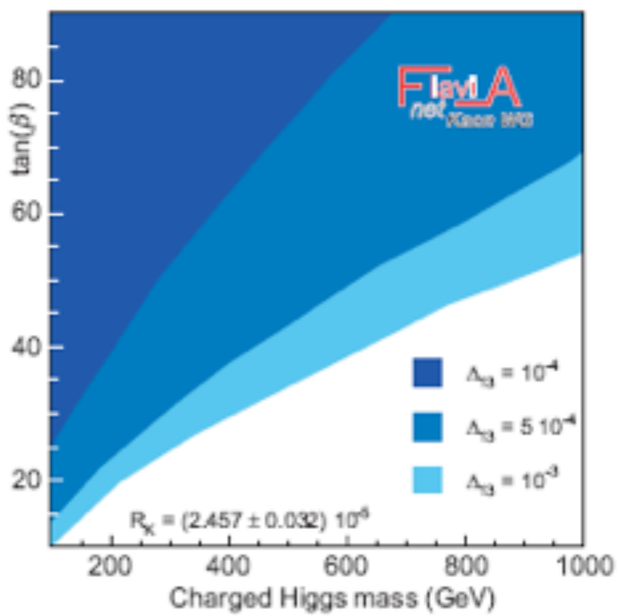


- Leptonic Kaon decays provide precision measurements of |Vus|

$$V_{us} = \sin\theta_C = \lambda = 0.2255(7)$$

- Can be used to test unitarity:

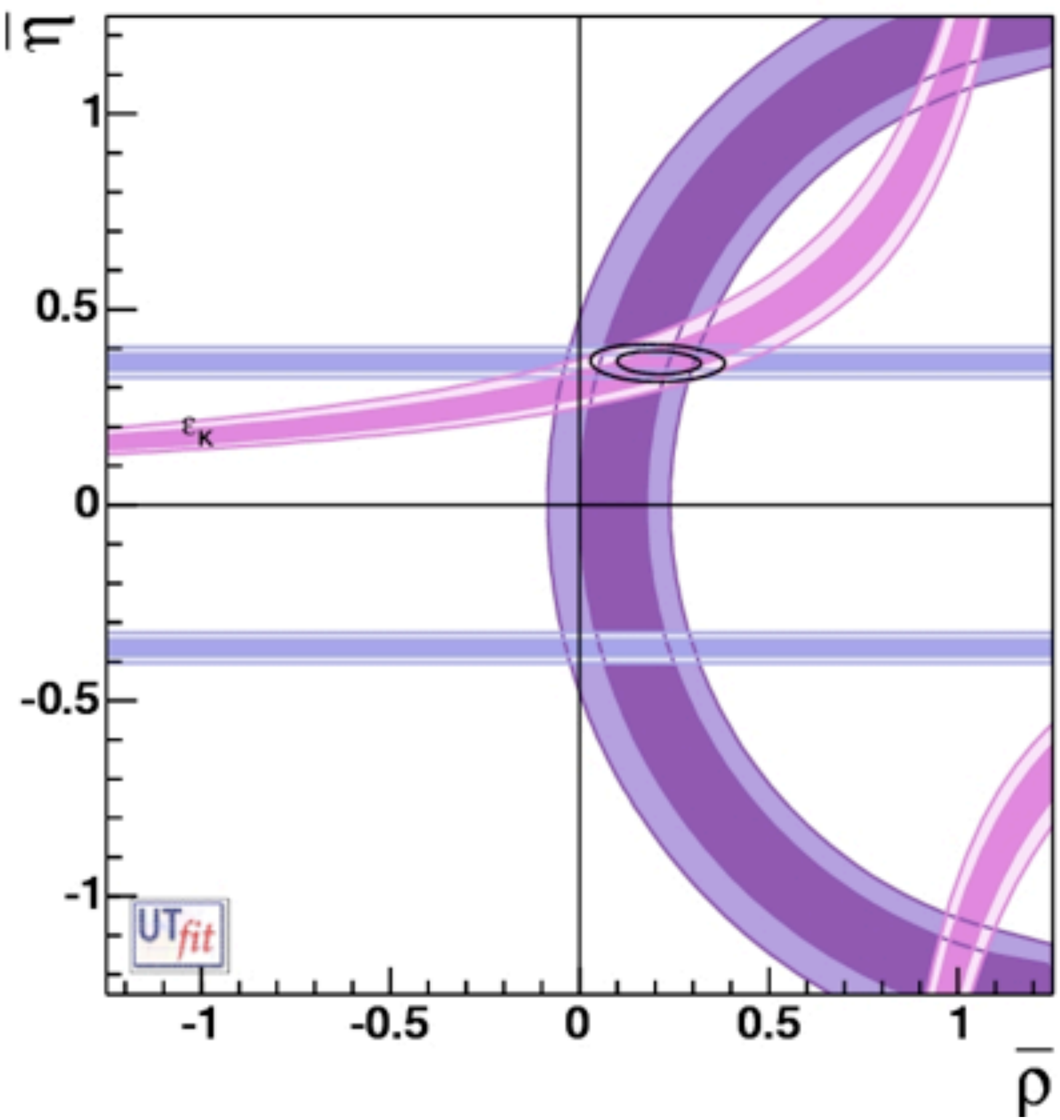
$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999(5)(9)$$



- Ratio of $|V_{us}|$ measured in μ vs e modes sensitive to charged Higgs mass:

$$R_K^{\rm LFV} \approx R_K^{\rm SM}\left[1 + \left(\frac{m_K^4}{M_{H\pm}^4}\right)\left(\frac{m_\tau^2}{M_e^2}\right)|\Delta_{13}|^2\tan^6\beta\right].$$

Kaons & the UT



- Interpreting Kaon results in terms of UT parameters often difficult because of large hadronic uncertainties.

- However, there are channels where these uncertainties essentially vanish:

  $K^+ \rightarrow \pi^+ \nu\nu$ and $K^o \rightarrow \pi^o \nu\nu$

- These could provide clean, independent UT constraints in the foreseeable future (NA62 for charged, KOTO for neutral)

Conclusions

- The interaction (or lack thereof) between the SM and the BSM sector is one of the defining and discriminating characteristics of New Physics models. This is the focus of CKM/CP violation measurements in the future.

- We have good reason to hope for evidence of NP at LHC(b) (e.g. large φ_s). To understand and test this NP, we need the next level of precision.

- The clean strategies exist that translate very high statistics measurements into precise, powerful constraints on SM/NP parameters. To exploit them will require the next generation of flavour physics experiments.

- This will decisively increase the NP reach in B sector. And beyond: CPV in charm -within reach at the next generation of heavy flavour experiments- is uncharted territory (remember how B and K took off after its discovery). New, very clean precision measurements are possible at dedicated K experiments.

Backup

Comparing LHCb-Upgrade and SFF

... for measurements discussed in this talk.

	LHCb-Upgrade	SFF
γ	✓	✓
$b \to s$ penguins	✓	✓
$\lvert V_{ub} \rvert$	×	✓
B_s-mixing, φ_s	✓	×
Charm mixing & CPV	✓	o
α	✓	✓

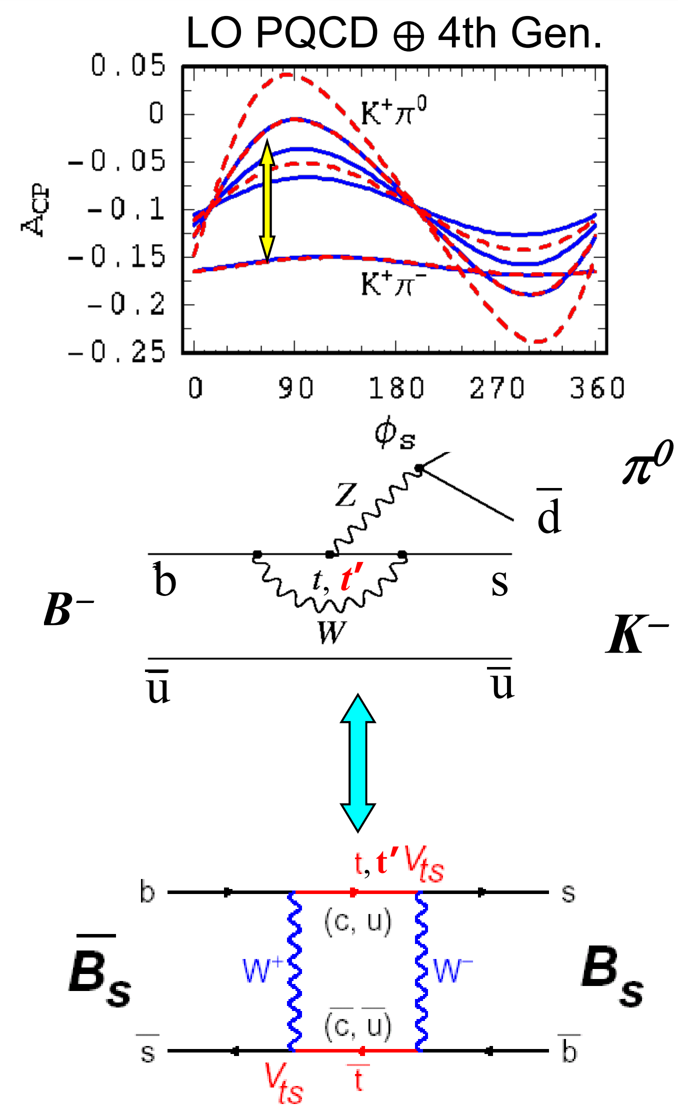
✓ = can deliver significant improvement relative to 2014

× = cannot

o = some improvement

ΔA$_{CP}$(Kπ)

- Time-integrated CP asymmetry
  A$_{CP}$($B^+ \rightarrow K^+\pi^0$) = 5.0%±2.5%
  A$_{CP}$($B^0 \rightarrow K^+\pi^-$) = -9.7%±1.2%
- In SM, would expect them to be similar.
- 4-th generation? (could also neatly accommodate large φs). A Soni et al arXiv:0807.1971 [hep-ph] (2008), WS Hou, Nagashima, Soddu, PRL'05
- Can be accommodated within uncertainties of hadronic effects: M. Ciuchini et al: Phys.Lett.B674:197-203,2009, M. Duraisamy,et al arXiv:0812.3162 [hep-ph]
- Clarification might come from $B_d \rightarrow K_s\pi^0$. Also $B_s \rightarrow K^*K^*$ and $B \rightarrow K\pi\pi$ Dalitz plots probe similar physics.



WS.Hou (FPCP 09, slide 55) and references therein

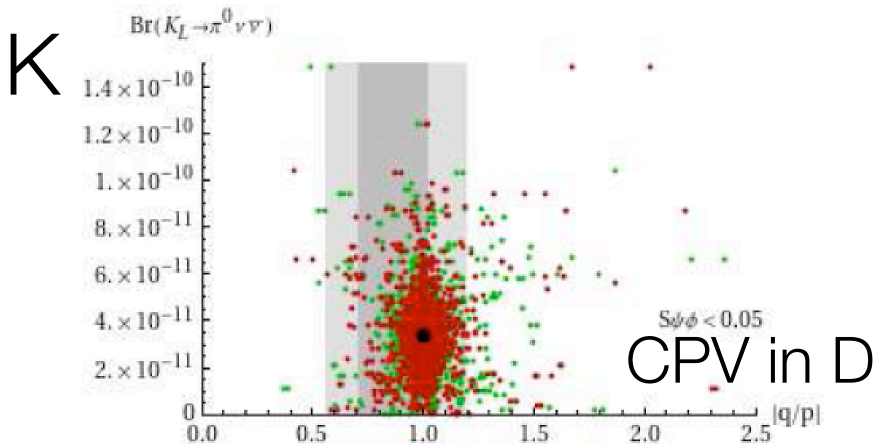
alpha

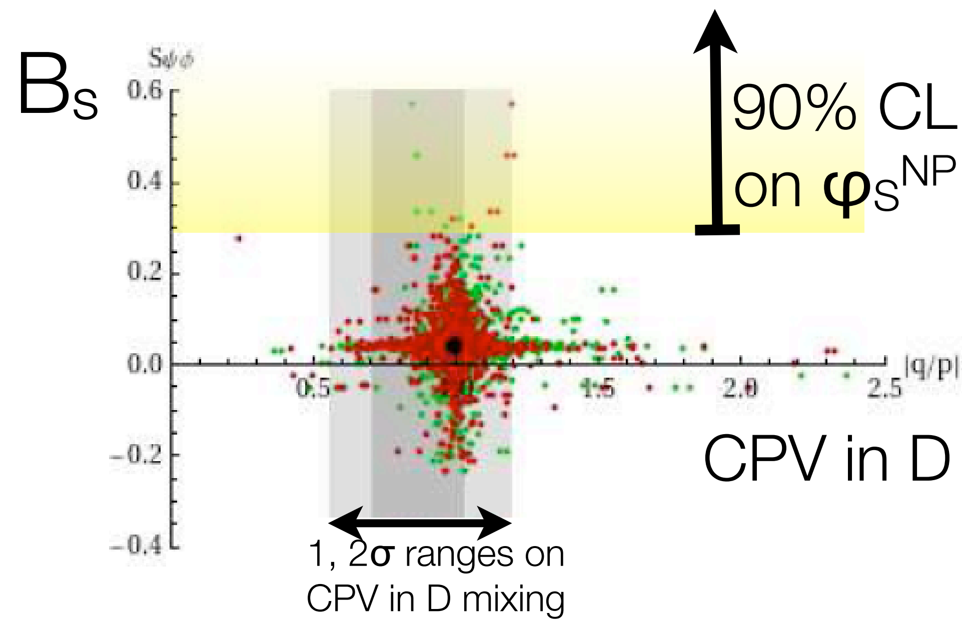
- $B\to\pi\pi$, $B\to\rho\rho$, and $B\to\rho\pi$ measure $2(\beta + \gamma)$, known as π-α. $B_s\to KK$ measures $2(\beta_s + \gamma)$.
- All proceed via both, tree and loop (penguin) diagrams. To interpret the measurement we need to disentangle the two contributions.
- Many strategies exist. All combine several channels and rely on symmetries of the strong interaction (isospin, U-spin). Control channels to estimate breaking effects.
- Not as clean a way to extract β or γ, but important independent measurement, plus: Loop contributions sensitive to NP.

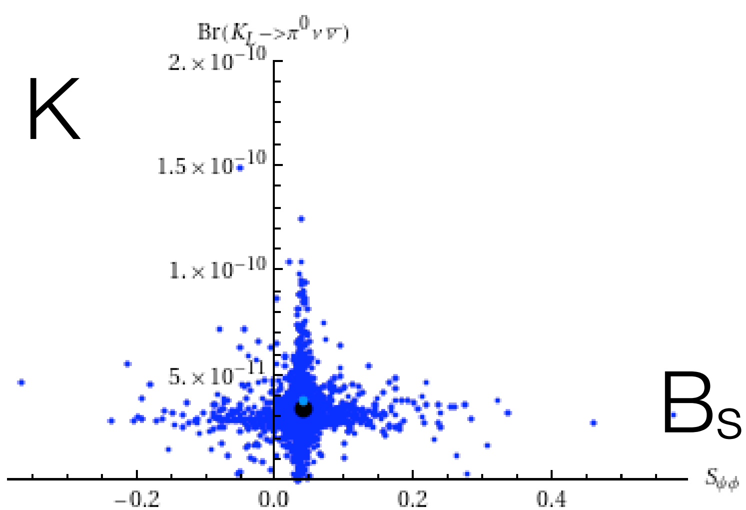
	σ Now	σ 2014	σ theor arXiv: 0802.3201	LHCb-Upgr. (stat)/ SuperB
$\pi^+\pi^-$ $\pi^0\pi^0$			3°	3°
$\rho^+\rho^-$ $\rho^0\rho^0$	7°	(*)	3°	1.5°
$\rho^\pm\pi^0$ $\rho^0\pi^\pm$		2.5°	1.5°	1°/2°
$B\to\pi^+\pi^-$ $B_s\to K^+K^-$		5°	$<3°$ (my guess)	1°

*) LHCb will improve the accuracy in $\rho\rho$ by improving the precision on $B\to\rho^0\rho^0$

Littlest Higgs with T-parity in B, D and K observables:

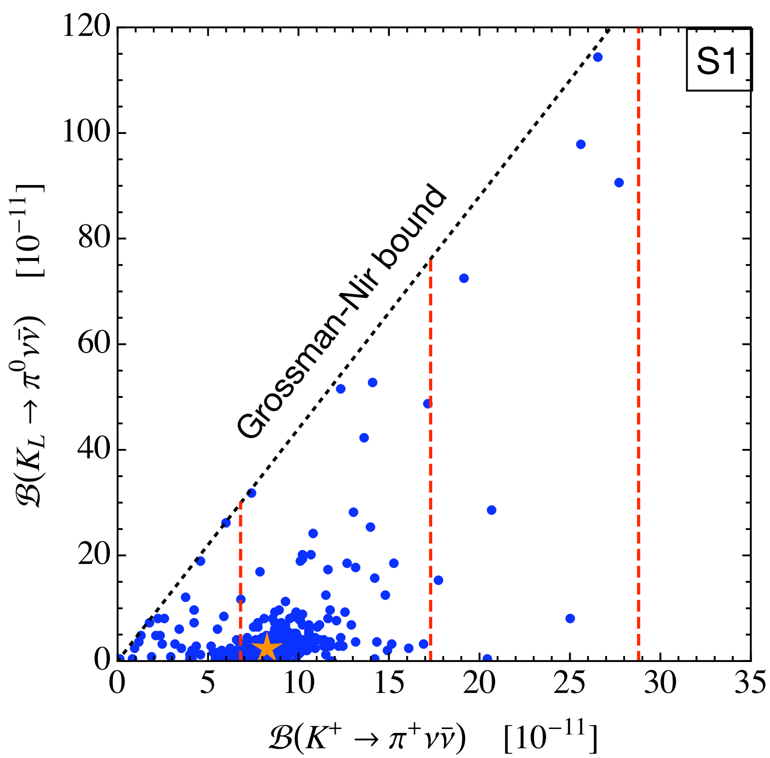






Rare K decays: Golden modes*

- Spectacular corrections in very clean $K \to \pi\nu\bar{\nu}$ decays. Even Grossman-Nir bound, $\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) < 4.4\,\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})$, can be saturated



★ SM: $\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) \approx 8.3 \cdot 10^{-11}$,
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) \approx 2.7 \cdot 10^{-11}$

- - central value and 68% CL limit $\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \cdot 10^{-11}$ from E949

● consistent with quark masses, CKM parameters, and 95% CL limit $|\varepsilon_K| \in [1.3, 3.3] \cdot 10^{-3}$

*Grossman and Nir, hep-ph/9701313; Bauer *et al.*, paper in preparation

Neubert FPCP 09

K/pi puzzle, Bs mixing, and 4th generation

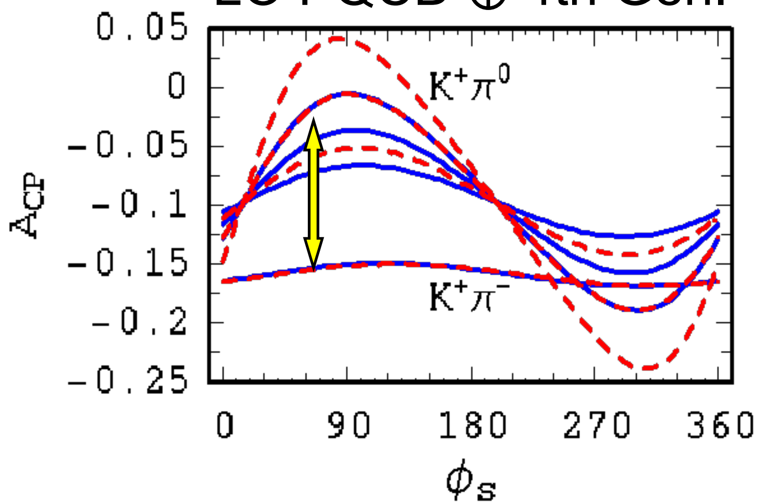
- Evidence for 4th family: Amarjit Soni (Brookhaven) , Ashutosh Kumar Alok (Tata Inst.) , Anjan Giri (Punjabi U.) , Rukmani Mohanta (Hyderabad U.) , Soumitra Nandi (Harish-Chandra Res. Inst.) arXiv:0807.1971 [hep-ph] (2008)

- Can be accommodated within uncertainties of hadronic effects: M. Ciuchini (INFN, Rome3) , E. Franco (INFN, Rome) , G. Martinelli (INFN, Rome & Rome U.) , M. Pierini (CERN) , L. Silvestrini (INFN, Rome) . Nov 2008. Published in Phys.Lett.B674:197-203,2009.

- Murugeswaran Duraisamy, Alexander L. Kagan (Cincinnati U.) . Jan 2009. 4pp.e-Print: arXiv:0812.3162 [hep-ph]

$\Delta A = A_{K^+\pi^0} - A_{K^+\pi^-} \sim 15\%$ and $\boxed{P_{EW}^{b\to s}}$

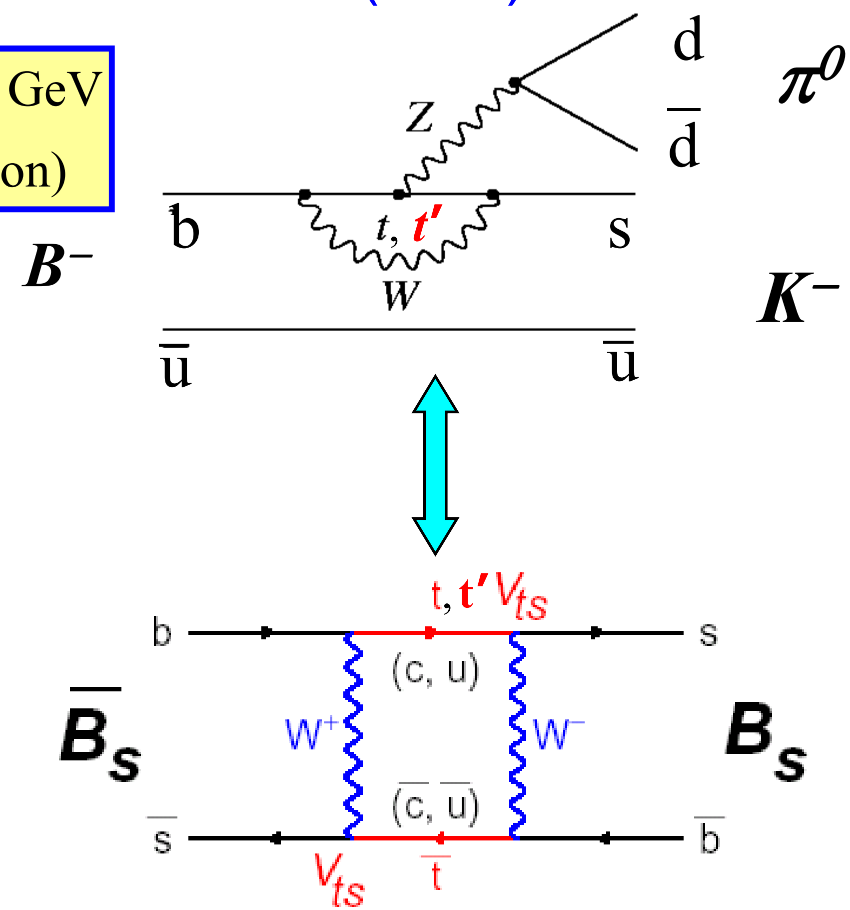
LO PQCD ⊕ 4th Gen.



WSH, Nagashima, Soddu, PRL'05

$\Delta A \approx 12\%$ vs 15% (data)

$m_{t'} = 300$ GeV
(illustration)



ASL & NP

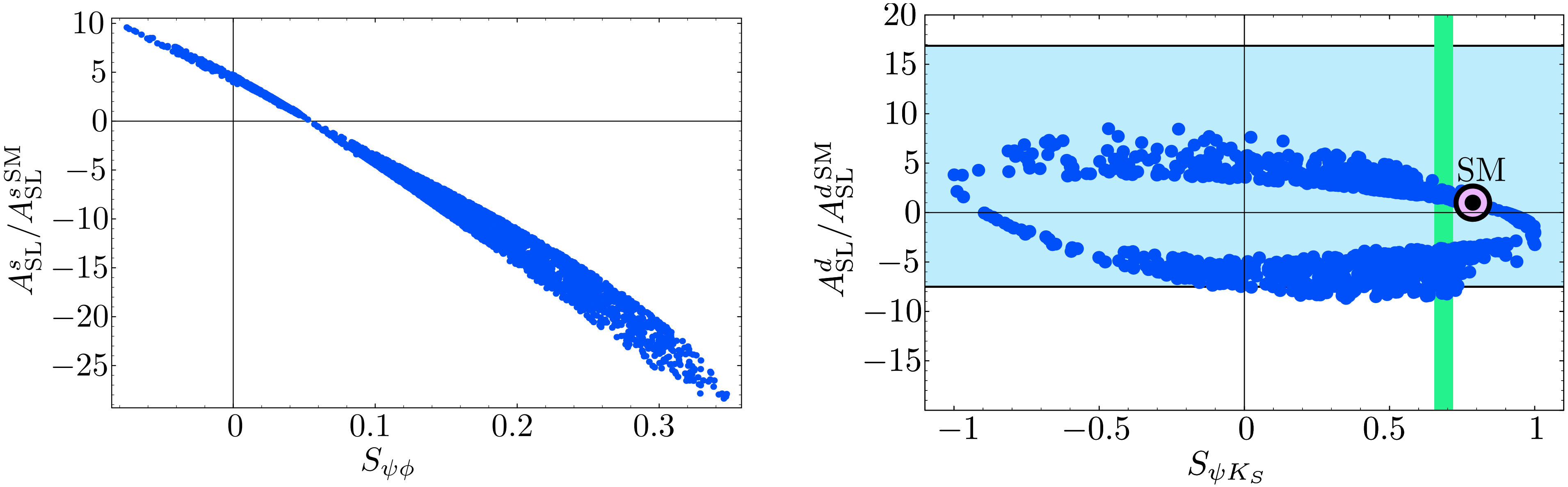
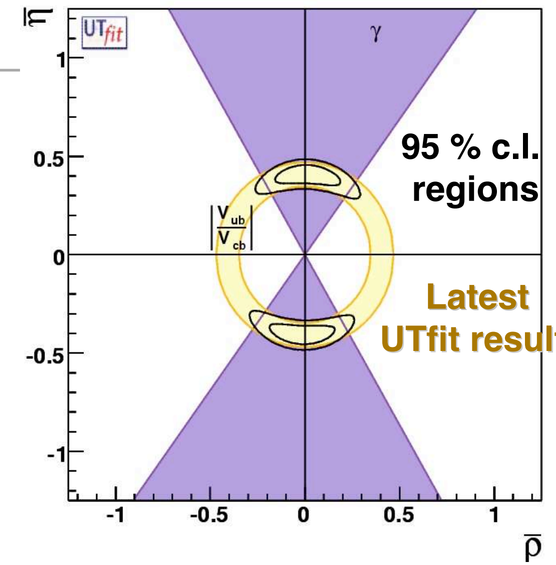
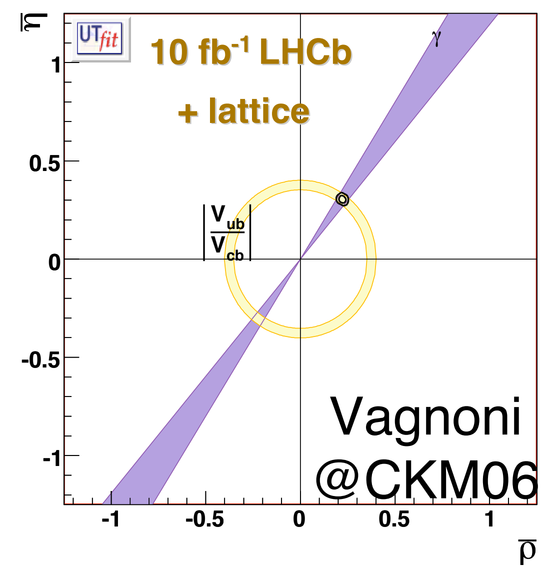
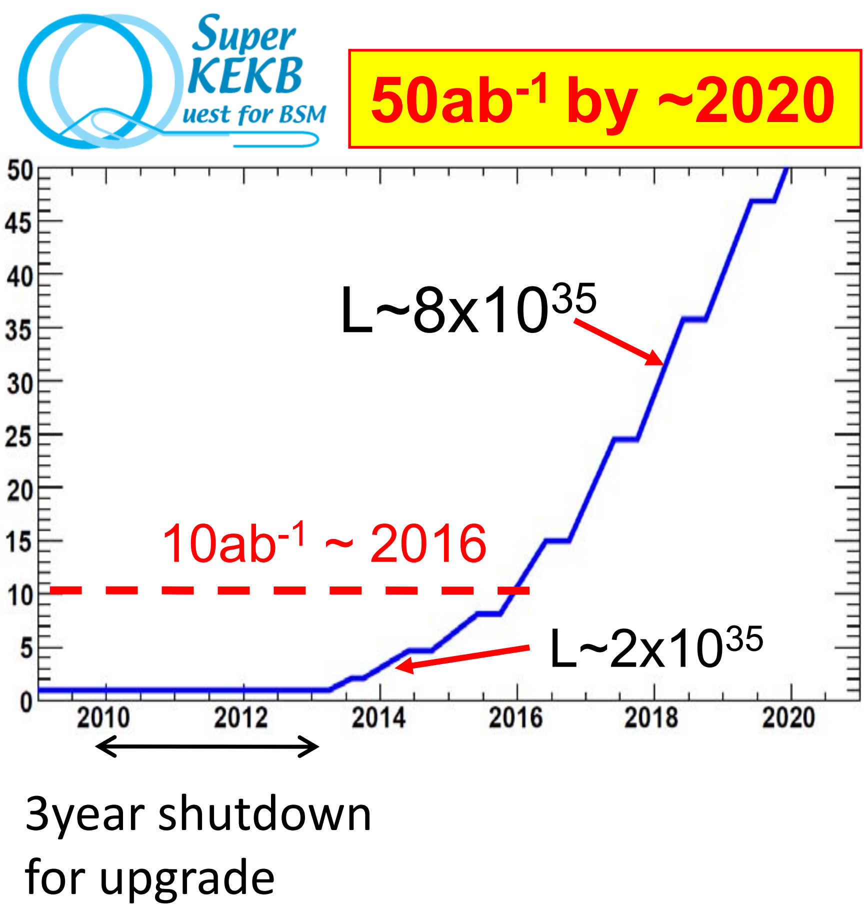
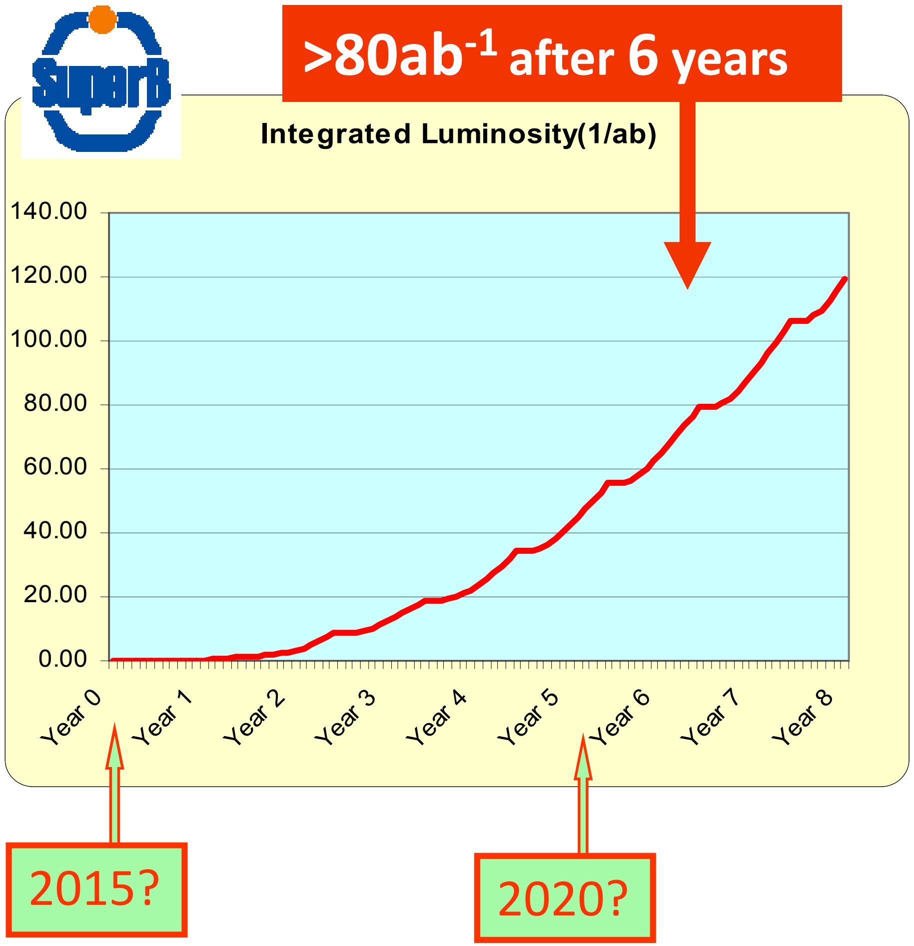


Figure 2-18. *Left (right) plot shows the correlation between A^s_{SL} (A^d_{SL}) and $S_{J/\psi\phi}$ ($S_{J/\psi K_S}$) computed in the Littlest Higgs Model with T-parity (see text). The shaded areas represent the present experimental constraints.*


95 % c.l.
regions
Latest
UTfit result

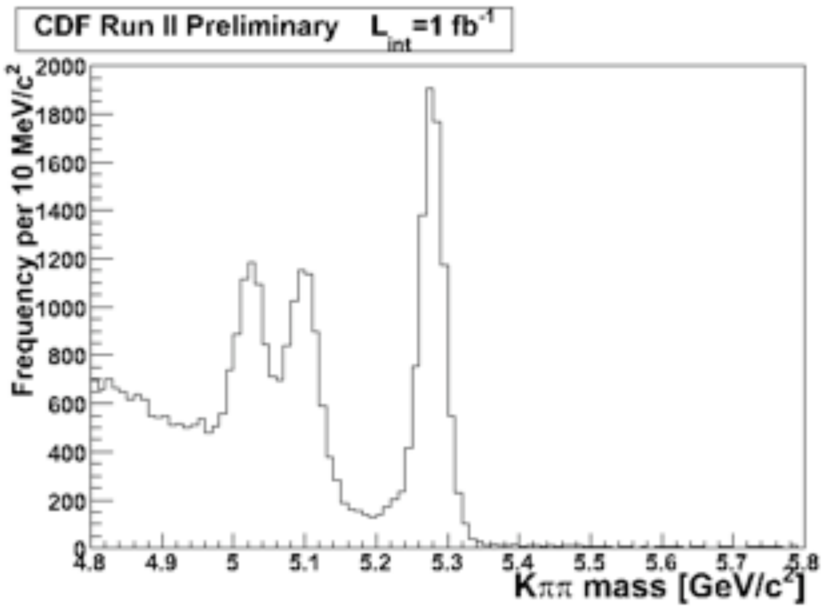

10 fb^{-1} LHCb
+ lattice
Vagnoni
@CKM06

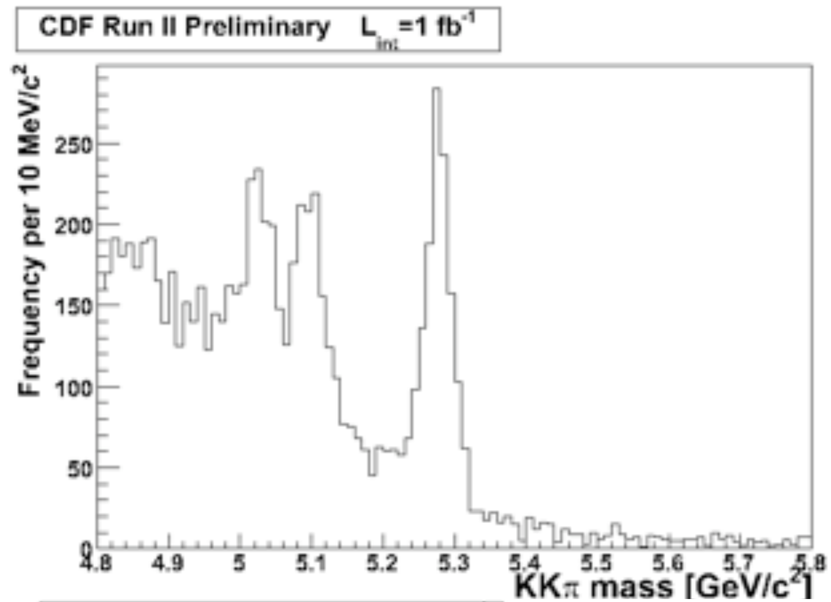


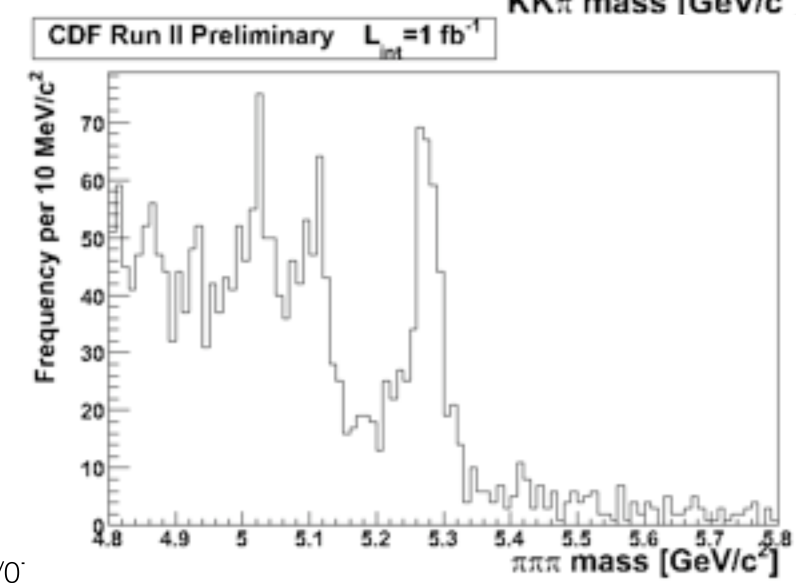


Yoshihide Sakai at FPCP 2009

B->D(hh)K at CDF


CDF Run II Preliminary L_{int}=1 fb^{-1}
Frequency per 10 MeV/c^2
$K\pi\pi$ mass [GeV/c^2]


CDF Run II Preliminary L_{int}=1 fb^{-1}
Frequency per 10 MeV/c^2
$KK\pi$ mass [GeV/c^2]


CDF Run II Preliminary L_{int}=1 fb^{-1}
Frequency per 10 MeV/c^2
$\pi\pi\pi$ mass [GeV/c^2]

LHCb Upgrade

- **What is LHCb Upgrade?**
  - Run at ten times the design luminosity, namely at 2×10^{33}
  - Needs detector and trigger upgrade
  - Increase trigger efficiencies for hadrons by at least a factor two
  - Accumulate data sample of 100 fb^{-1}
- **Sensitivities**
  - LHCb upgrade will provide us with a very powerful microscope
  - Use theoretically clean observables
  - **Probe/measure NP at percent level**

Sensitivities for integrated lumi of 100 fb^{-1}

Observable	Sensitivity
$S(B_s \to \phi\phi)$	$0.01 - 0.02$
$S(B_d \to \phi K^0_S)$	$0.025 - 0.035$
$\phi_s\ (J/\psi\phi)$	0.003
$\sin(2\beta)\ (J/\psi K^0_S)$	$0.003 - 0.010$
$\gamma\ (B \to D^{(*)}K^{(*)})$	$< 1^\circ$
$\gamma\ (B_s \to D_s K)$	$1 - 2^\circ$
$\mathcal{B}(B_s \to \mu^+\mu^-)$	$5 - 10\%$
$\mathcal{B}(B_d \to \mu^+\mu^-)$	3σ
$A_T^{(2)}(B \to K^{*0}\mu^+\mu^-)$	$0.05 - 0.06$
$A_{\mathrm{FB}}(B \to K^{*0}\mu^+\mu^-)\ s_0$	$0.07\ \mathrm{GeV}^2$
$S(B_s \to \phi\gamma)$	$0.016 - 0.025$
$A^{\Delta\Gamma_s}(B_s \to \phi\gamma)$	$0.030 - 0.050$
charm x'^2	2×10^{-5}
mixing y'	2.8×10^{-4}
CP y_{CP}	1.5×10^{-4}

Also studying Lepton Flavour Violation in $\tau\to\mu\mu\mu$

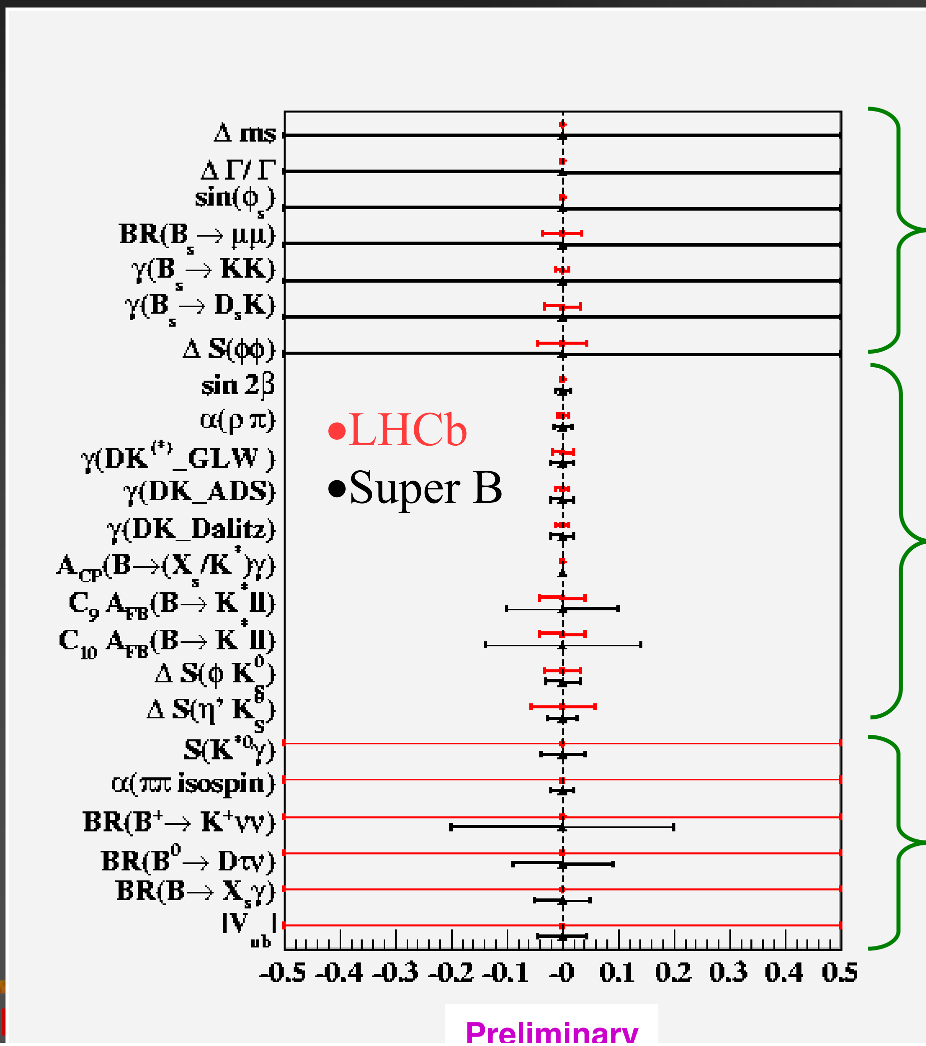
LHCC meeting F. Muheim 7

Comparison with Super B factory

Sensitivity Comparison ~2020

LHCb 100 fb^{-1} vs Super-B factory 50 ab^{-1}

SuperB numbers from M Hazumi - Flavour in LHC era workshop; LHCb numbers from Muheim

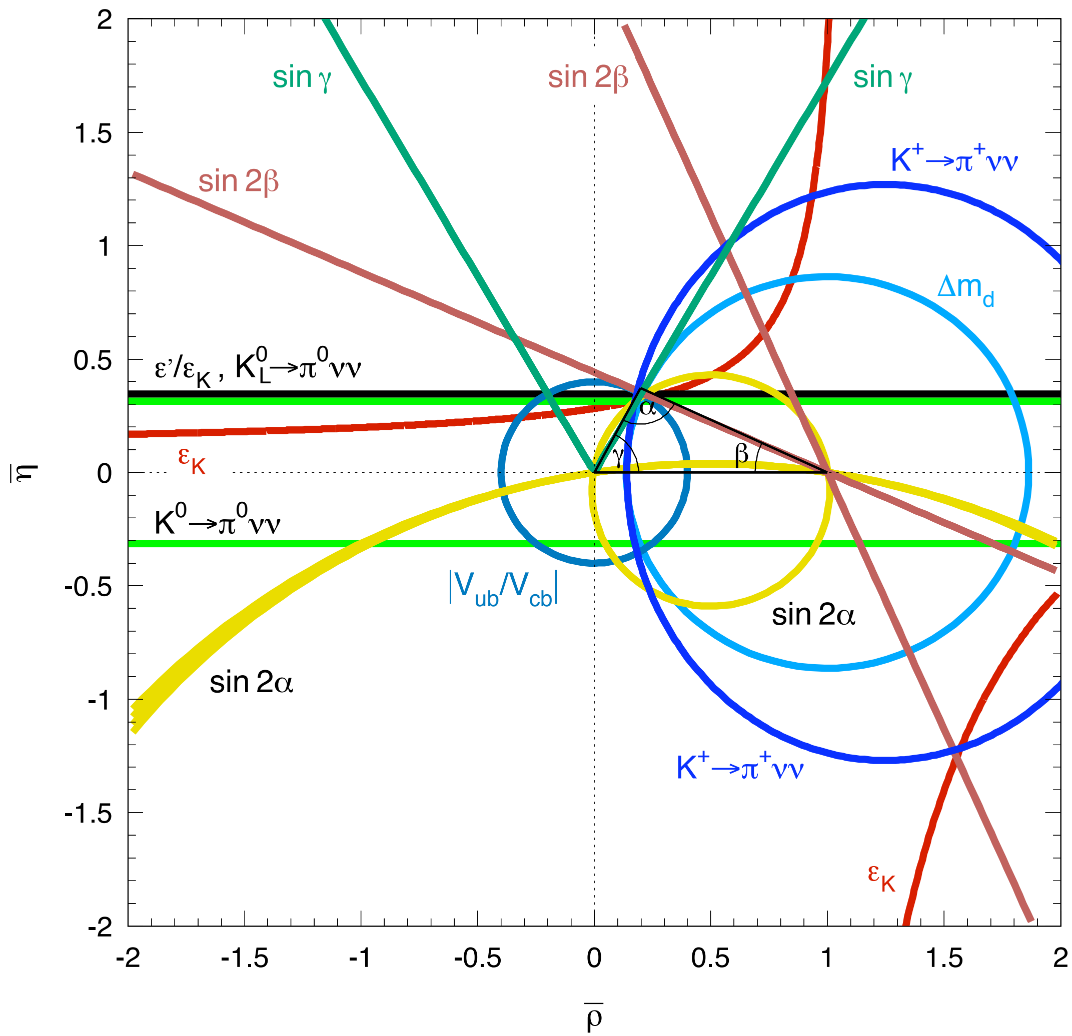


B_s only accessible at LHCb

Common

No IP
Neutrals, ν

46



arXiv:hep-ph/0406184v3

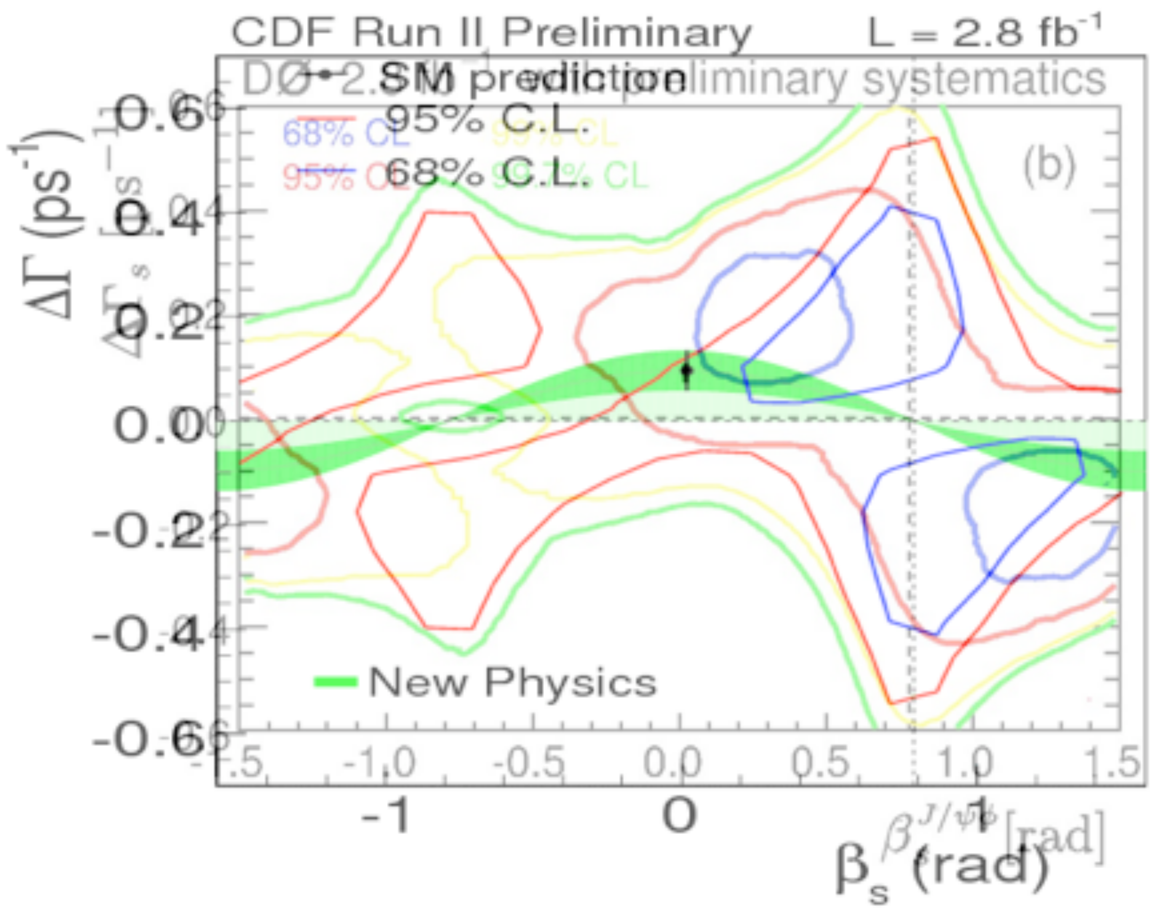
Other Physics Sensitiviti

	Channel	Yield	B/S	Precision
γ	$B_s \to D_s^{-+} K^{+-}$	5.4k	< 1.0	$\sigma(\gamma) \sim 14^o$
	$B_d \to \pi^+ \pi^-$	36k	0.46	$\sigma(\gamma) \sim 4^o$
	$B_s \to K^+ K^-$	36k	< 0.06	
	$B_d \to D^0$ (Kπ,KK) K^{*0}	3.4 k, 0.5 k, 0.6 k	<0.3, <1.7, < 1.4	$\sigma(\gamma) \sim 7^o$ - 10^o
	$B^- \to D^0 (K^-\pi^+, K^+\pi^-) K^-$	28k, 0.5k	0.6, 1.5	$\sigma(\gamma) \sim 5^o$ - 15^o
	$B^- \to D^0 (K^+K^-, \pi^+\pi^-) K^-$	4.3 k	1.0	
	$B^- \to D^0 (K_S\pi^+\pi^-) K^-$	1.5 - 5k	< 0.7	$\sigma(\gamma) \sim 8^o$ - 16^o
α	$B_d \to \pi^+ \pi^- \pi^0$	14k	< 0.8	$\sigma(\alpha) \sim 10^o$
	$B \to \rho^+\rho^0, \rho^+\rho^-, \rho^0\rho^0$	9k, 2k, 1k	1, <5, < 4	
β	$B_d \to J/\psi(\mu\mu)K_S$	216k	0.8	$\sigma(\sin 2\beta) \sim 0.022$
Δm_s	$B_s \to D_s^- \pi^+$	120k	0.4	$\sigma(\Delta m_s) \sim 0.01$ ps^{-1}
ϕ_s	$B_s \to J/\psi(\mu\mu)\phi$	131k	0.12	$\sigma(\phi_s) \sim 0.023$
Rare decays	$B_s \to \mu^+\mu^-$	17	< 5.7	
	$B_d \to K^{*0} \mu^+\mu^-$	4.4 k	< 2.6	Zero to ±0.3 GeV^2
	$B_d \to K^{*0} \gamma$	35k	< 0.7	$\sigma(A_{CP}) \sim 0.01$
	$B_s \to \phi \gamma$	9.3 k	< 2.4	
charm	$D^{*+} \to D^0 (K^-\pi^+) \pi^+$	100 M		

- Or su mo
- Fo fb

Flavour in the Era of the LHC, March, 2007

$B_s \rightarrow J/\psi\varphi$ at DØ and CDF



Progress / Plan

2004.06: LoI for SuperKEKB
2008.01: KEK Roadmap
SuperKEKB is identified as high priority
2008.12: New collaboration (Belle II) formed officially
13 countries, 43 institutes
Spokesperson selection in progress
2009.03: BPAC (Chair: T.Nakada) endorsement
2009.03: FY2008/9 supplemental budget:
~5M$ for Belle II upgrade
2009.05: ~27M$ for KEKB upgrade R&D

2009.07: 3rd Open Belle II collab. meetnig

Progress / Plan

2007.09: CDR; 320 signatures, ~85 institutes

2008.06: Mini MAC formed (Chair: J.Dorfan)

↓ recommendation

2008.12: TDR phase was approved by INFN

15M € /3 years (2009-2011)

Management structure formed

Director: M.Georgi

Deputies: D.Hitlin, D.Leith, G.Wormser

Accelerator: J.Seeman

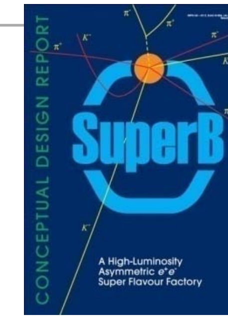
Detector: F.Forti, B.Ratcliff

TDR ready by end of 2010

2009.04: 2nd MAC:

further endorsement

2009.06: General Meetnig



arXiv:0709.0451

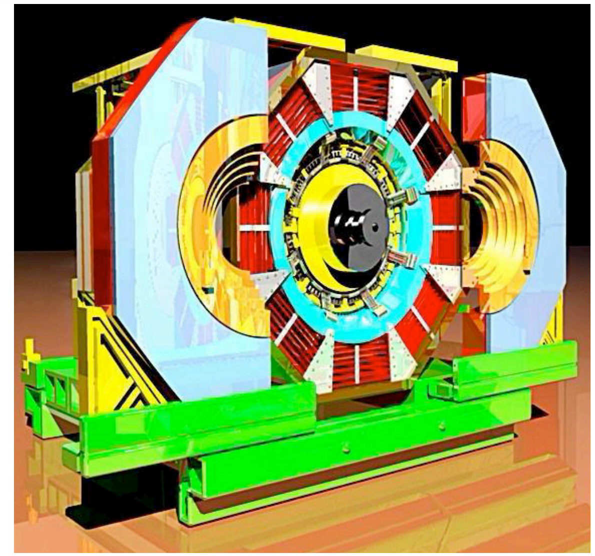
THE UNIVERSITY OF WARWICK

www.ippp.dur.ac.uk

Workshop on New Physics with SuperB
14th-17th April 2009

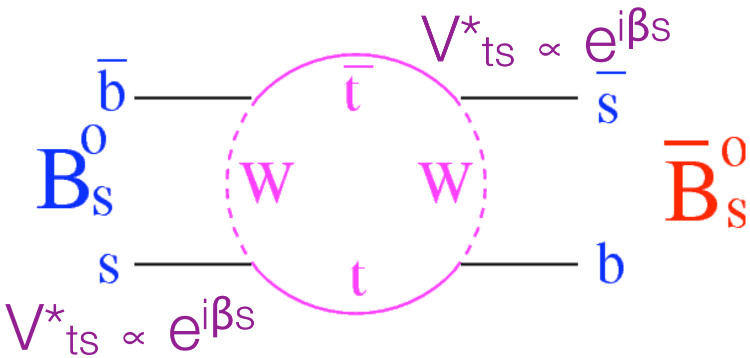
BES-III time line

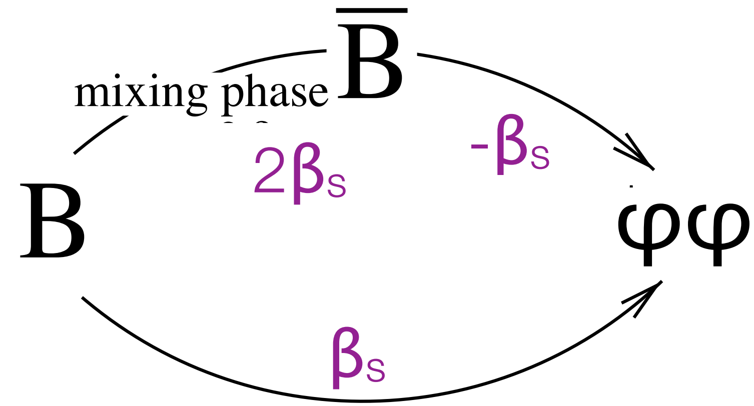
- First runs at reduced energy successful
- This year: Run at J/psi resonance, increase luminosity
- If that is stable, run through psi(3770) resonance after summer
- Running at psi(3770) starts most likely in 2011 <ask Roy>



$B_s \to \phi\phi$

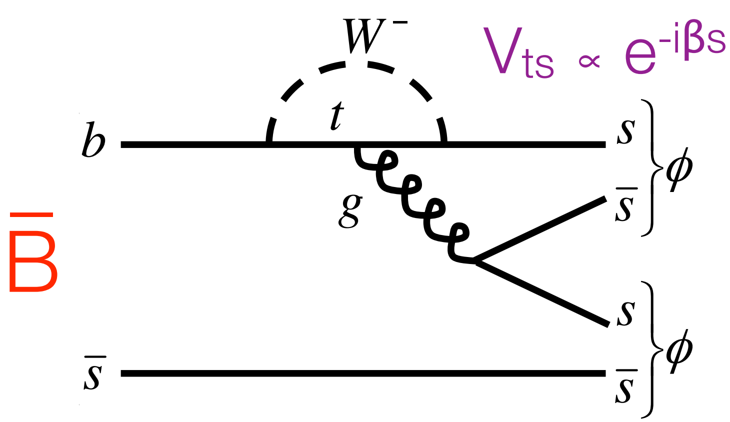
- In SM, phase from Bs mixing ($2\beta_s$)...





Phase difference = $2\beta_s - \beta_s - \beta_s = 0$

- ...cancels exactly with the phase from the b->s penguin:



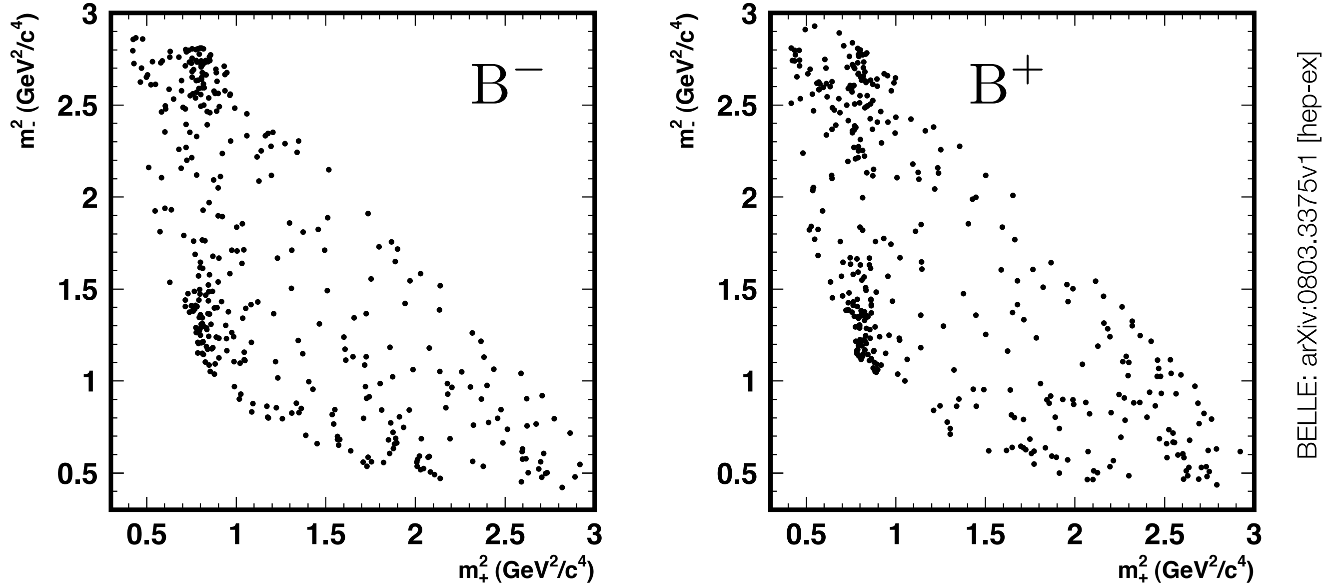
Clean measurement of NP in mixing and/or $b \to s$ penguins.

	σ Now	σ 2014	σ theor. (now)	LHCb Upgr.
$B_s \to \phi\phi$	∞	0.05	0.01	0.01

Observable	SM Prediction	MSSM Flavor Content
Δm_K	$\sim (V_{cs}^* V_{cd})^2$	$(\delta_{AB})_{12}$
ϵ	$\sim\mathrm{Im}(V_{ts}^* V_{td})\mathrm{Re}(V_{cs}^* V_{cd})$	$(\delta_{AB})_{12}$
$\epsilon^{'}/\epsilon$	$\sim\mathrm{Im}(V_{ts}^* V_{td})$	$(\delta_{AB})_{12}$
$b \to s\gamma$	$\sim V_{tb} V_{ts}^*$	$(\delta_{AB})_{23}$
$A_{CP}(b \to \ s\gamma)$	$\sim \alpha_s(m_b)\frac{V_{ub}}{V_{cb}}\frac{m_c^2}{m_b^2}$	$(\delta_{AB})_{23}$
Δm_{B_d}	$\sim (V_{td}^* V_{tb})^2$	$(\delta_{AB})_{13}$
Δm_{B_s}	$\sim (V_{ts}^* V_{tb})^2$	$(\delta_{AB})_{23}$
$A_{CP}(B \to \ \psi K_S)$	$= \sin 2\beta$	$(\delta_{AB})_{13}$
$A_{CP}(B \to \ \phi K_S)$	$= \sin 2\beta$	$(\delta_{AB})_{23}$

Dalitz Plots for γ at Belle&BaBar

$$B^{\pm} \to (D^0 \to K_s \pi^+ \pi^-) K^{\pm}$$



Combined result (both experiments, several D decay modes)

CKM fitter: $\gamma = 70^{o}{}^{+27^o}_{-29^o}$

UTFit: $\gamma = 78^o \pm 12^o$

BaBar: Phys.Rev.D78:034023,2008, BELLE: arXiv:0803.3375v1 [hep-ex]
CKMfitter: Eur. Phys. J. C41, 1-131 (2005) [hep-ph/0406184], http://ckmfitter.in2p3.fr

ATLAS, CMS and LHCb for φ_s

ATLAS, CMS (~3 years at $\mathcal{L}$=10^{33}, $\int\mathcal{L}dt$ =30/fb)

	ATLAS	CMS	Statistical error on parameter	ATLAS	CMS
Signal statistics, 30 fb^{-1}	$2.4 \cdot 10^5$	$3.3 \cdot 10^5$	$\delta\phi_s$	0.067	0.049
Proper time resolution	0.083 ps	0.1 ps	$\delta\Delta\Gamma_s/\Delta\Gamma_s$	13%	4.3%
B_s^0mass resolution	16.6 MeV	14 MeV	$\delta\Gamma_s/\Gamma_s$	1%	0.29%
Background	$\sim$ 30%	$\sim$ 28%	$\delta A_{\|\|}/A_{\|\|}$	0.7%	1.0%
Tag quality using μ, e, jet-charge tags	3.9	3.9	$\delta A_{\perp}/A_{\perp}$	3%	0.8%

LHCb per year at $\mathcal{L}$=10^{32} ($\int\mathcal{L}dt$ =2/fb): 0.03

LHCb after 6/fb (3 nominal years): 0.017

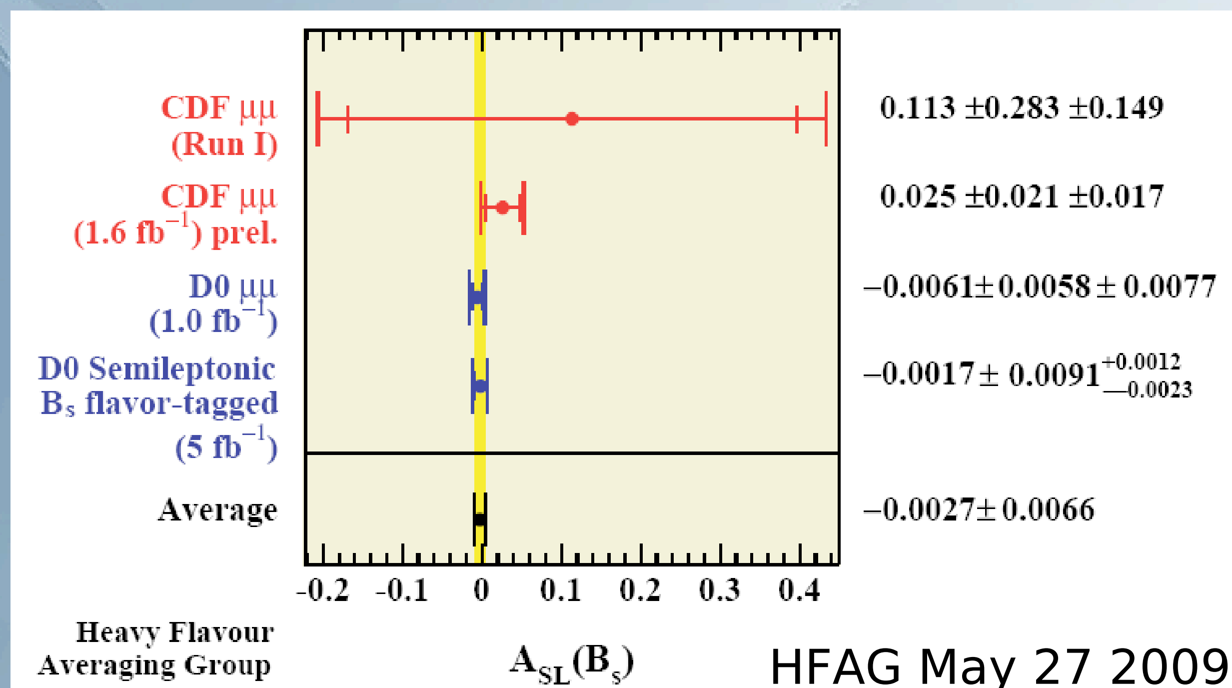
LHCb after 10/fb (5 nominal years): 0.013

Conclusions

The B_s^0 semileptonic asymmetry has been measured with a $5fb^{-1}$ data sample to be:

$$-0.0017 \pm 0.0091(\text{stat})^{+0.0012}_{-0.0023}(\text{syst})$$

Submitted
arXiv: 090



This analysis supersedes t previous sem CP asymmet and improve statistical un by ~2x

Compare, Apr 09: $A^s_{sl} = -0.0037 \pm 0.0094$

PEP-II Records

Last update:
April 8, 2008

Peak Luminosity

12.069×10^{33} cm^{-2}sec^{-1} — August 16, 2006

1722 bunches — 2900 mA LER — 1875 mA HER

Integration records of delivered luminosity

Best shift (8 hrs, 0:00, 08:00, 16:00)	339.0 pb^{-1}	Aug 16, 2006
Best 3 shifts in a row	910.7 pb^{-1}	Jul 2-3, 2006
Best day	858.4 pb^{-1}	Aug 19, 2007
Best 7 days (0:00 to 24:00)	5.411 fb^{-1}	Aug 14-Aug 20, 2007
Best week (Sun 0:00 to Sat 24:00)	5.137 fb^{-1}	Aug 12-Aug 18, 2007
Peak HER current	2069 mA	Feb 29, 2008
Peak LER current	3213 mA	Apr 7, 2008
Best 30 days	19.776 fb^{-1}	Aug 5 – Sep 3, 2007
Best month	19.732 fb^{-1}	August 2007

Total delivered

557 fb^{-1}

PEP-II turned off April 7, 2008

γ reach from theoretically clean tree modes

	Now	2014	LHCb-Upgrade/
$B_s \to D_s K$		27k	500k/
$B^+ \to D(K_S\pi\pi)K^+$		25k	500k/
$B^+ \to D(hh)K^+$		280k	5.6M

- Essentially no theory error. Sub-degree precision is really sub-degree precision on SM parameters - and translates directly into NP reach.
- Requires input from $\psi(3770) \to DD$. CLEO-c data make significant impact.
- Statistics in $\psi(3770)$ will increase by ×25 (BES III) - or even ×100 should SuperB run at $\psi(3770)$ for 1 months.

Jonathan's Lattice Predictions

Summary: targeted precision

Quantity	CKM	Hadronic ME	Error
f_K/f_π	$\lvert V_{us}\rvert$	f_K/f_π	$< 0.1\%$
$K \to \pi l \nu$	$\lvert V_{us}\rvert$	$f^+_{K\pi}(0)$	$< 0.1\%$
ϵ_K	$\mathrm{Im}\, V^2_{td}$	B_K	1%
$D_{(s)} \to l\nu$	$\lvert V_{cd}\rvert, \lvert V_{cs}\rvert$	$f_{D_{(s)}}$	$< 1\%$
$B \to l\nu$	$\lvert V_{ub}\rvert$	f_B	2%
Δm_d	$\lvert V_{td}\rvert$	$f_{B_d}\sqrt{B_{B_d}}$	2%
$\Delta m_d/\Delta m_s$	$\lvert V_{td}/V_{ts}\rvert$	ξ	0.8%
$B \to D^{(*)} l\nu$	$\lvert V_{cb}\rvert$	$F_{B\to D^{(*)} l\nu}$	0.5%
$B \to \pi l\nu$	$\lvert V_{ub}\rvert$	$f^+_{B\pi}(q^2)$	3%
$B \to [K^{(*)}, \rho][\gamma, l^+ l^-]$	$\lvert V_{td}/V_{ts}\rvert$	T_1 etc	4%

A_{SL}

- Measures CPV in mixing, i.e. the deviation from CP-eigenstate = mass eigenstates. Equivalent to ε_K, only in B-system.

$$\begin{aligned}\Delta\Gamma_s(\text{meas}) &= \Delta\Gamma_s^{SM}\cos\phi_s^{NP}\\ A_{SL}^s(\text{meas}) &= \frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s^{NP}\\ \sin(2\beta_s)(\text{meas}) &= \sin(2\beta_s-\phi_s^{NP})\end{aligned}$$

- Current measurements $\mathcal{A}_{\mathrm{SL}}^s = -0.0027 \pm 0.0066$
- SM: $A_{SL}^s \approx 10^{-5}$
- LHCb (10/fb): σ(stat) ~ 0.001
  LHCb (100/fb): σ(stat) ~ 0.0003
  (systematics challenging)
- SuperB at ϒ(5S): σ ~0.004 - 0.006

- In SM, equivalent quantity in B_d system 20 × larger $A_{SL}^d \approx 2\cdot 10^{-4}$
- Current measurement (B-factories + CLEO): $A^d_{SL}=-0.0047 \pm 0.0046$
- Super B could reach precision < 10^{-3}

SM values from: A. Lenz, and U. Nierste, *JHEP* **06**, 072 (2007), `hep-ph/0612167`

A$_{\text{SL}}$

- Measures CPV in mixing, i.e
deviation from CP-eigensta
mass eigenstates. Equivale
ε_K, only in B-system.

Expect significant improvements.
How much exactly is hard to guess -
certainly systematics limited.

$$\sin(2\beta_s)(\text{meas}) = \sin(2\beta_s - \phi_s^{NP})$$

- Current measurements
$\mathcal{A}_{\text{SL}}^s = -0.0027 \pm 0.0066$
- SM: $A_{SL}^s \approx 10^{-5}$
- LHCb (10/fb): σ(stat) ~ 0.001
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(systematics challenging)
- SuperB at Υ(5S): σ ~0.004 - 0.006

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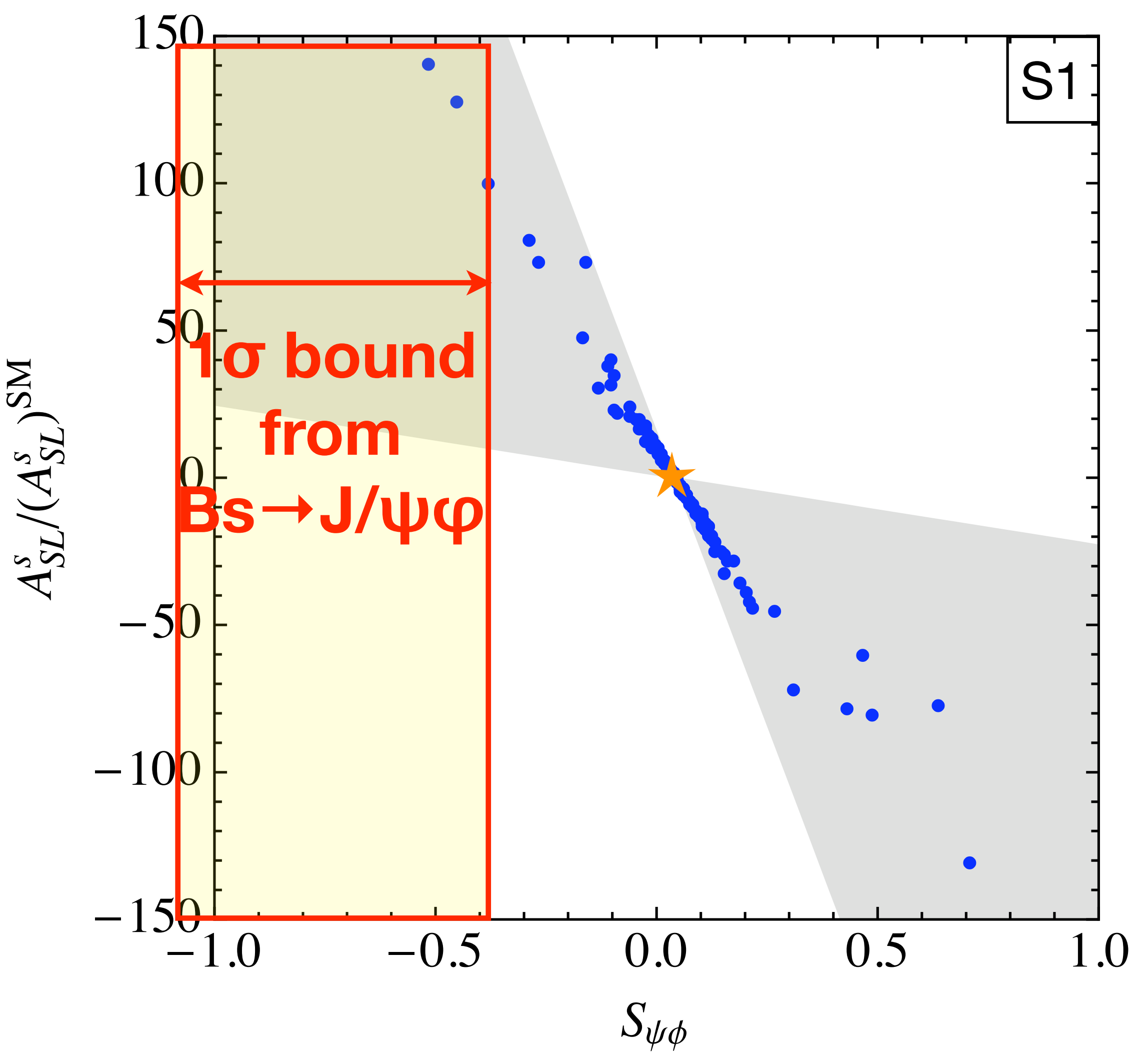
NP Example: A^s_{SL} and φ_s^{NP} in RS models



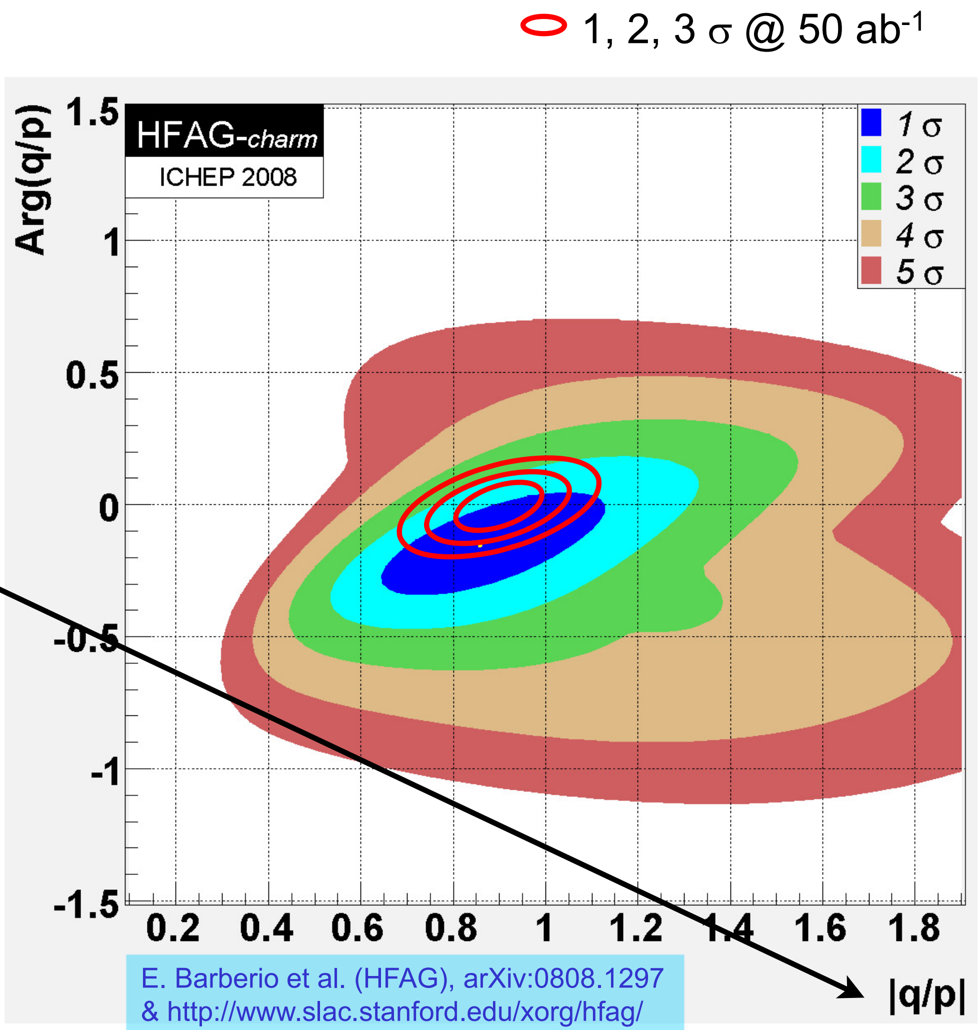
φ_s^{NP} and A_{SL} in RS model with Warped Extra Dimensions.

Parameters constrained to fit current measurements (FCNC in K mixing etc)

From Neubert, FPCP 09, see Blanke *et al.*, arXiv: 0809.1073; Bauer *et al.*, paper in preparation

CP Violation in charm

- Arg(q/p) equivalent to 2β in B system (i.e. CPV in the interference between mixing and decay)
- 1-|p/q| equivalent to A_{sl} or ε_K, CPV in mixing.
- Plot shows current constraints, and Super-KEKB (50 ab–1) superimposed.
- Expect LHCb/Upgrade to do very well, but no comparison plot, yet.



The New Physics phase φ_S^{NP}

- All other parameters in this list are sensitive to the same NP phase φ_S^{NP}.

$$\Delta m_s, \Delta\Gamma_s, A_{SL}^s, \sin(2\beta_s)$$

- If NP contributes to Bs mixing, instead of

$$\left.\begin{array}{rcl} \Delta\Gamma_s^{SM}/\Gamma_s & \sim & 10\% \\ A_{SL}^s & \sim & 2\cdot 10^{-5} \\ \sin(2\beta_s) & \sim & 0.04 \end{array}\right\} \sim 0$$

- we'd measure

$$\begin{array}{rcl} \Delta\Gamma_s(\text{meas}) & = & \Delta\Gamma_s^{SM}\cos\phi_s^{NP} \\ A_{SL}^s(\text{meas}) & = & \dfrac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s^{NP} \\ \sin(2\beta_s)(\text{meas}) & = & \sin(2\beta_s - \phi_s^{NP}) \end{array}$$

Measured in $B_S \to J/\psi\varphi$

Other experiments

- CDF/D0: Still has most of its flavour physics data to analyse, expect very interesting results over next couple of years, but by 2014 these will have been superseded by LHCb.

- ATLAS & CMS: Will make an important contribution in measurements such as $B_s \to \mu\mu$ and $B_s \to J/\psi\varphi$, especially in the early running period. But by 2014 LHCb precisions will completely dominate.

- PANDA: Can do charm physics, but cannot compete with LHCb in open charm (i.e. D mesons), neither does it aim to. PANDA focuses on spectroscopy and QCD.

Unique properties of $\psi(3770) \to DD$

- Input for many different $B^{\pm} \to DK^{\pm}$ modes. Transforms otherwise limiting systematics into small statistical error in high-precision γ measurement. Need a measurement for each D decay mode.

- Invaluable input to charm mixing and CPV measurements.

- Unbeatable precision on charm form-factors as precision test of LQCD (essential for $|V_{ub}|$), and/or $|V_{cd}|$ for UT constraints from ε_K.

- Current values (CLEO-c) mostly statistics limited. Large number of important measurements, just one typical example:

Not clear this will be done, but would be very worthwhile.

	CLEO-c stat ⊕ sys	BES-III stat	Super-B at $\psi(3770)$, 1 month, stat	Important input for:
$\cos(\delta^{K\pi})$	$0.24 \oplus 0.06$	0.06	0.03	D mixing and γ