Flavour physics at B-factories and other machines

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Overview

- Highlight of last year
- B-factories (B, D, τ, …)
  - BaBar and Belle
- Super Flavour Factories
  - SuperB and SuperKEKB
- CLEO-c
- BES-III
- Kaon Physics
  - KTeV & NA48
  - KLOE
  - NA62
- MEG ($\mu^{\pm}\rightarrow e^{\pm}\gamma$)
- $\mu\rightarrow e$ conversion.
- Summary

Note: See summary talks by A. Golutvin and G. Punzi for hadron machines, and A. Buras for a theoretical overview.

Highlight of last year

- Kobayashi and Maskawa were recognized for their work on extending quark mixing model to include CP violation!

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

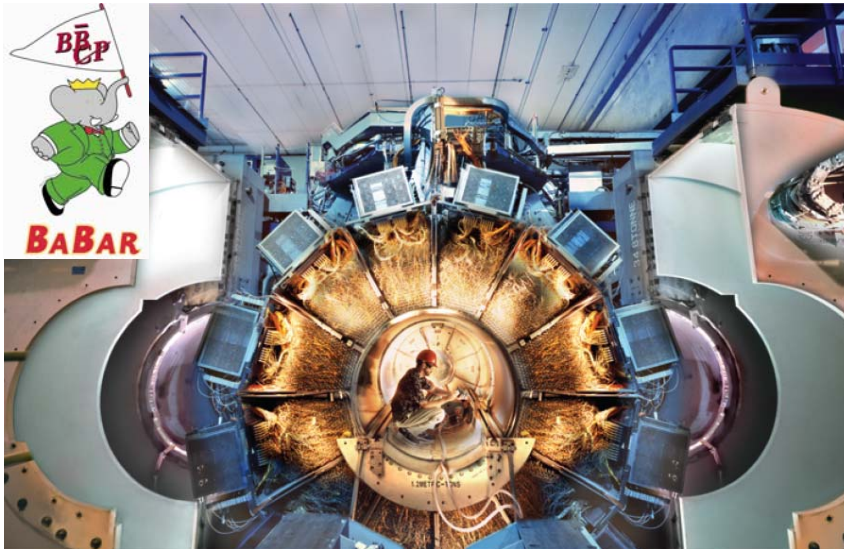
In a framework of the renormalizable theory of weak interaction, problems of *CP*-violation are studied. It is concluded that no realistic models of *CP*-violation exist in the quartet scheme without introducing any other new fields. Some possible models of *CP*-violation are also discussed.

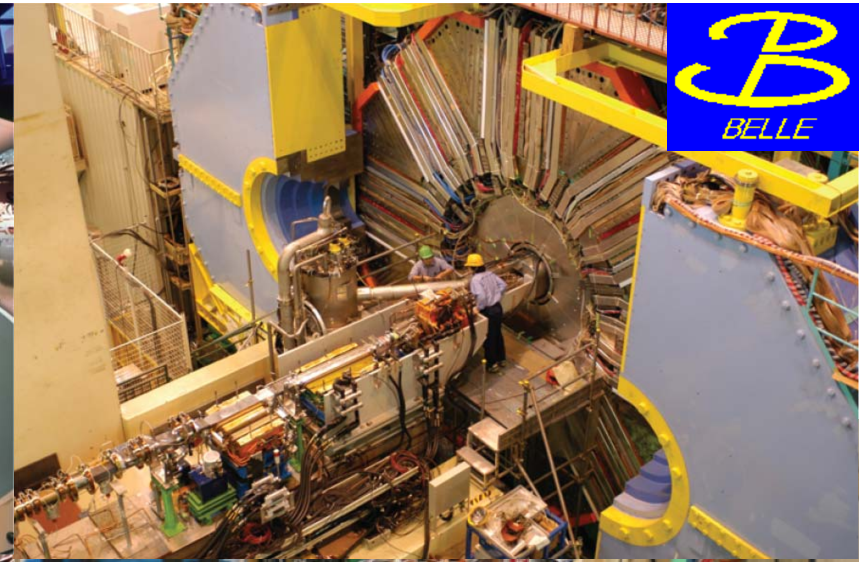
M. Kobayashi and T. Maskawa, Prog. Theor. Phys 49, 652 (1973).

B-factories

PEP-II and BaBar

KEKB and Belle

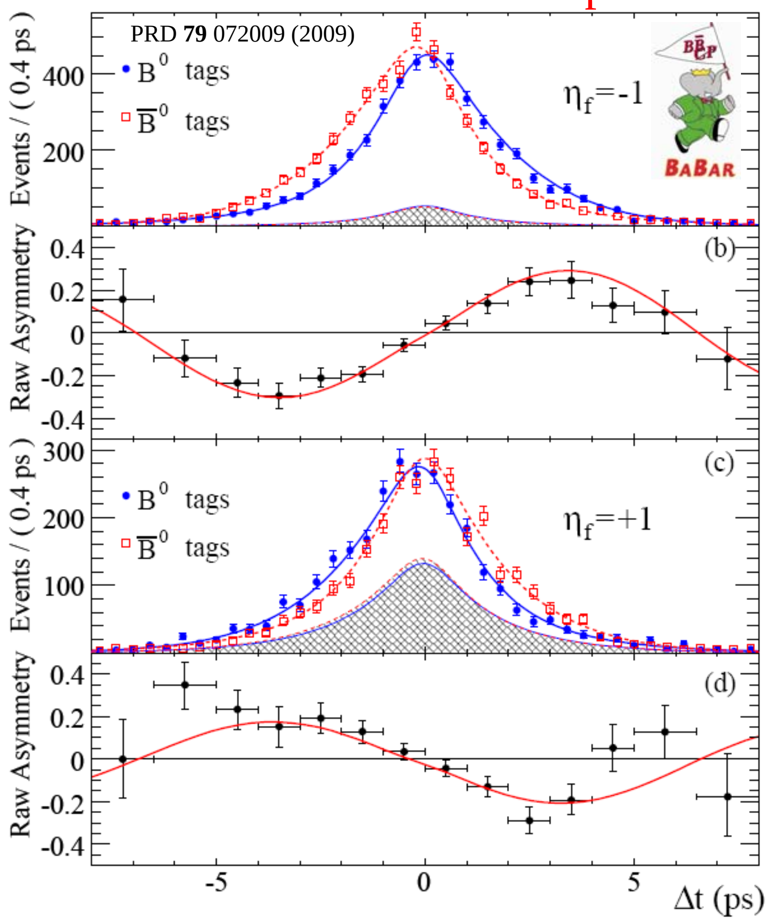




CP Violation: β (ϕ_1) from $c\bar{c}s$ decays

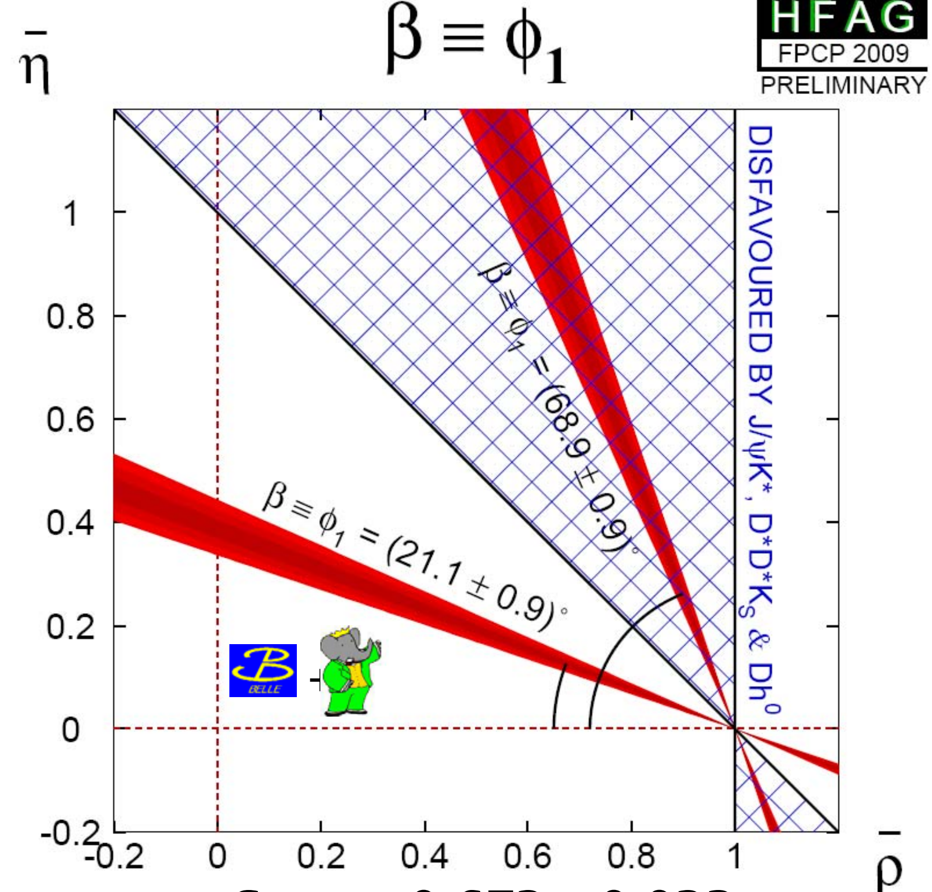
- Using B→ $J/\psi K^0$, $J/\psi K^*$, $\psi(2S)K_S$, $\eta_c K_S$, & $\chi_{c1} K_S$ decays.

BaBar's final result has been published:



$$S = -0.687 \pm 0.028 \pm 0.012$$

$$C = 0.024 \pm 0.020 \pm 0.016$$



$$S_{WA} = -0.672 \pm 0.023$$

$$C_{WA} = 0.004 \pm 0.019$$

Still limited by statistics!

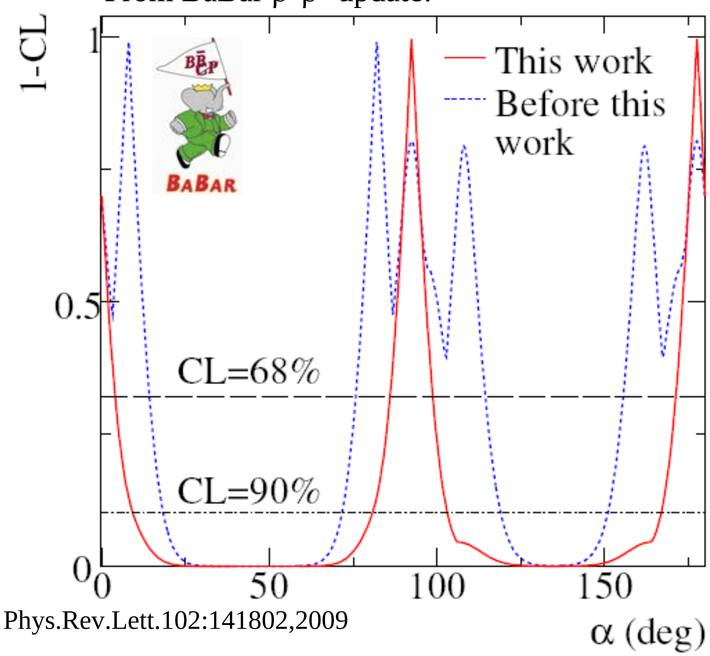
CP Violation: α (ϕ_2)

- Update of $\rho^+\rho^0$ has significant impact on precision using SU(2) analysis [now agrees with precision from SU(3) approach]:

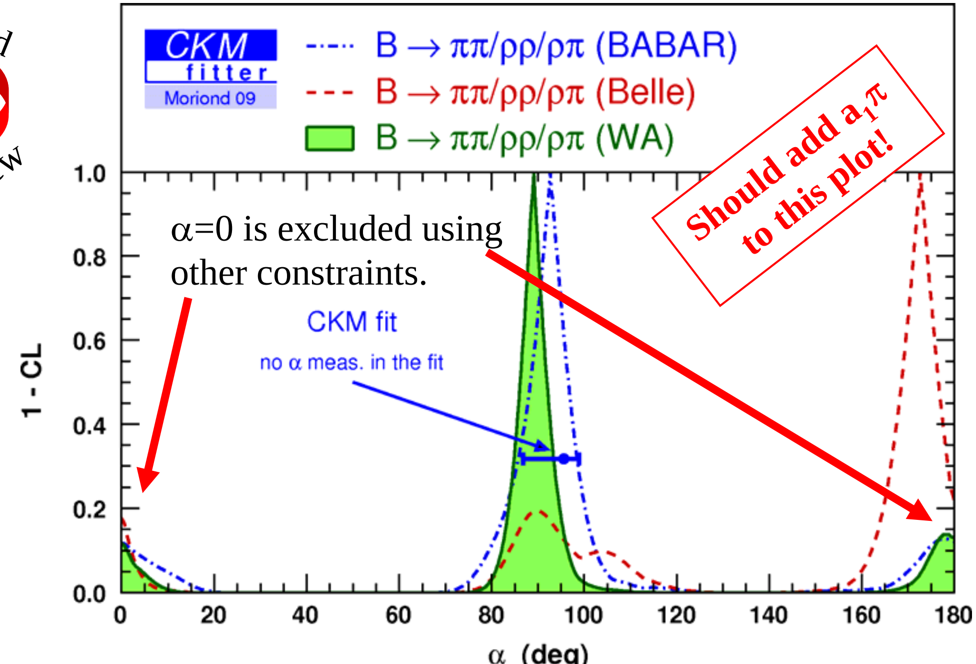
$$\mathcal{B}(B^+ \to \rho^+\rho^0)_{WA} = (18.2 \pm 3.0)\times 10^{-6} \quad \text{Old}$$
$$= (24.0 \pm 2.0)\times 10^{-6} \quad \text{New}$$

- BaBar measure S^{00} and C^{00} helps resolve ambiguities!

From BaBar $\rho^+\rho^0$ update:



Phys.Rev.Lett.102:141802,2009



$$\alpha(CKM\,Fitter) = \left(89.0^{+4.4}_{-4.2}\right)^\circ$$

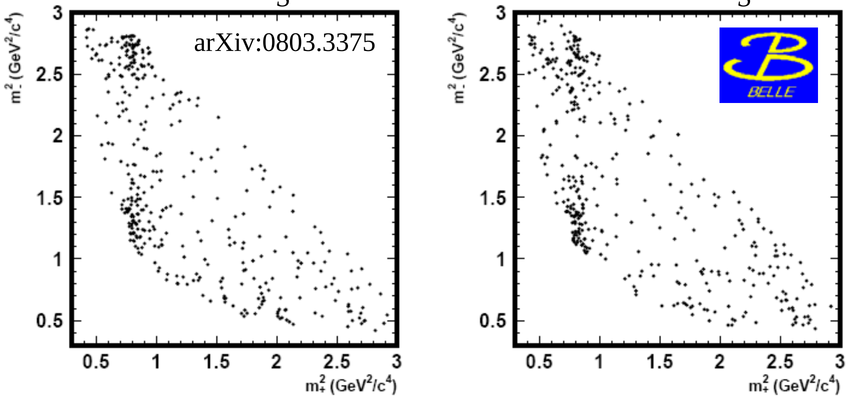
$$\alpha(UTFit) = (92 \pm 7)^\circ$$

+ BaBar have measured α from $a_1\pi$ and $K_1\pi$ decays to 13°: Lombardo.

CP Violation: γ (ϕ_3)

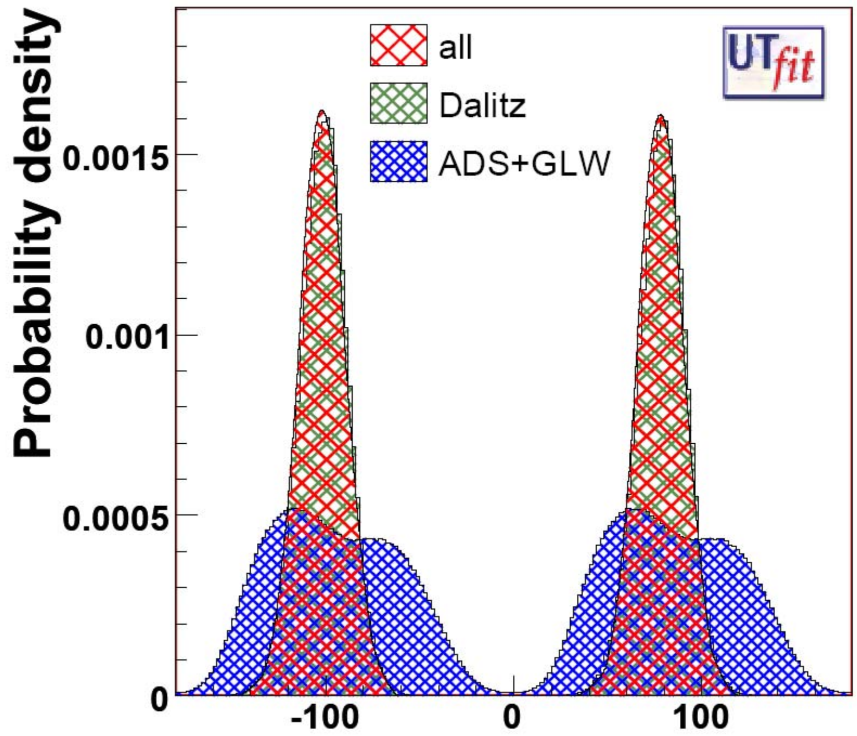
- The GGSZ 'Dalitz Plot' method dominates constraint on γ.
- Uses $B^- \to D^{(*)}K^{(*)-}$.

$B^- : \bar{D}^0 \to K_S^0\pi^+\pi^-$ $\qquad$ $B^+ : \bar{D}^0 \to K_S^0\pi^+\pi^-$



$$\gamma_{All\ Modes} = \left(78.4^{+10.8}_{-11.6} \pm 3.6 \pm 8.9\right)^\circ$$

- Model uncertainty can be reduced by measuring D→$K_S\pi\pi$ (see later).
- BaBar and Belle differ in the value of r obtained from the data.
- BaBar have a new ADS result (See Lopez March).



$$\gamma(CKMFitter) = \left(70^{+27}_{-30}\right)^\circ$$

$$\gamma(UTFit) = \left(78 \pm 12\right)^\circ$$

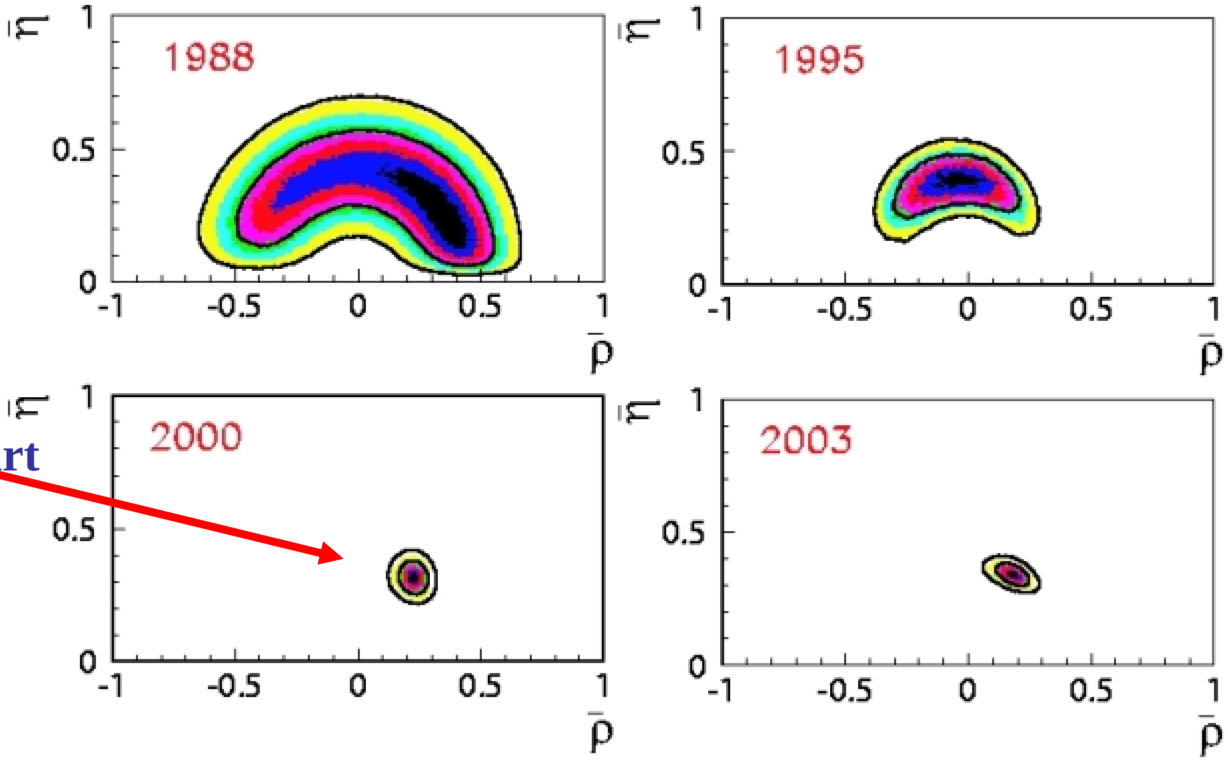
Measurement of γ requires patience … and a combination of methods.

Testing the Standard Model

- α+β constrained Unitarity Triangle to 5°!

$$\alpha + \beta + \gamma = \left(180^{+27}_{-30}\right)^{\circ} \; / \; \left(191 \pm 14\right)^{\circ}$$ CKM fitter / UT fit

B-factories start producing results.



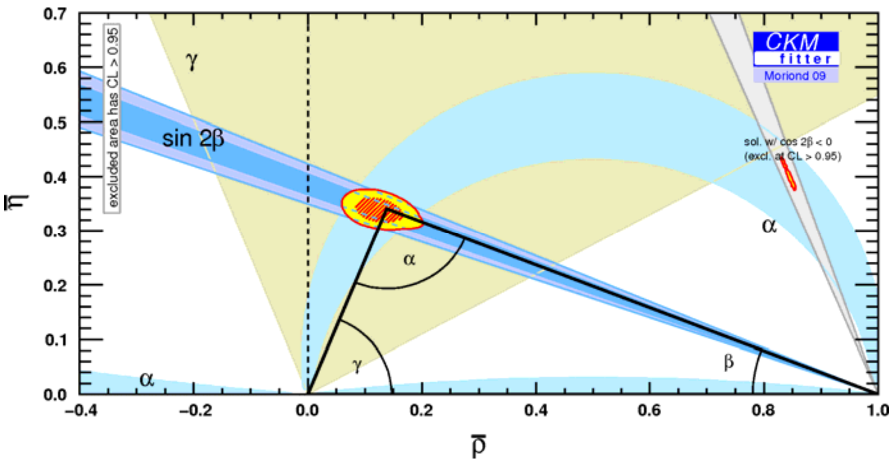
History of constraints on the Unitarity Triangle.
Direct measurements gave a leap forward in precision!

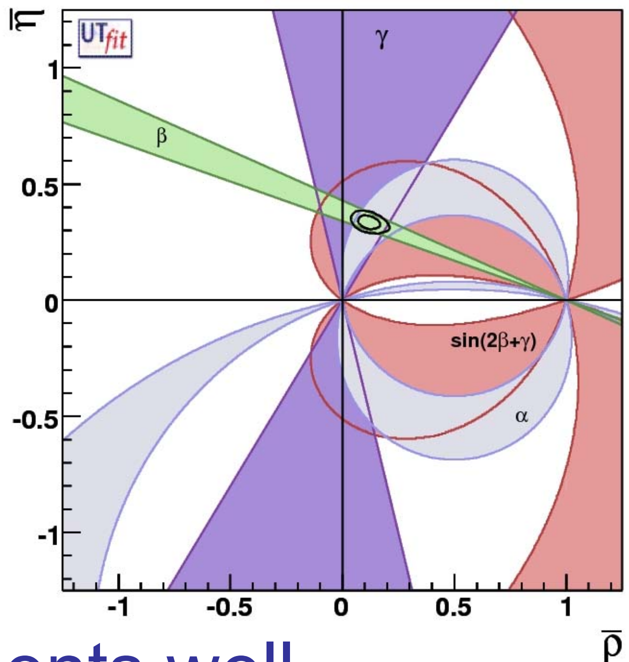
Testing the Standard Model

- $\alpha+\beta$ constrained Unitarity Triangle to 5°!

$$\alpha+\beta+\gamma = \left(180^{+27}_{-30}\right)^\circ \;/\; \left(191\pm14\right)^\circ$$ CKM fitter / UT fit

- But poor precision on over-constraint.





- CKM describes measurements well.
- Still plenty of room for new physics!

Testing the Standard Model

- We were reminded that we should be careful with what we compare:
  - NP could affect $c\bar{c}s$ sin2β.

1) Predict sin2β from indirect constraints.

$$[\sin(2\beta)]^{\text{prediction}}_{\text{no } V_{ub}} = 0.87 \pm 0.09\,.$$ (green)

2) Compare to $c\bar{c}s$ measurement.

$$[\sin 2\beta]_{c\bar{c}s} = 0.672 \pm 0.023$$ (yellow)

3) Compare to clean penguin measurements.

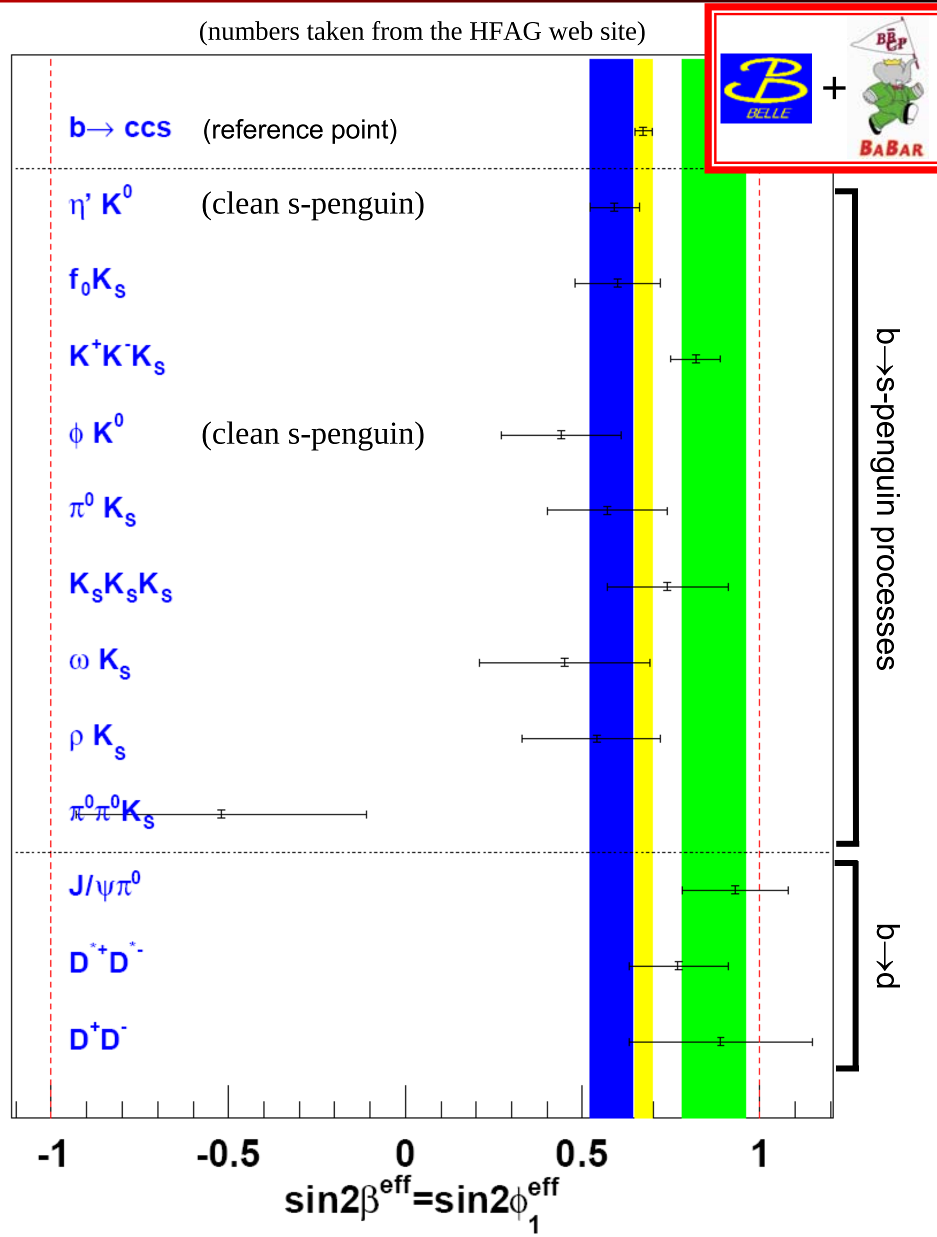
$$[\sin 2\beta]^{clean}_{b\to s-penguin} = 0.58 \pm 0.06$$ (blue)

(or the average of the two)

Are these 2.1–2.7σ hints for new physics?

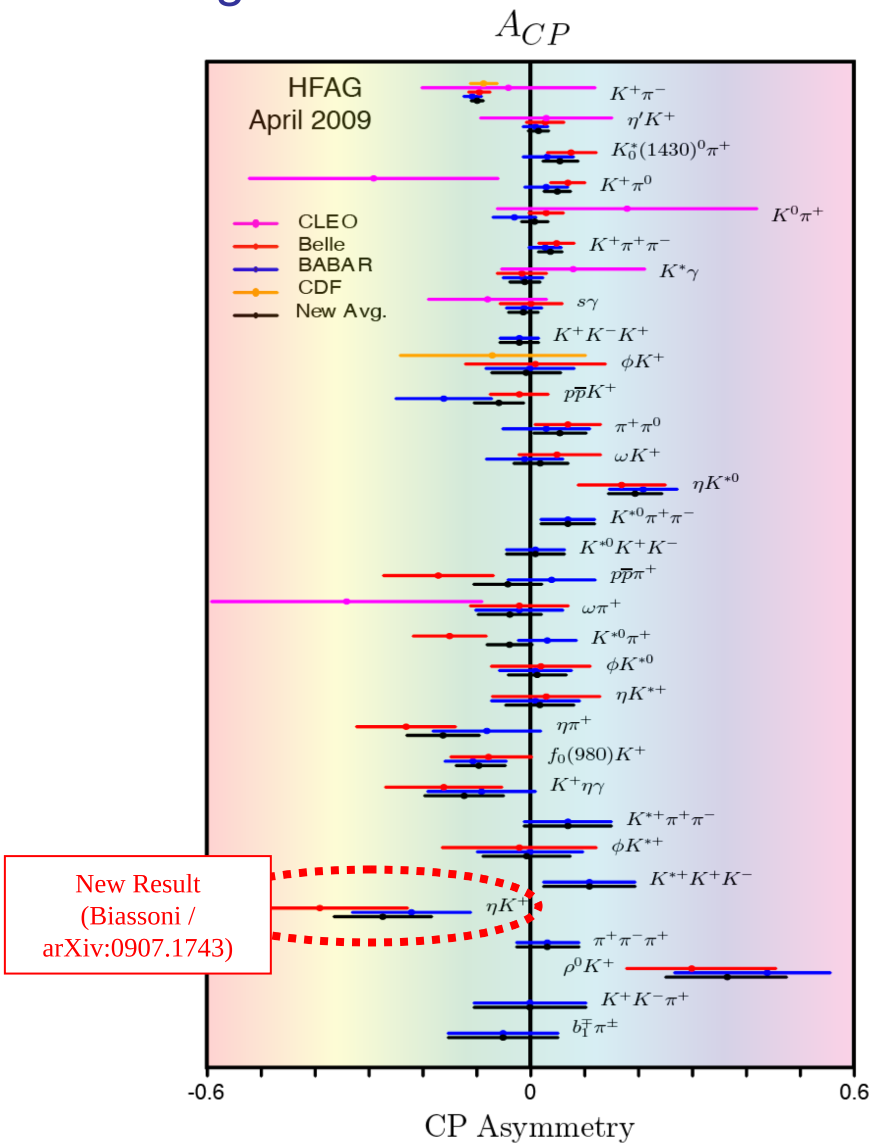
Lunghi and Soni, Phys.Lett.B**666** 162-165 (2008).
Buras and Guadagnoli Phys Rev D **78** 033005 (2008).

- **Can theory error be reduced for other modes?**



Direct CP Violation

- Many searches, but only a few signs of direct CPV …



- Observed direct CP Violation in (>5σ):

$$B^0 \to K\pi$$

$$B^0 \to \pi^+\pi^-$$

- Evidence for direct CP Violation in (>3σ):

$$B^0 \to \eta K^{*0}$$

$$B^+ \to \eta K^+$$

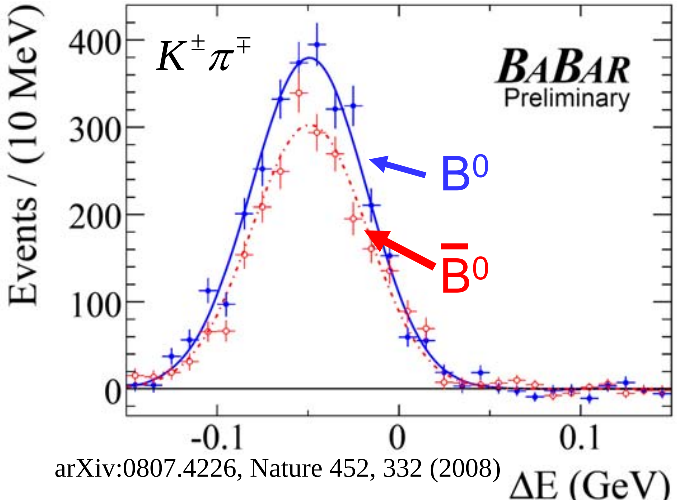
$$B^\pm \to \rho^0 K^\pm$$

$$B^0 \to \rho^\pm \pi^\mp$$

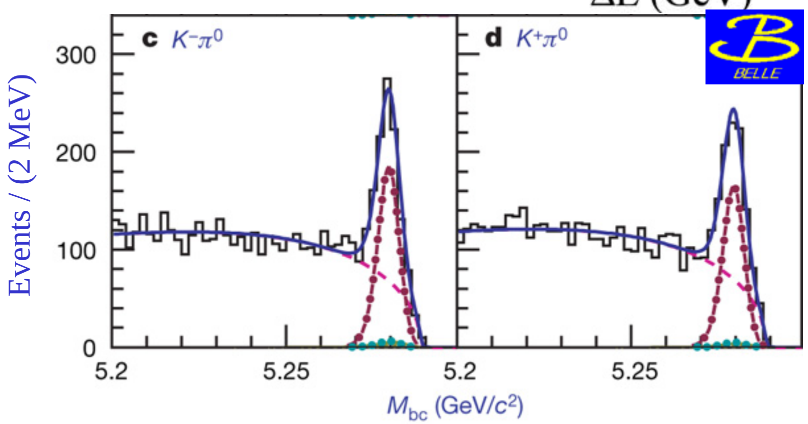
$$B^\pm \to D^{0(*)} K^\pm$$

- These measurements tell us something interesting…

- $\Delta A_{K\pi} = A_{K^\pm\pi^\mp} - A_{K^\pm\pi^0}$ is small and positive in the SM.



arXiv:0807.4226, Nature 452, 332 (2008)



- Clear direct CPV signal in neutral mode, and absence of a signal in charged mode.

$$WA: \quad A_{K^\pm\pi^\mp} = -0.098 \pm 0.012$$

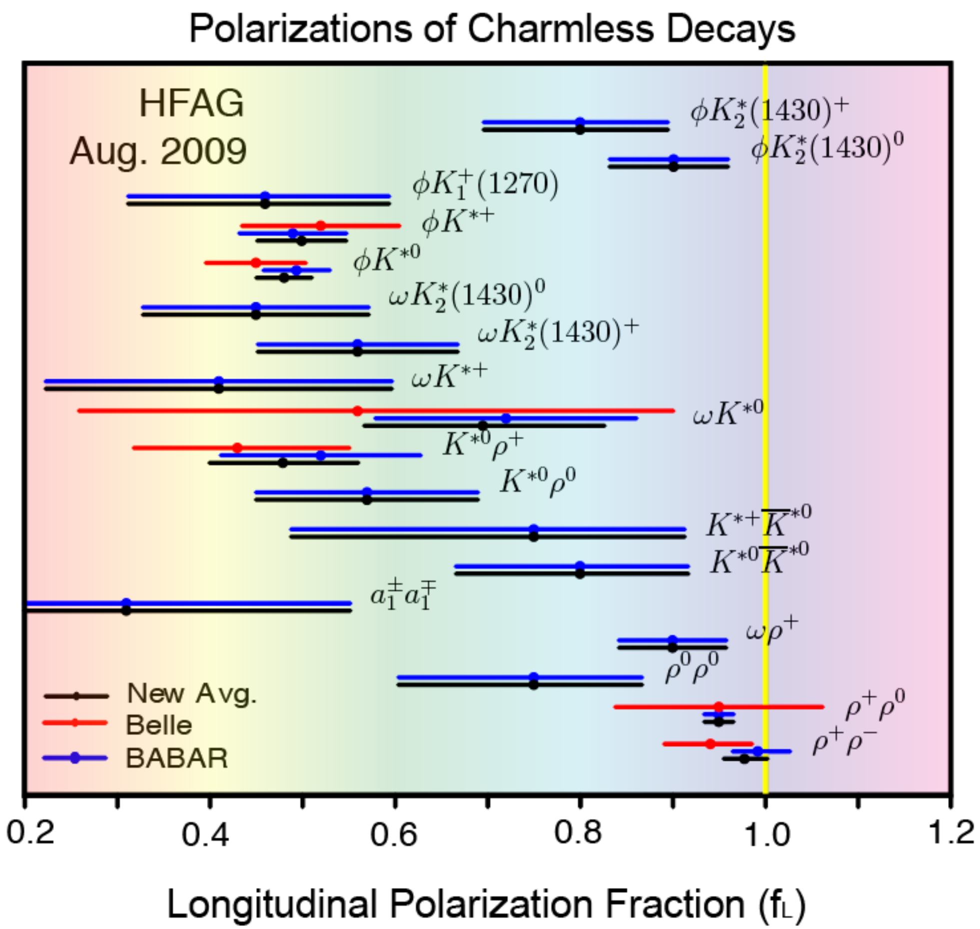
$$WA: \quad A_{K^\pm\pi^0} = 0.050 \pm 0.025$$

$$\Delta A_{K\pi} = -0.148 \pm 0.028$$

- SM requires opposite sign!
- This is called the $K\pi$ puzzle.
- $\Delta A_{K\pi} \neq 0$ at 5.3 σ.
- Is this new physics?
- See S. Mishima.
- Need to measure $K_S\pi^0$ at a Super Flavour Factory for a data driven solution with sum rules.

Polarization Puzzle

- Expectation is f_L~1 in B→VV decays.



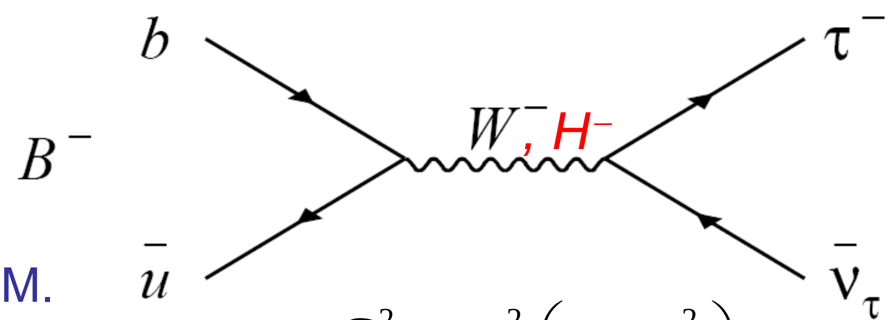
- B→ρρ decays fit the pattern:

$$f_L = 1 - \frac{m_V^2}{m_B^2} \sim 1$$

- f_L ~ 0.5 for some penguin dominated modes: notably ϕK* and $K^{*0}\rho^+$.
- VT decays add confusion.
- Null results from searches for B →b_1(ρ, K*) and a_1(ρ, K*).
- $f_L(B\to a_1^+a_1^-) = 0.31 \pm 0.24$
  arXiv:0907.1776
- **What mechanism(s) result in the observed behaviour? Is this NP?**
- What about other AV & AA decays?

Rare Decays: $B^+ \to \tau^+ \nu$

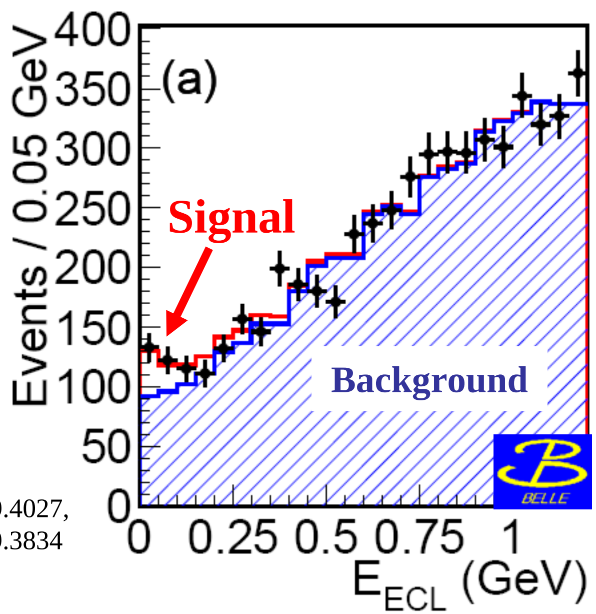
- Within the SM, sensitive to f_B and $|V_{ub}|$: $\mathcal{B}_{SM} \sim 1.6 \times 10^{-4}$.
- $\mathcal{B}$ affected by new physics.
  - MFV models like 2HDM / MSSM.
  - Unparticles.



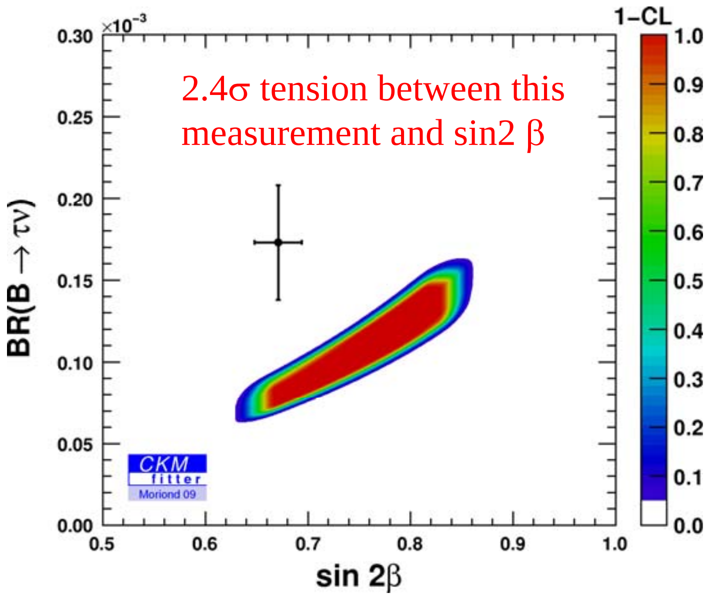
$$\mathcal{B}_{SM}(B^+ \to l^+ \nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1 - \frac{m_l^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$

- Fully reconstruct the event (modulo ν).

$$\mathcal{B}_{\mathrm{WA}} = (1.73 \pm 0.35) \times 10^{-4}$$



arXiv:0809.4027,
arXiv:0809.3834



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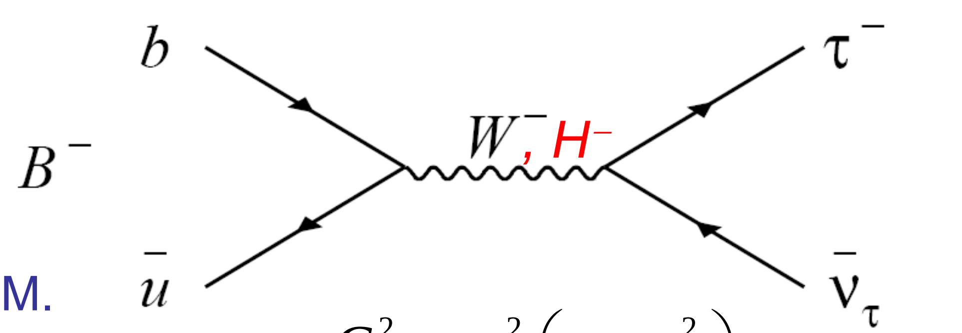

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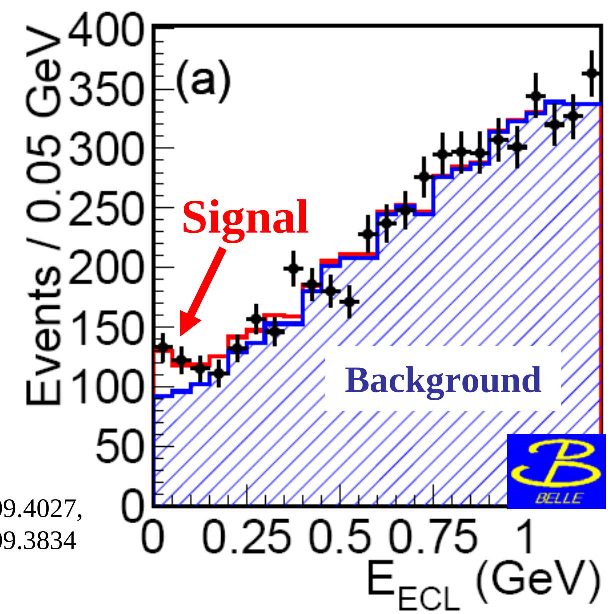
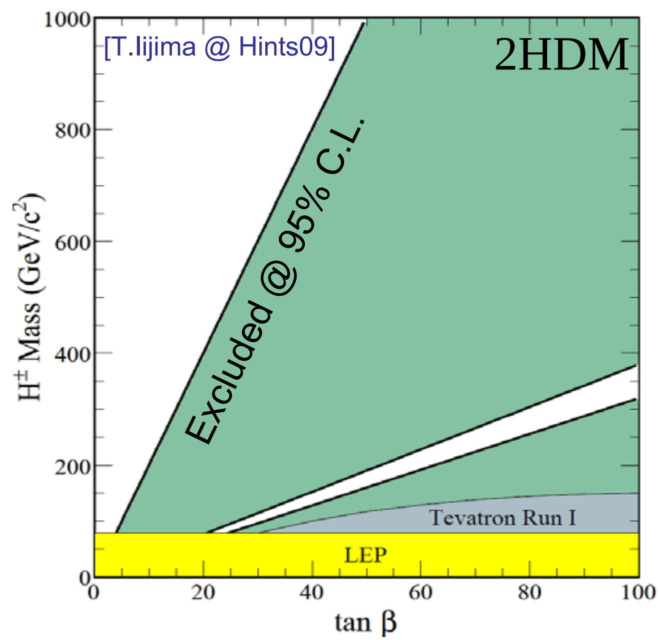


arXiv:0809.4027, arXiv:0809.3834

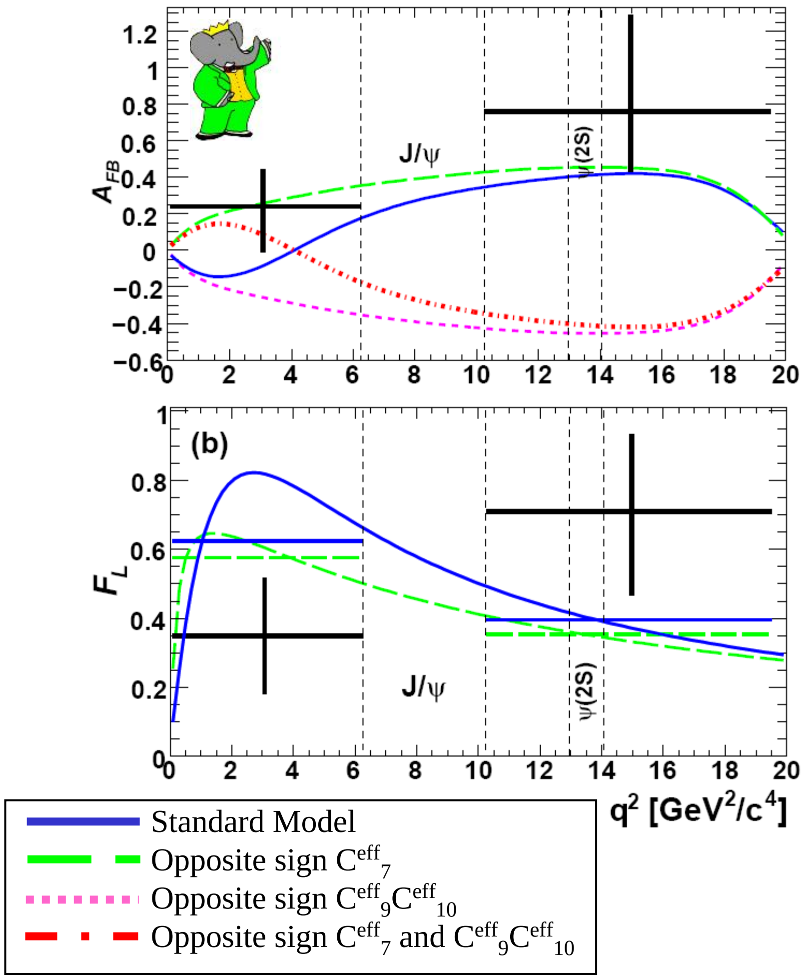


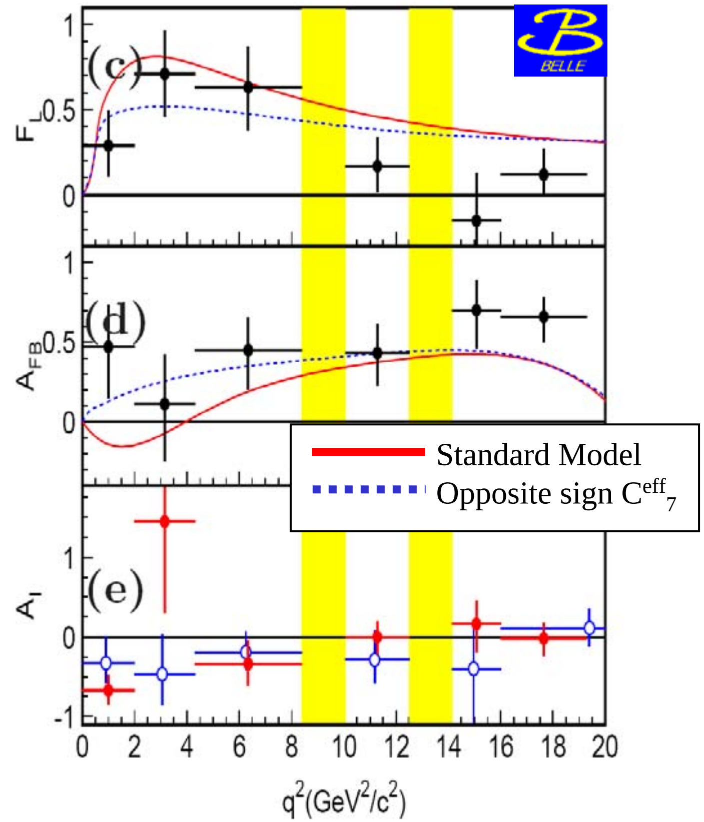
2HDM: W.-S Hou PRD **48** 2342 (1993)
MSSM: G. Isidori arXiv:0710.5377
Unparticles: R. Zwicky PRD**77** 036004 (2008)

Rare Decays: $B \to K^{*}\ell^{+}\ell^{-}$

PRD 79 031102 (2009), arXiv:0904.0770

- Like B→VV decays, a lot of information is contained in decay kinematics: f_L, A_{FB}, $R_{K(*)}$ (as well as $\mathcal{B}$ and testing isospin).
  - All of these observables are sensitive probes of new physics.

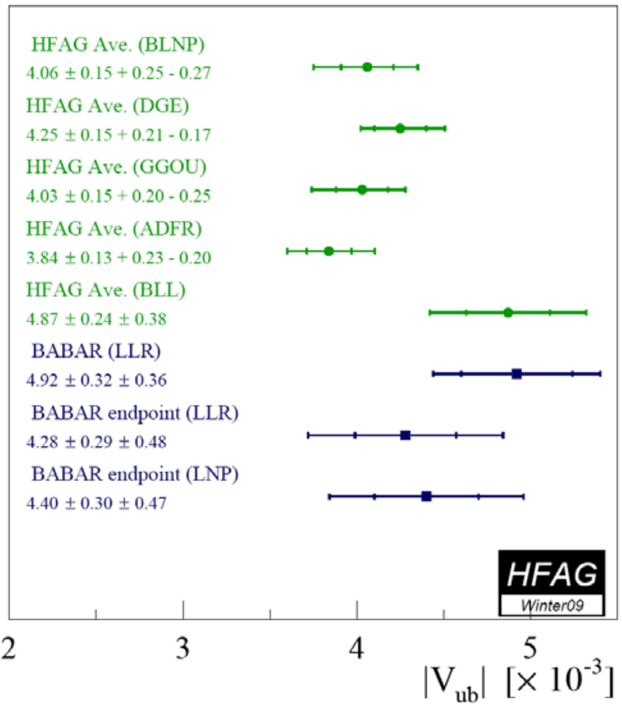


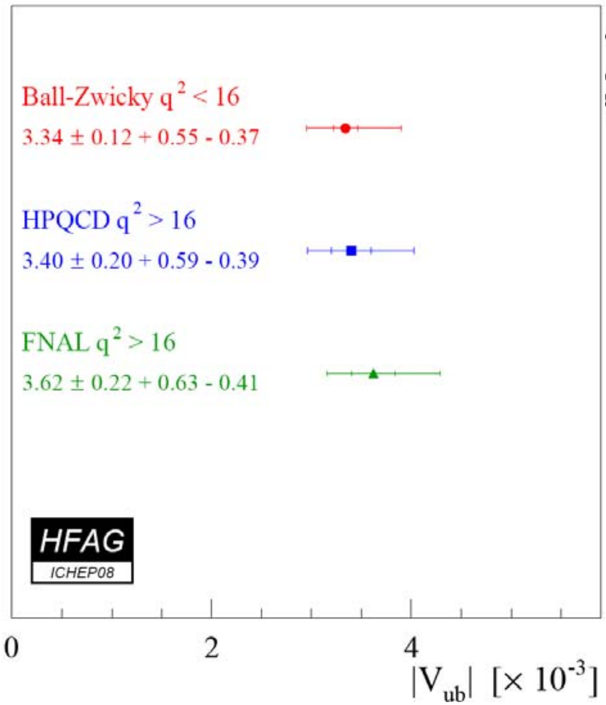


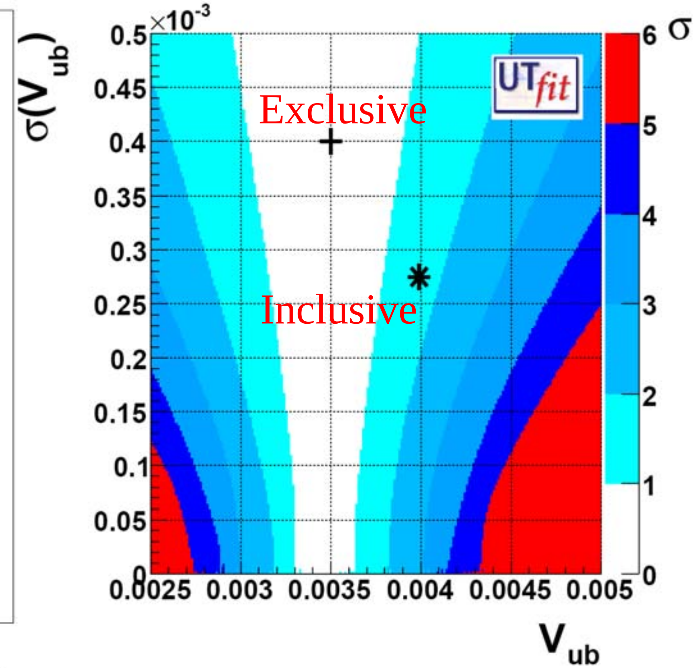
- A_{FB} is consistent with the SM.
- Prefers a non-SM solution.
- Need more data to resolve this issue.

V_{ub}

- No change to the situation:
  - Tension between inclusive and exclusive results and sin2β.







Inclusive $|V_{ub}|$

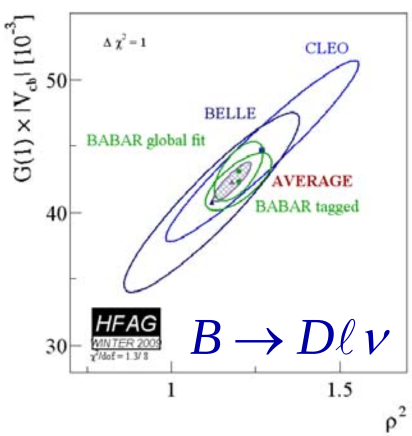
Exclusive $|V_{ub}|$

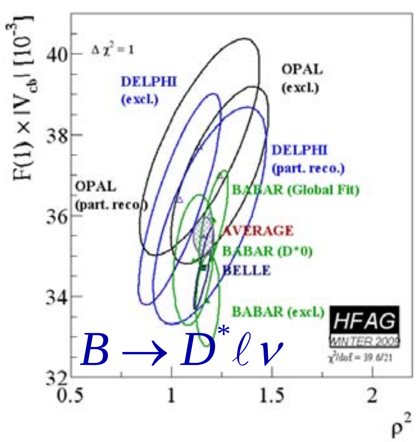
V_{cb}

Global fit results for $|V_{cb}|$ taken from HFAG: Winter 09

Exclusive:

- $F(1)|V_{cb}|$ and ρ_F^2 from untagged $B^+ \to D^{*0} l^+ \nu$.
- $G(1)|V_{cb}|$ and ρ_G^2 from untagged $B^+ \to D\, l^+ \nu$.
- $F(1)|V_{cb}|$, ρ_F^2, $G(1)|V_{cb}|$, and ρ_G^2 from untagged $B^+ \to D^{*0} l^+ \nu X$.



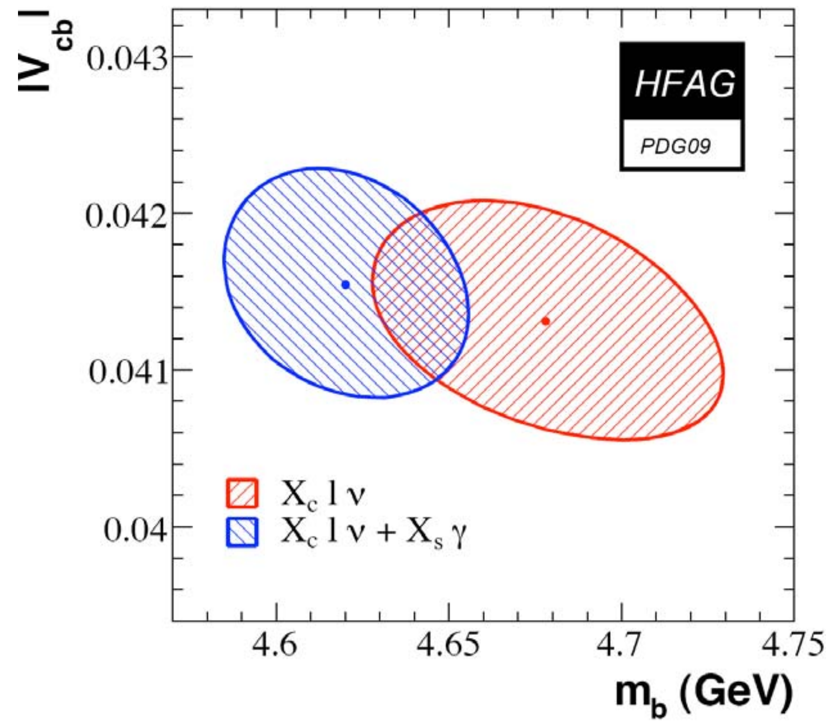


$$G(1)|V_{cb}| = (42.3 \pm 0.7 \pm 1.3) \times 10^{-3} \quad [D \ell \nu]$$

$$F(1)|V_{cb}| = (35.49 \pm 0.48) \times 10^{-3} \quad [D^{*-} \ell \nu]$$

New Belle result shown at EPS (not included in these averges): see Dungel.

Inclusive:



$$|V_{cb}| = (41.54 \pm 0.43 \pm 0.08 \pm 0.58) \times 10^{-3} \quad [X_c \ell \nu \,\&\, X_s \gamma]$$

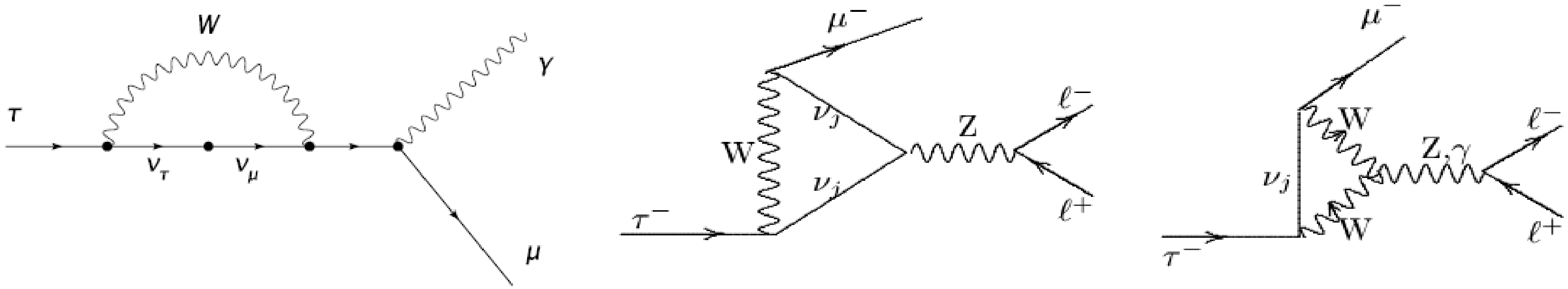
$$|V_{cb}| = (41.31 \pm 0.49 \pm 0.08 \pm 0.58) \times 10^{-3} \quad [X_c \ell \nu]$$

Disagreement between inclusive and exclusive with D* [Rotondo]

P. Gambino, N. Uraltsev, Eur.Phys.J. C34 (2004) 181-189
D. Benson, I. Bigi, N. Uraltsev, Nucl.Phys. B710 (2005) 371-401
D. Benson, I.I. Bigi, T. Mannel, N. Uraltsev, Nucl.Phys. B665 (2003) 367-401

τ Physics: LFV

- Neutrinos are massive, so LFV is a part of the SM at $\sim 10^{-54}$ for $\tau \to \mu\gamma$, and $\ell\ell\ell$.



- NP could enhance $\mathcal{B}$ up to $\sim 10^{-7}$. (e.g. see hep-ph/0610344)

	Table from A. Cervelli, CIPANP '09	$\tau \to \mu\gamma$	$\tau \to lll$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	10^{-54} – 10^{-40}	10^{-40}
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8}
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8}	10^{-10}
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

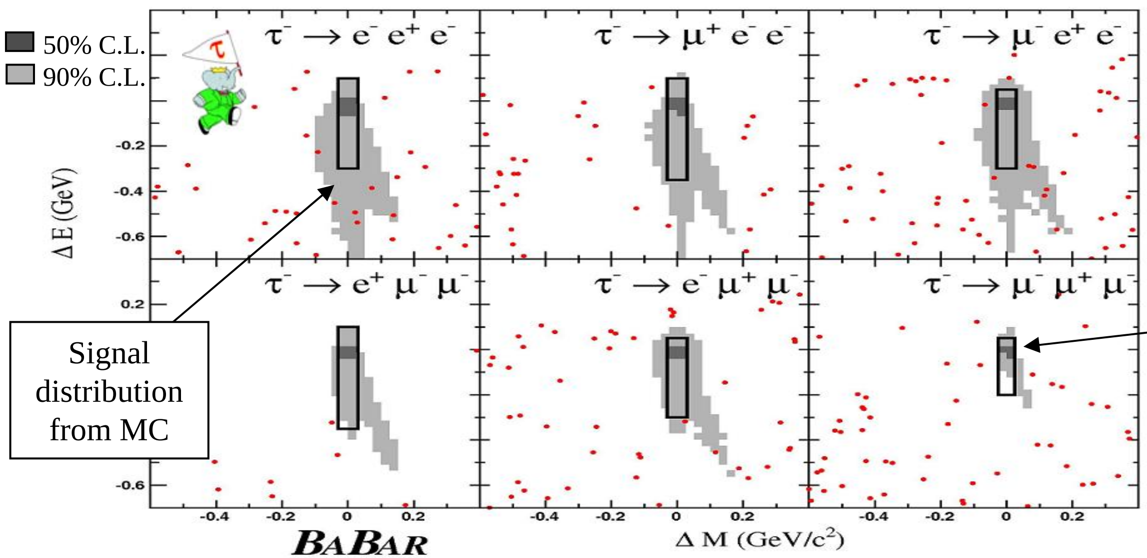
τ Physics: LFV

- New $\tau \to 3\ell$ results from BaBar & Belle (472 & 872fb^{-1}).

Mode	ϵ [%] BaBar (Belle)	UL [$\times 10^{-8}$] BaBar (Belle)
$e^+e^-e^+$	8.6 (6.0)	2.9 (2.7)
$e^+e^-\mu^+$	8.8 (9.3)	2.2 (1.8)
$e^+e^+\mu^-$	12.6 (11.5)	1.8 (1.5)
$e^+\mu^-\mu^+$	6.4 (6.1)	3.2 (2.7)
$e^-\mu^+\mu^+$	10.2 (10.1)	2.6 (1.7)
$\mu^+\mu^-\mu^+$	6.6 (7.6)	3.3 (2.1)

Already at sensitivities comparable with LHC reach!

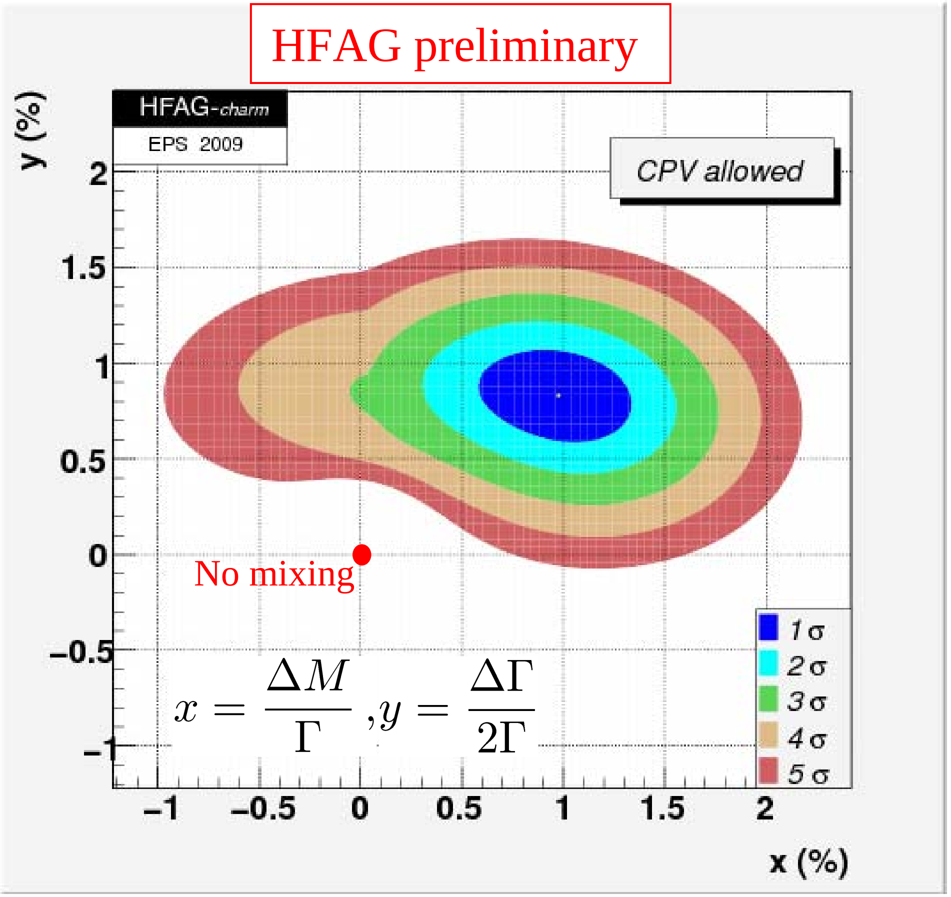
(BaBar & Bell Results are Preliminary)

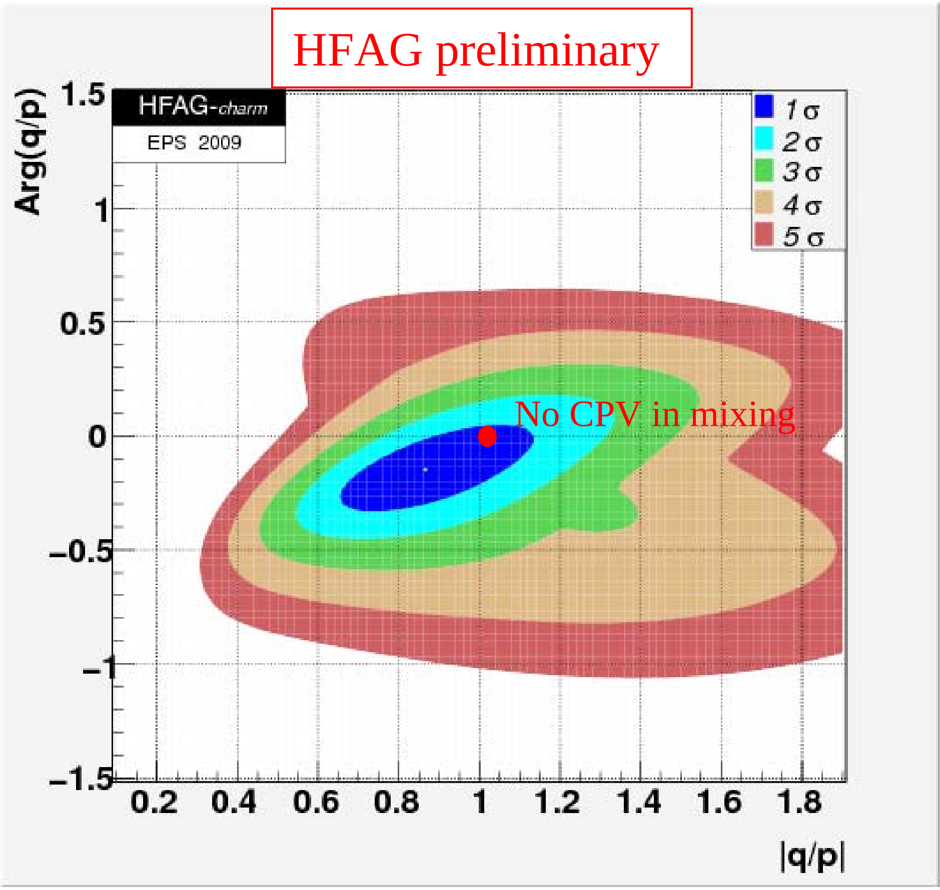


- Improved PID and reconstruction lead to significant improvements in BaBar limits.
- No events in signal box for any of the modes (both experiments).
- Place interesting constraints on models!

- B-factories also have results on $\ell\gamma$, ℓh^0, and ℓV!

Charm Mixing and CPV





- Mixing established at 10.2σ combining all measurements.
- No observation (yet) in a single channel (measurements ~4σ).

- No evidence for CPV in mixing.
- Data consistent with:

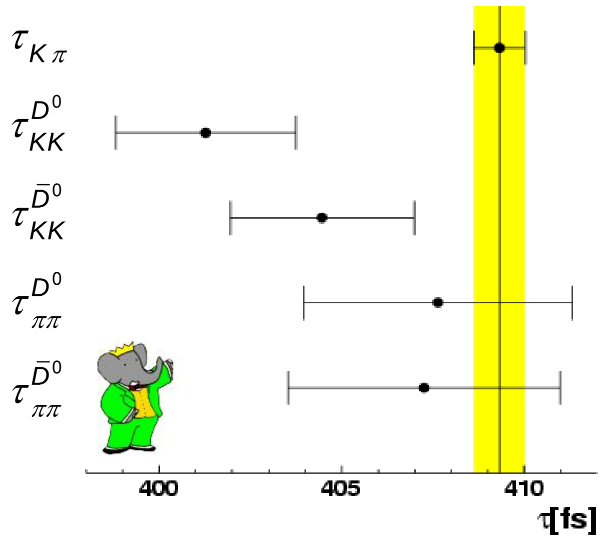
$$\frac{q}{p} = 1$$

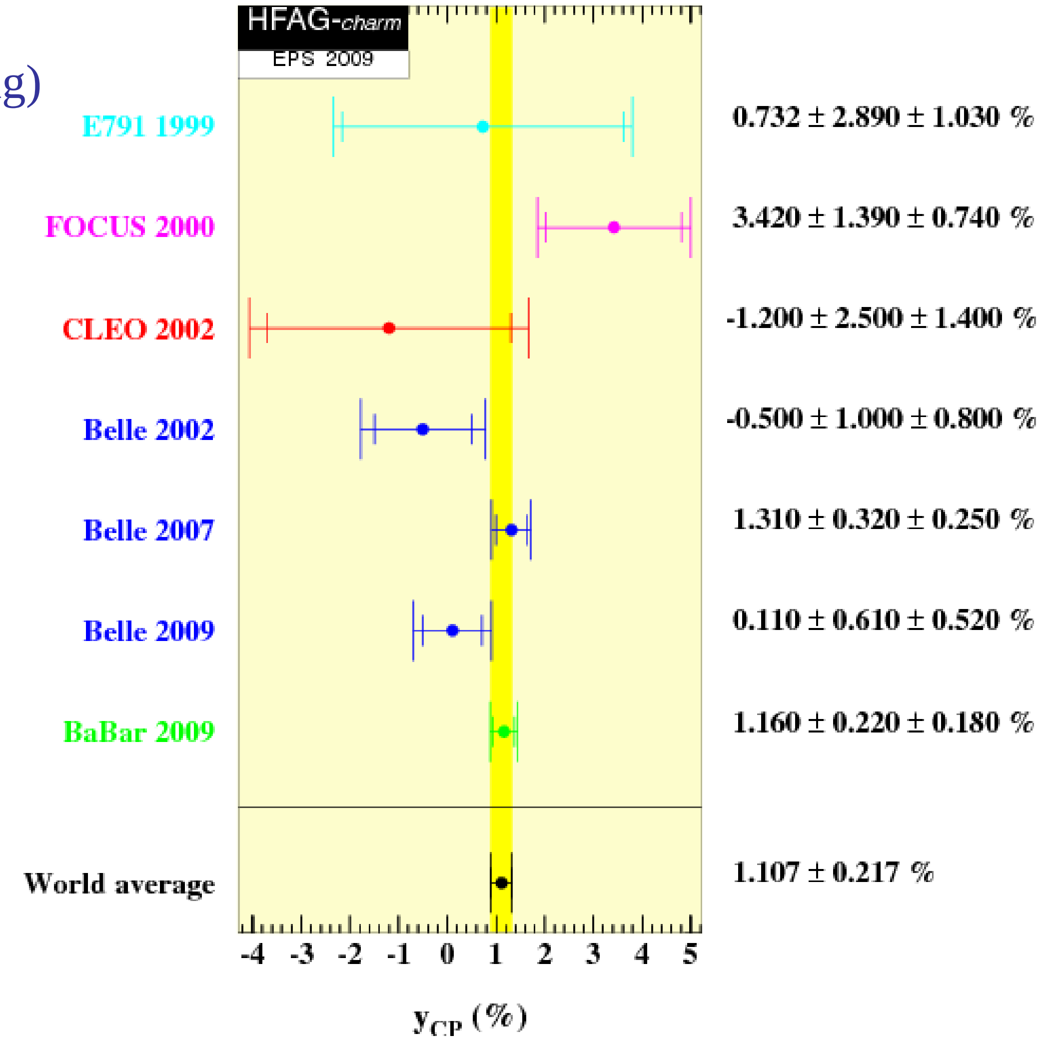
Lifetime Ratio: y_{CP}

- Compare τ for Cabibbo favored $D^0 \rightarrow K\pi$ and Cabibbo suppressed $D^0 \rightarrow h^+h^-$ decays.

$$y_{CP} = \frac{\tau_{K\pi}}{\tau_{hh}} - 1 \qquad \text{(mixing)}$$

$$\Delta y = \frac{\tau_{K\pi}}{\tau_{hh}} \left(\frac{\tau_{hh}^{D^0} - \tau_{hh}^{\bar{D}^0}}{\tau_{hh}^{D^0} + \tau_{hh}^{\bar{D}^0}} \right) \qquad \text{(CPV)}$$

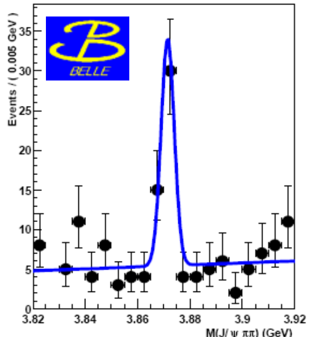




Tagged sample lifetimes differ $\Rightarrow y_{CP} \neq 0$.

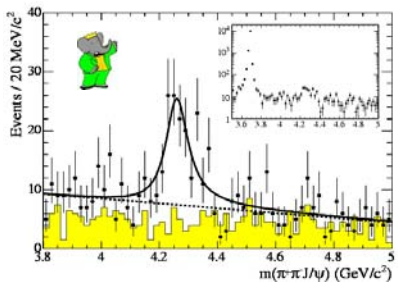
Spectroscopy

- Study of new Charmonium states started several years ago with the X(3872) from B decay, and Y(4260) from ISR.



$X(3872)$

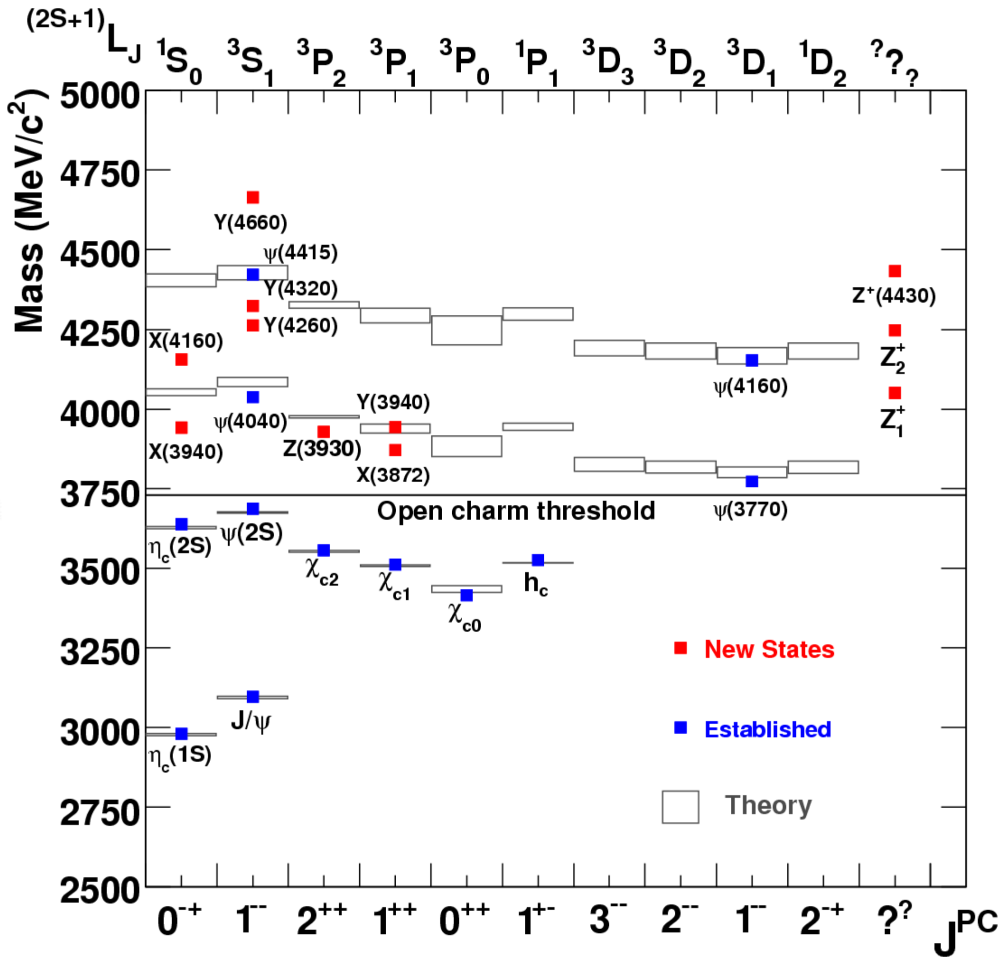
PRL**91** 262001 (2003)



$Y(4260)$

PRL**95** 142001 (2005)

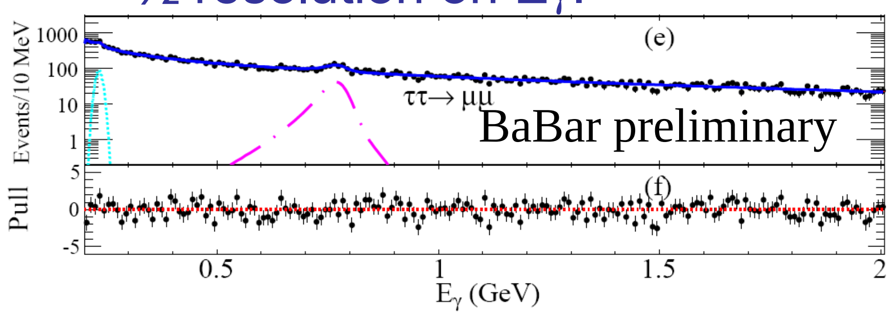
- Still finding many new states.
- The nature of many of these still not understood.
- Z(4430)⁻ is puzzling: Belle see this state (6σ), but BaBar don't (<3σ).
- More data are needed (at future experiments) to resolve all of the outstanding issues.

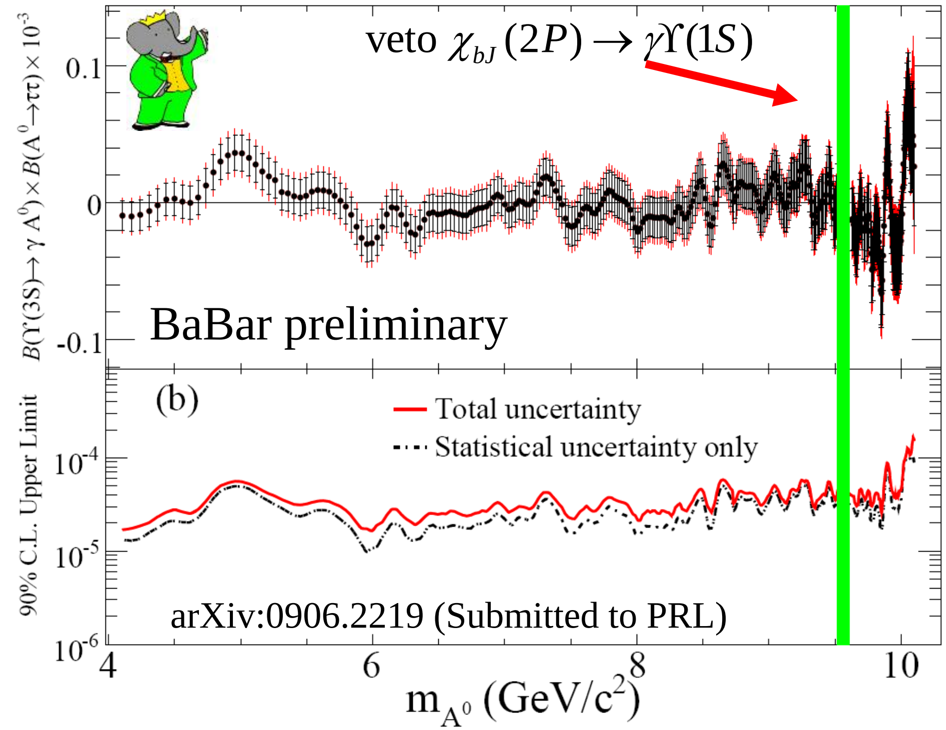


After a 30 year search: The $b\bar{b}$ ground state was discovered by BaBar: η_b.

Low mass Higgs search

- Search for $\Upsilon(3S) \rightarrow \gamma A^0$ with $A^0 \rightarrow \tau^+\tau^-, \quad \tau^+ \rightarrow \ell^+\nu_\ell\bar{\nu}_\tau$.
- NMSSM predicts A^0 could be a light.
- Expectation
  $$B\left(\Upsilon(3S) \rightarrow \gamma A^0\right) \sim 10^{-4}$$
  - Where $A^0 \rightarrow \tau\tau$ dominates.
- Sample of 122×10^6 3S decays.
- Scan for a signal in E_γ distribution in steps of ½ resolution on $E\gamma$.





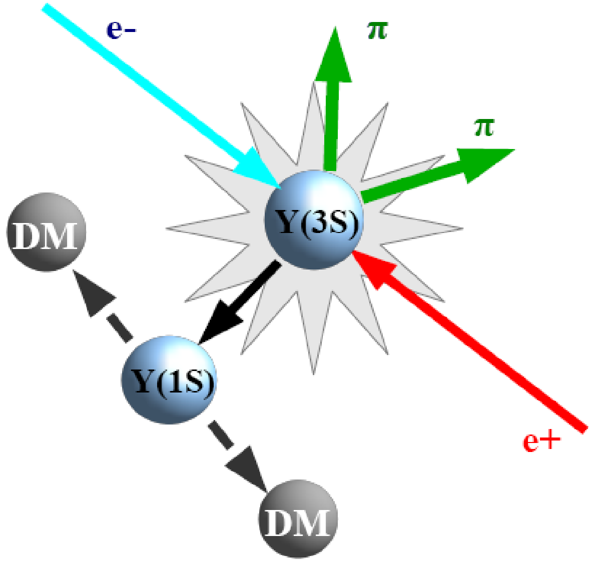
- Γ_{A0} is expected to be small, so assume the width is resolution on E_γ.

Upper limits of ~few $\times 10^{-5}$ obtained.

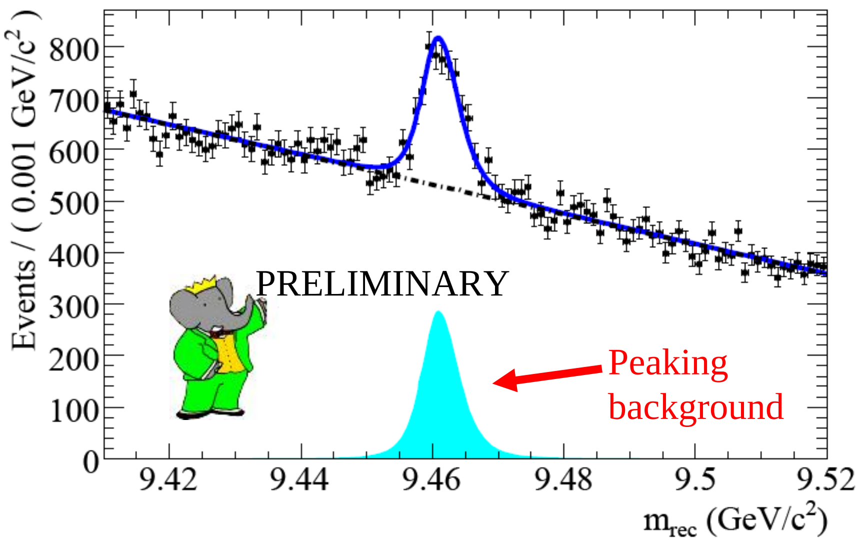
- Also searched for $A^0 \rightarrow \mu\mu$ and invisible decays: arXiv:0905.4539 & arXiv:0808.0017:
  - These are 4 to 10 times better than previous results.

$\Upsilon\to$invisible

- Dark Matter scenarios could lead to $\Upsilon\to$invisible enhancements above SM rate to $\mathcal{B}\sim10^{-3}-10^{-4}$. R. McElrath, Phys. Rev. D **72**, 103508 (2005)



- Using 91.4M $\Upsilon(3S)$ decays.
- Reconstruct $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S)$.
- with $\Upsilon(1S)\to invisible$.
- SM expectation: $\mathcal{B}(\Upsilon(1S)\to\nu\bar{\nu})\approx1\times10^{-5}$



- Fit $-118\pm105\pm124$ events.
- Corresponding UL (90% C.L.) constrains NP scenarios:
  $\mathcal{B}(\Upsilon(1S)\to\text{invisible})<3.0\times10^{-4}$
- Factor of 10 better than previous UL from Belle.

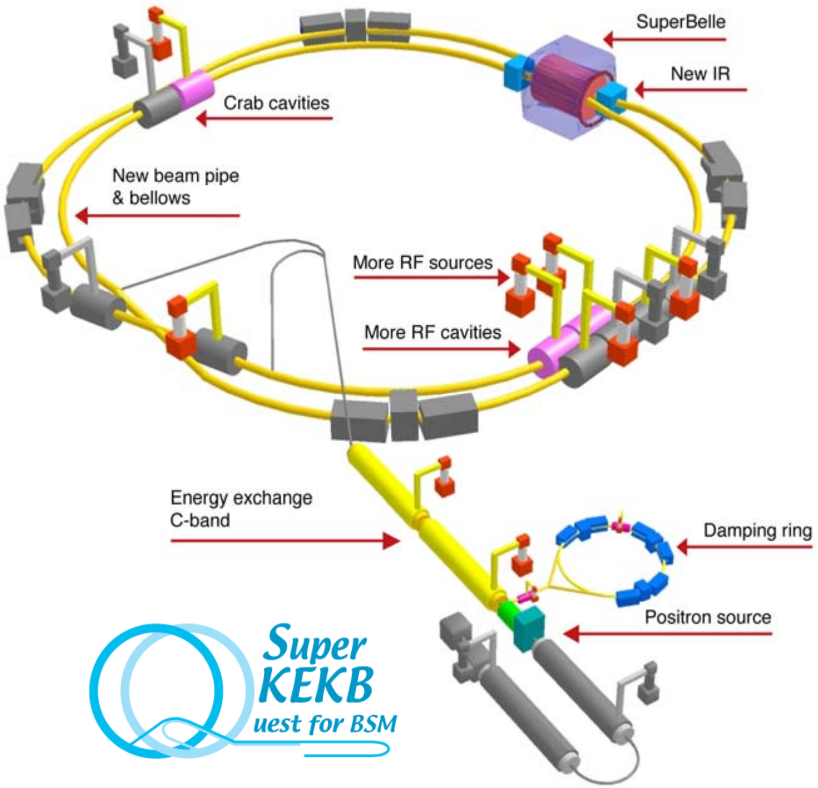
Hints of and Constraints on New Physics?

- The B-Factories measure some tension with the SM:
  - sin2β
    - 2.1 - 2.7σ discrepancy between SM and measurements in Charmonium and (theoretically clean) s-penguins.
  - V_{ub}
    - Inclusive and exclusive measurements not in good agreement.
  - $A_{K\pi}$: the Kπ puzzle
    - >5σ discrepancy between theory and measurement: is this real, or are there large corrections needed for theory (see S. Mishima).
  - The polarization puzzle persists.
- They also continue to constrain New Physics parameter space with rare B and τ decays.
  - $B^{\pm}\to\tau^{\pm}\nu$, $s\ell^{+}\ell^{-}$, $\tau\to 3\ell$, …
- Υ(NS) physics potential to constrain lepton universality and search for dark matter and light Higgs particles.

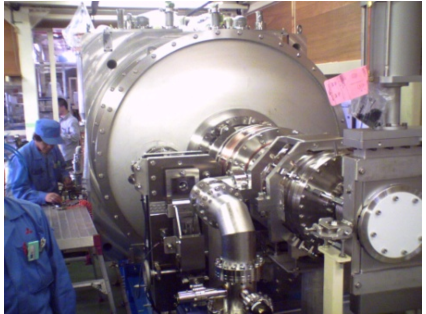
Super Flavour Factories

- SuperB (Italy)

- SuperKEKB (Japan)



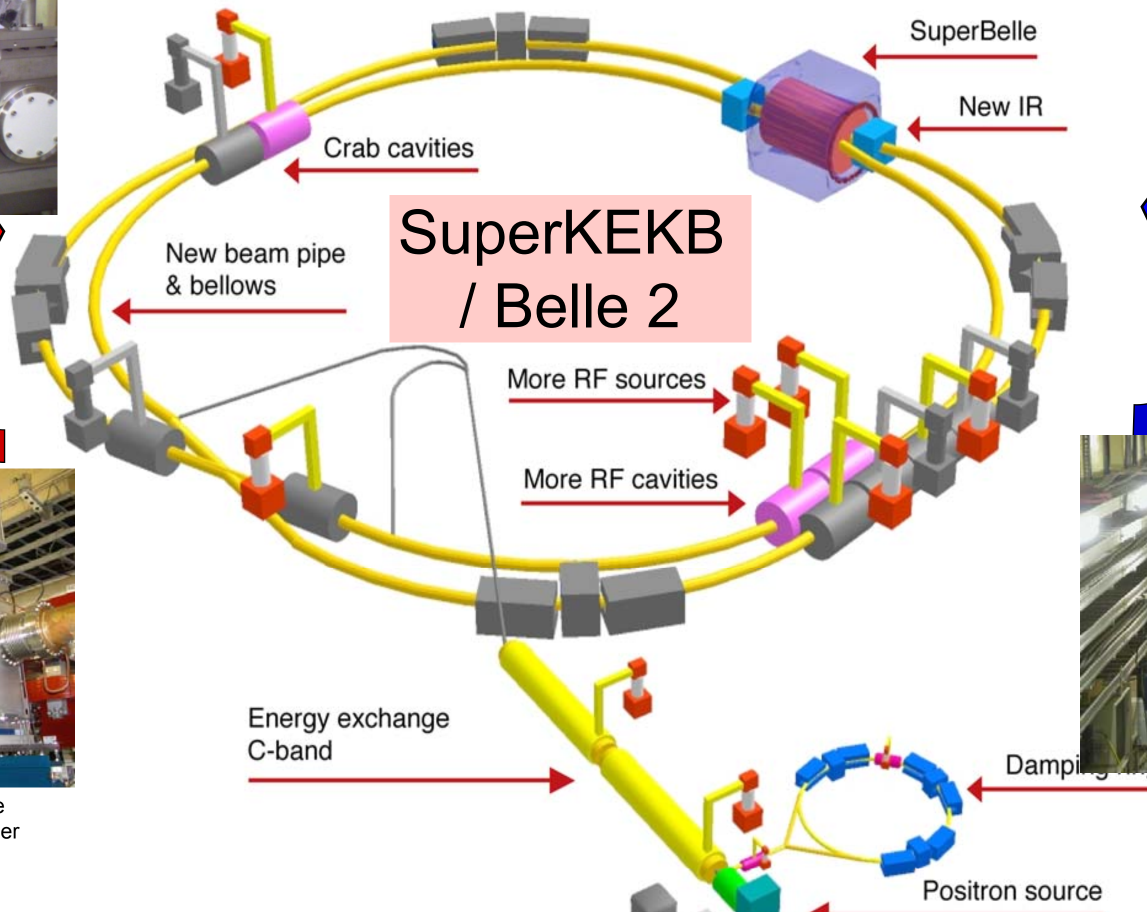
Ushiroda Hints '09 workshop, March KEK



Crab cavities will be installed and tested with beam in 2006.

$\beta^*_y = \sigma_z = 3$ mm

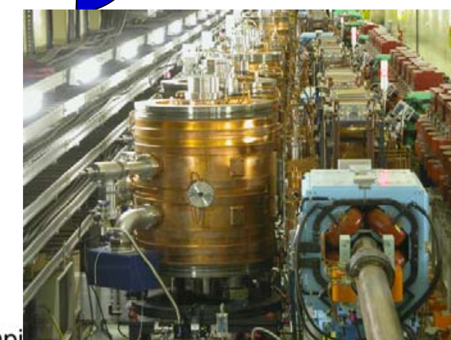
SuperKEKB / Belle 2



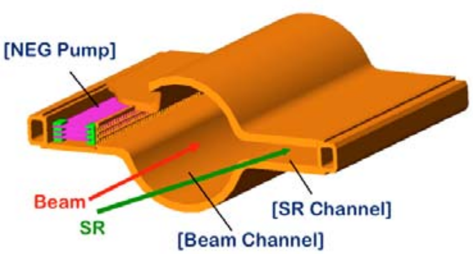
e^+ 4.1 A

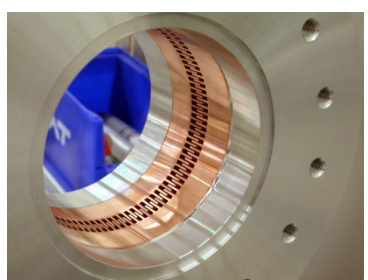
e^- 9.4 A

The superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW.



The state-of-art ARES copper cavities will be upgraded with higher energy storage ratio to support higher current.





The beam pipes and all vacuum components will be replaced with higher-current-proof design.

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

$\mathcal{L} = 8 \times 10^{35}$ cm^{-2}s^{-1}.

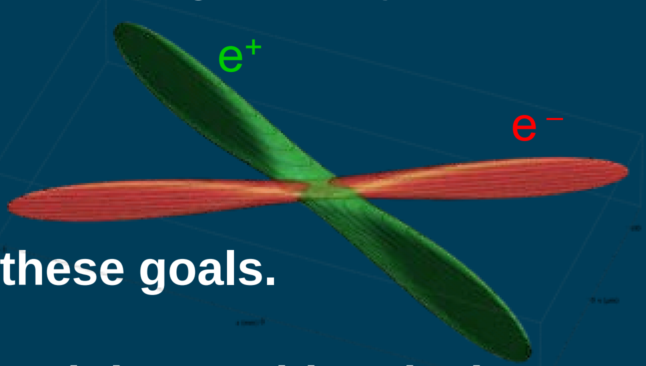
Integrate 50ab^{-1}

Now working toward a low emittance design.

SuperB (In a Nutshell)

- Asymmetric energy e^+e^- collider, with roughly 7GeV e^- on 4GeV e^+.
- Low emittance operation (like LC).
- Polarised beams [60-80%].

- Luminosity 10^{36} cm^{-2}s^{-1}
  - 75ab^{-1} data at the Υ(4S).
  - Will collect data at other Υ resonances, and at charm threshold.
  - Start data taking as early as 2015.



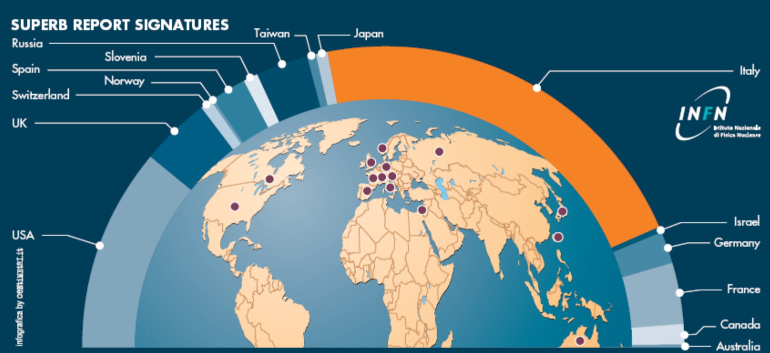
- Crab Waist technique developed to achieve these goals.

- MAC approved the machine design earlier this year.

http://www.pi.infn.it/SuperB/

Precision B, D and τ decay studies and spectroscopy.

- New Physics in loops.
  - 10 TeV reach at 75ab^{-1}.
  - Rare decays.
  - ΔS CP violation measurements.
- Lepton Flavour & CP Violation in τ decay.
- Light Higgs searches.
- Dark Matter searches.
- Sample of data at the ψ(3770) can utilize quantum correlations in $D^0\overline{D}^0$.



Geographical distribution of CDR signatories.

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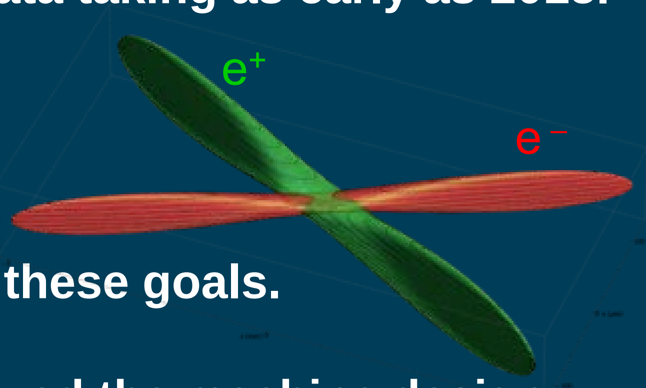

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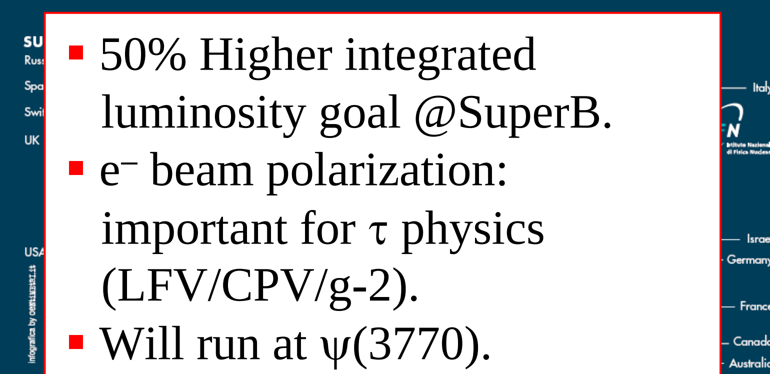


- 50% Higher integrated luminosity goal @SuperB.
- e^- beam polarization: important for τ physics (LFV/CPV/g-2).
- Will run at $\psi(3770)$.

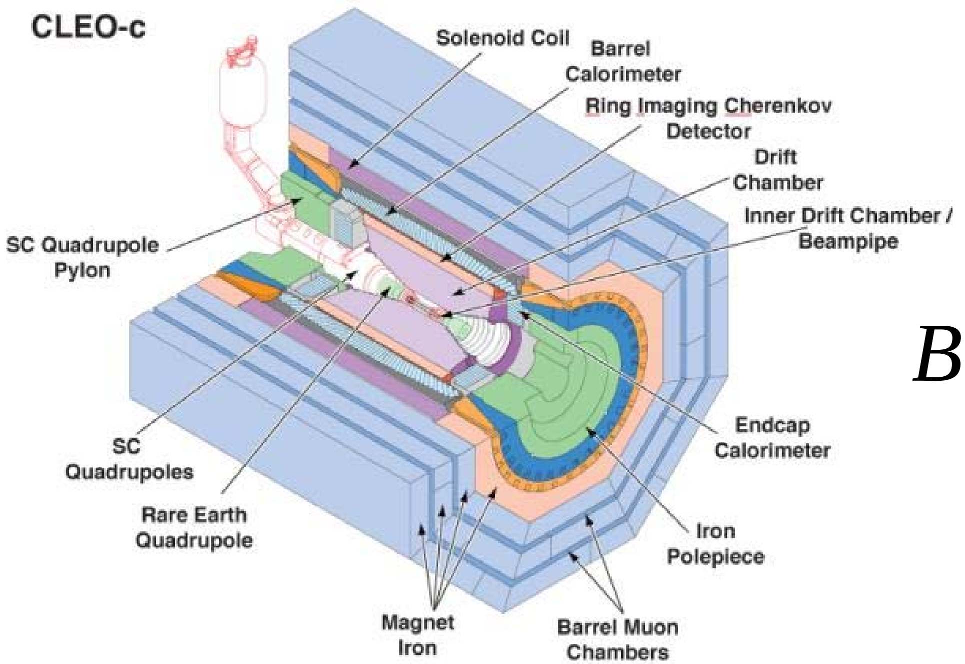
Geographical distribution of CDR signatories.

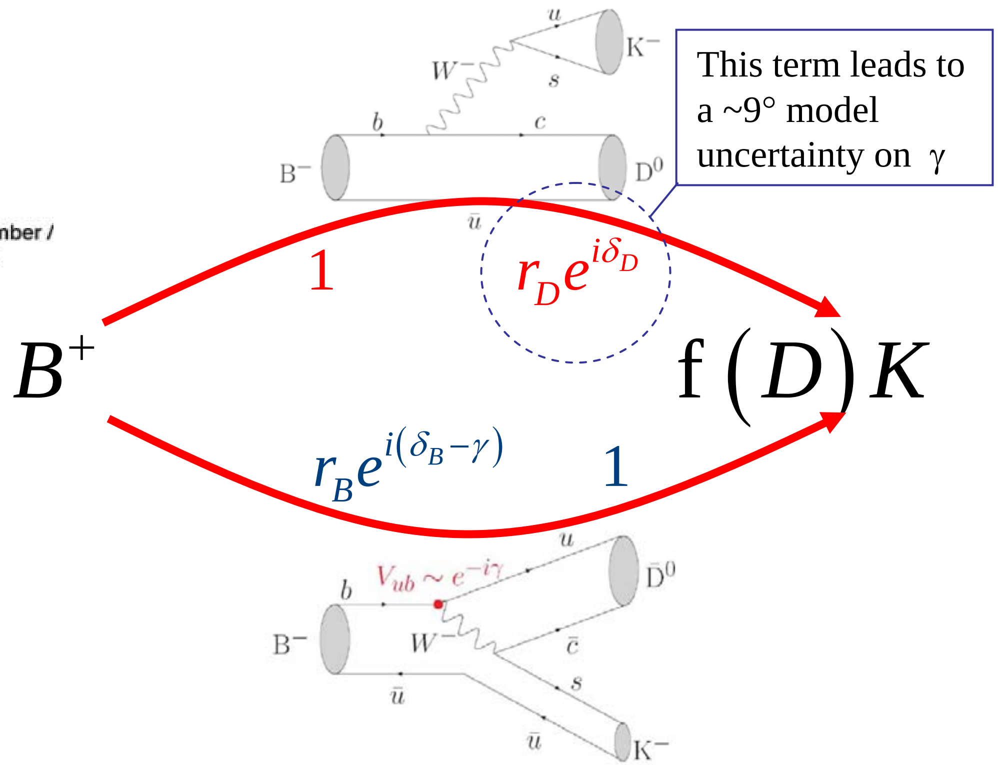
Super Flavour Factories

- Two projects being planned: SuperB/Belle-II.
- Strong international interest in doing this physics!
- Neither project is approved yet (or funded).
- Could have a healthy competition (like BaBar and Belle) starting 5 years from now.
  - Flavour physics is an important part of the European particle physics programme. Rich physics programme.
  - An e^+e^- collider at $\Upsilon(4S)$ energy region would be a significant milestone if
    - much more than 50 ab^{-1} data by the end of ~2020
    - moderate cost
  - Machine R&D for the TDR should be strongly supported to show that the concept can be realised. (R&D is also useful for the future machines. Continue collaboration with KEK?)

Quotes: RECFA Report on nano-beam Super Flavour Factory: T. Nakada, Nov 2008

CLEO-c





- Utilize quantum coherence at the $\psi(3770)$ to help constrain model uncertainty the GGSZ γ measurement.
- Model error will be important factor on experimental precision on γ.

- Can measure δ_D from:

$$e^+e^- \to \psi(3770)$$

$$\downarrow$$

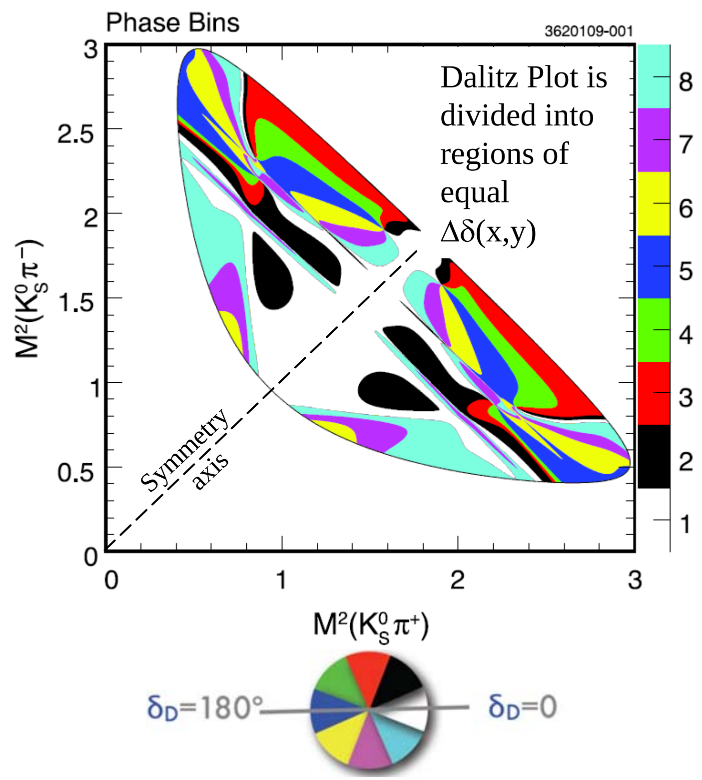
$$D^0\bar{D}^0 \to K_S\pi^+\pi^-$$

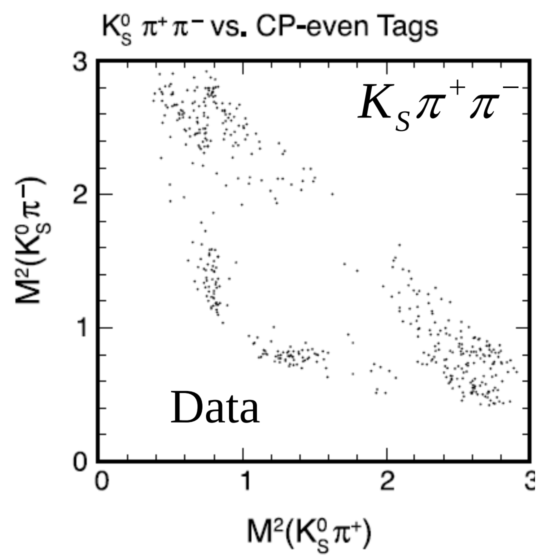
$$\to K^+K^- \,(\text{CP even})$$

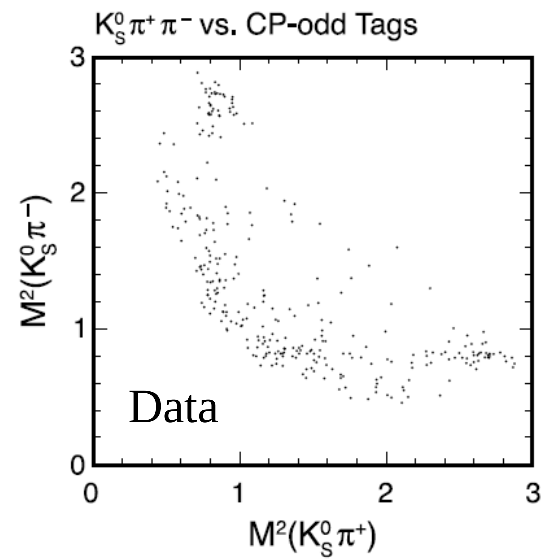
etc.

CLEO-c

- Use model independent approach proposed by Giri et al. to constrain δ_D.
  - $D^0 \rightarrow K_{S/L}\pi^+\pi^-$ decays recoil against flavor, CP and $K_S\pi\pi$ tags.
  - Interference between D^0 and $\bar{D}^0$ is parameterized by c_i and s_i.
    - These depend on $\Delta\delta_D$: the difference in phase between two points (x,y) and (y,x) on the Dalitz Plot.







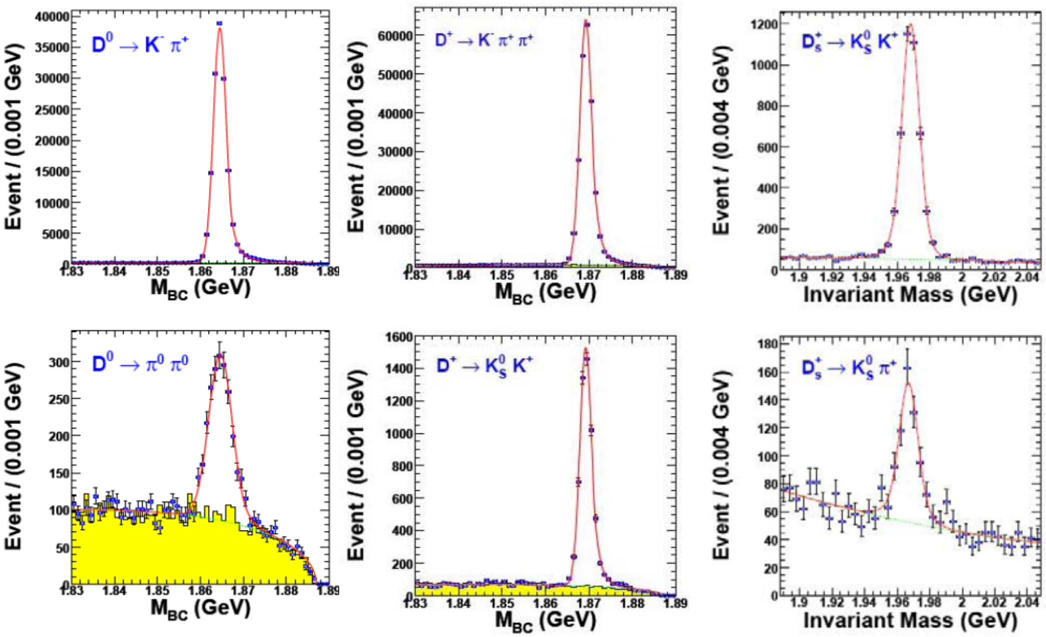
- Measured c_i and s_i significantly reduces model error expected on GGSZ γ determination.
- Using this result: $\sigma_{model} = 9° \rightarrow 1.7°$.

Giri et al: PRD**68** 054018 (2003).
Bondar et al.: EPJC**47** 347 (2006); EPJC **55** 51 (2008).
CLEO-c: arXiv:0903.1681.

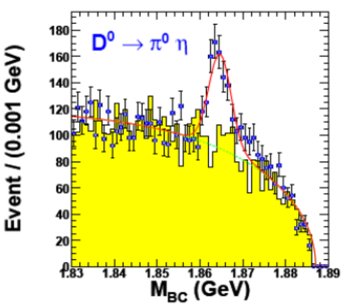
CLEO-c

- Many charm decays studied:
  - 818pb^{-1} at the $\psi(3770)$.
  - 586 pb^{-1} at 4170MeV [D_s decays].

D_s results using 300pb^{-1} of data published in PRL 100 161804 (2008).



Mode	This result $\mathcal{B}$ (%)
$D^0 \to K^+K^-$	$0.4052 \pm 0.0041 \pm 0.0044 \pm 0.0080$
$D^0 \to K_S^0 K_S^0$	$0.0159 \pm 0.0017 \pm 0.0008 \pm 0.0003$
$D^0 \to \pi^+\pi^-$	$0.1441 \pm 0.0022 \pm 0.0035 \pm 0.0029$
$D^0 \to \pi^0\pi^0$	$0.0836 \pm 0.0029 \pm 0.0030 \pm 0.0017$
$D^0 \to K^-\pi^+$	3.8910 external input [2]
$D^0 \to K_S^0\pi^0$	$1.2081 \pm 0.0115 \pm 0.0291 \pm 0.0239$
$D^0 \to K_S^0\eta$	$0.4769 \pm 0.0112 \pm 0.0260 \pm 0.0094$
$D^0 \to \pi^0\eta$	$0.0689 \pm 0.0058 \pm 0.0041 \pm 0.0014$
$D^0 \to K_S^0\eta'$	$0.9623 \pm 0.0317 \pm 0.0445 \pm 0.0190$
$D^0 \to \pi^0\eta'$	$0.0937 \pm 0.0112 \pm 0.0059 \pm 0.0019$
$D^0 \to \eta\eta$	$0.1653 \pm 0.0110 \pm 0.0137 \pm 0.0033$
$D^0 \to \eta\eta'$	$0.1063 \pm 0.0243 \pm 0.0097 \pm 0.0021$

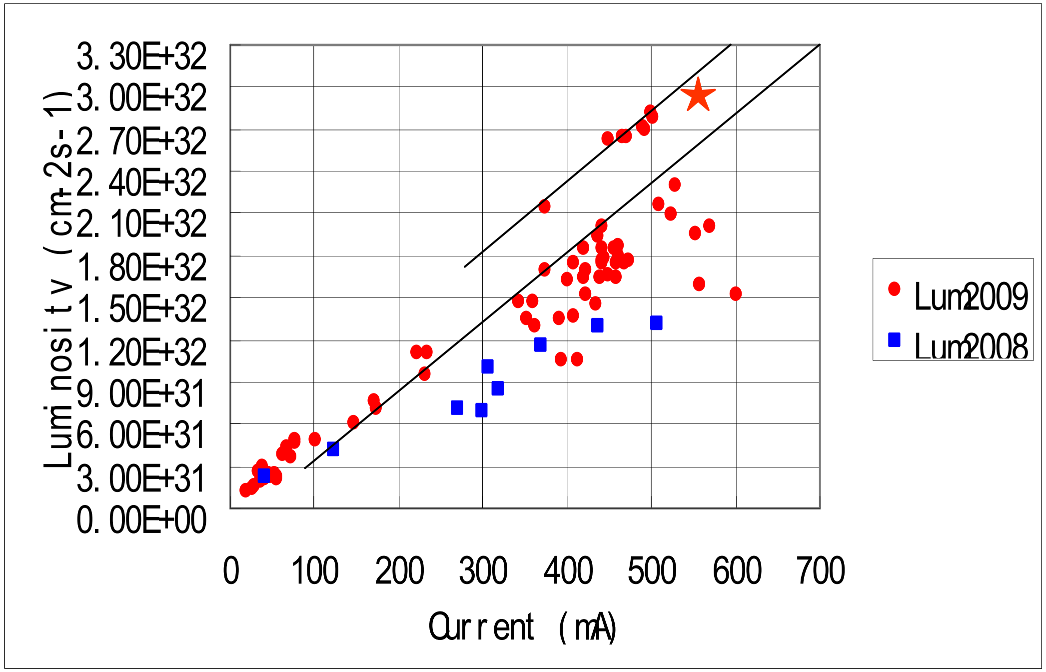


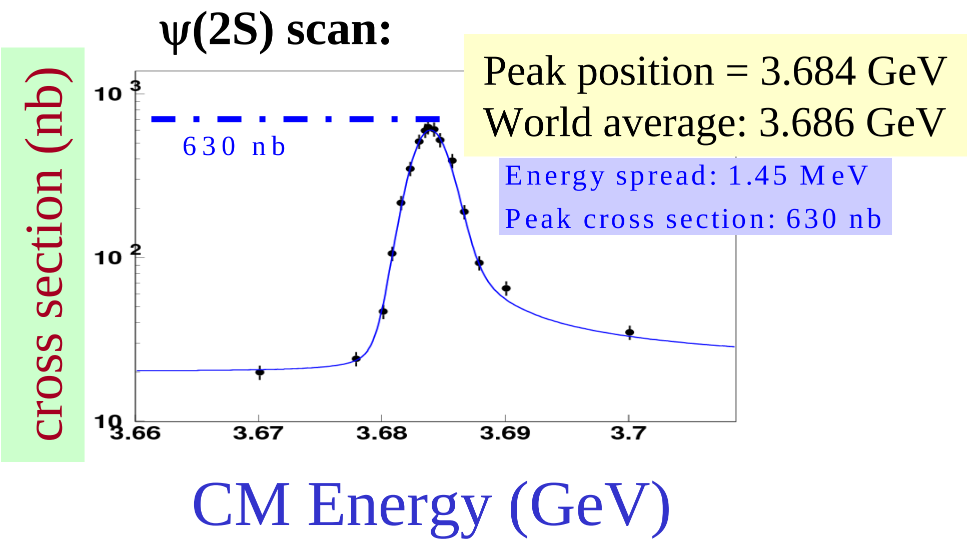
A smorgasbord of the recent results of D^0, D^+ and D_s decays To two pseudoscalar final states.

Also studied:
- Final states with ω.
- 3 body final states.
- f_D and f_{Ds} measurements.
- BES-III will hopefully follow on from where CLEO-c finishes.

BES-III

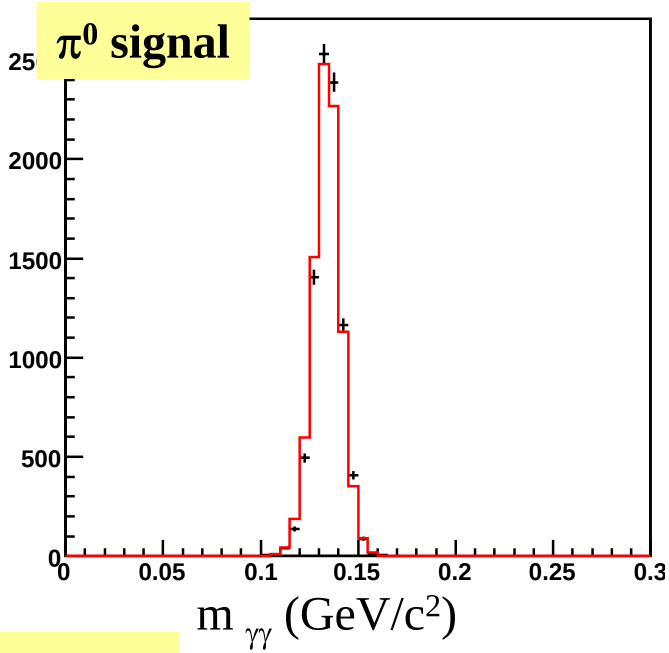
- Accelerator achieved $\mathcal{L}\sim3\times10^{32}cm^{-1}s^{-2}$ and is running well.
- Recorded 100M ψ(2S) events.
- J/ψ run started:
  - Aim: 300-500M events.

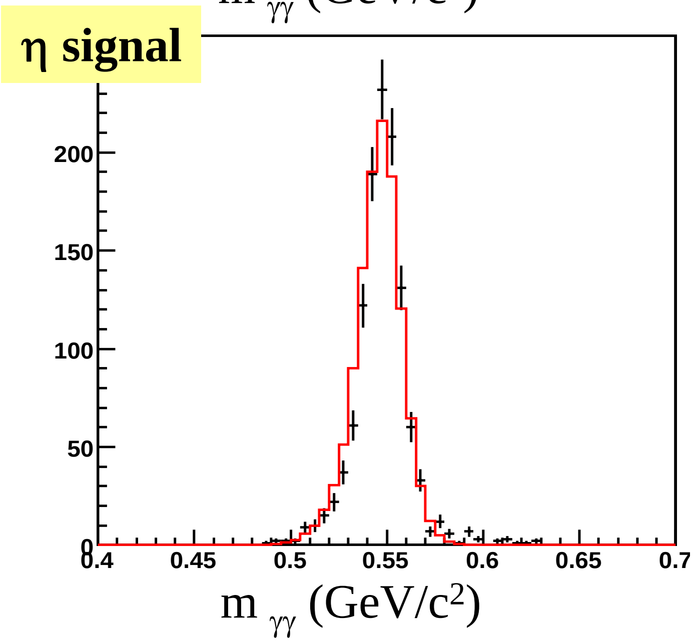


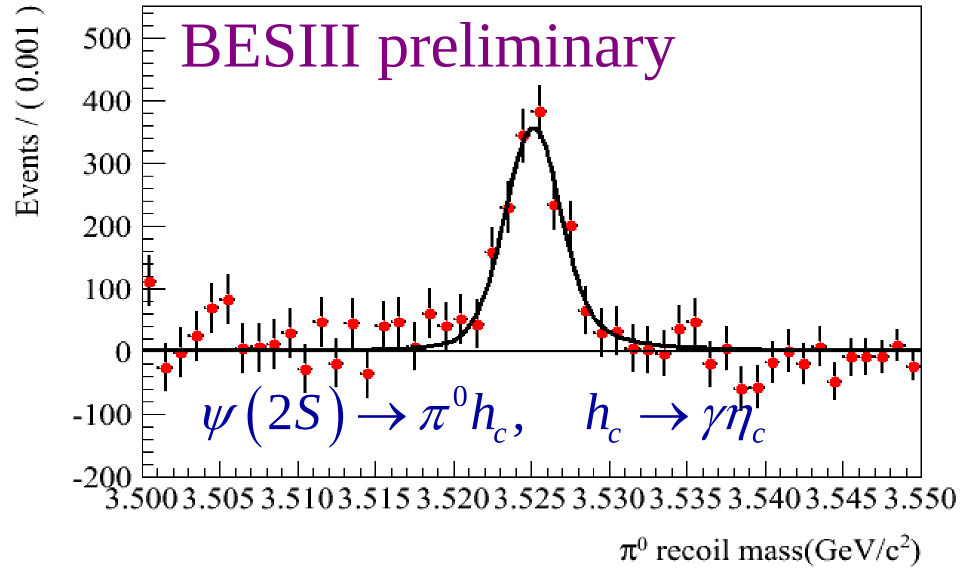


S. Olsen/Y. Wang CIPANP

BES-III

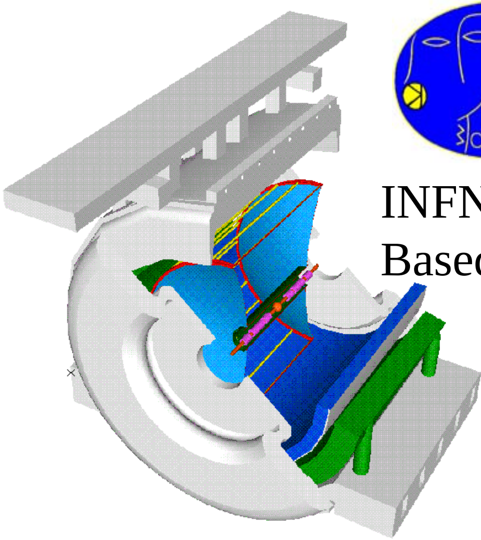




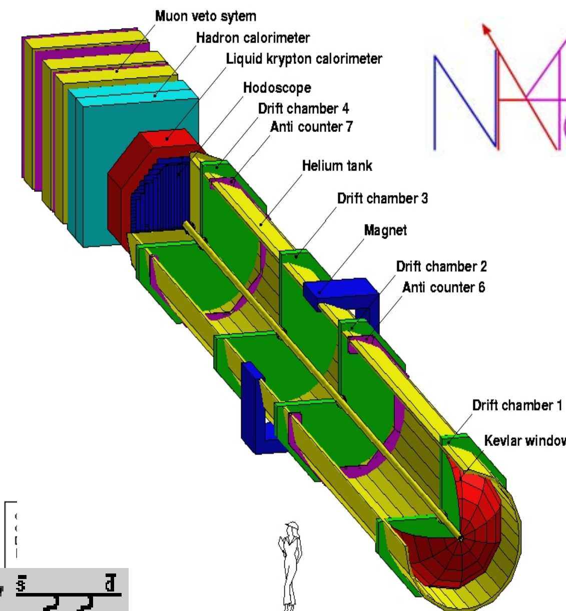


- Detector working well
  - Mass distributions of π^0, η, Λ, K^*, etc. confirm this.
- Physics results starting to appear from 2S data sample.
- Aim to record 20fb^{-1} at $\psi(3770)$, and above $D_s\bar{D}_s$ threshold soon.
- + Eidelman showed results from KEDR on J/ψ & charm.

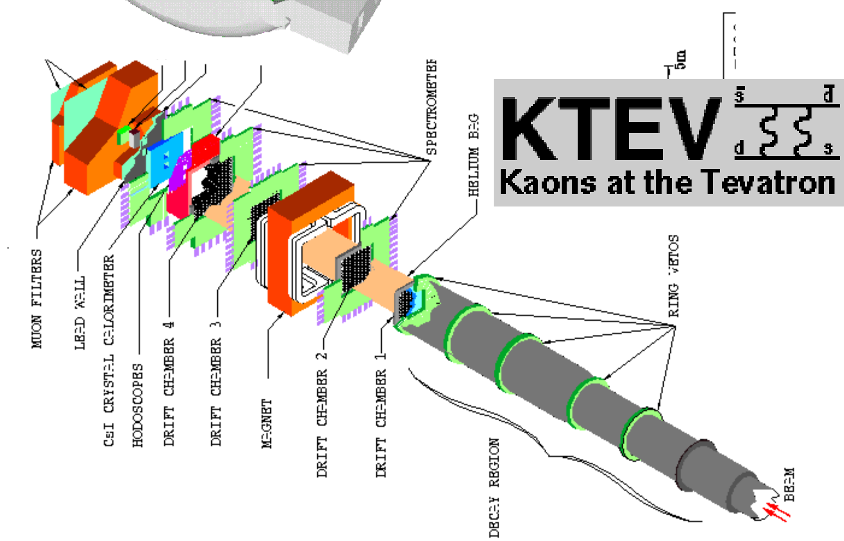
Kaon physics

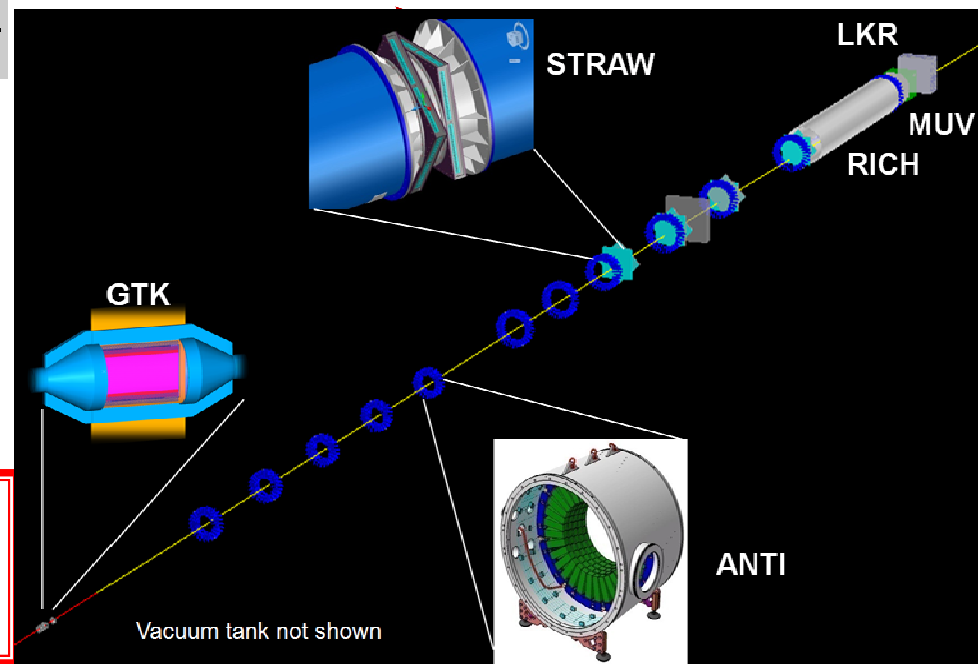


INFN Frascati
Based Experiment



CERN Based Experiment
R_K (2007-2008)
$K^+ \to \pi^+ \nu\nu$ (in preparation)





Also future experimental Kaon programmes
at JPARC (KOTO) and Fermilab
that I don't have time to talk about.

KTeV

- $\varepsilon'/\varepsilon \neq 0$ signifies direct CP violation in kaon decay.

$$R = 1 - 6\Re(\varepsilon'/\varepsilon) = \frac{N(K_L^0 \to \pi^0\pi^0)/N(K_S^0 \to \pi^0\pi^0)}{N(K_L^0 \to \pi^+\pi^-)/N(K_S^0 \to \pi^+\pi^-)}$$

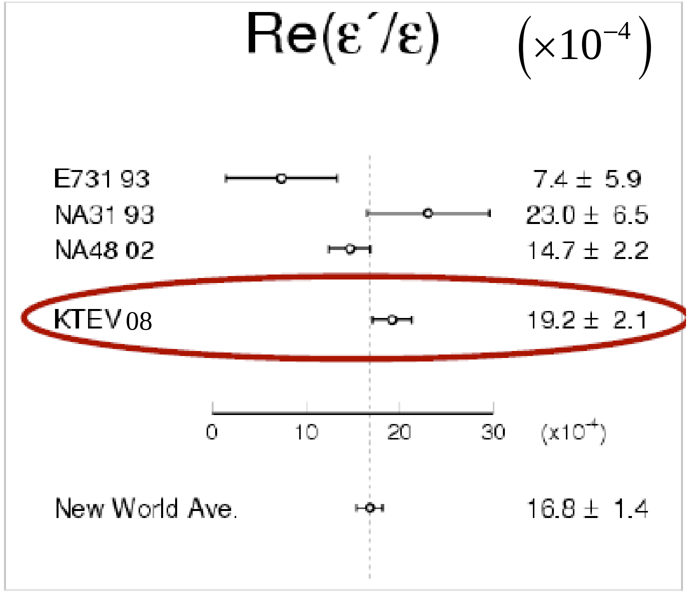
- First results a decade ago from KTeV and NA48.
- Final KTeV result needed a slightly better understanding of the calorimeter systematic error.
- Now available!

$$\Re(\varepsilon'/\varepsilon)_{KTeV} = (19.2 \pm 1.1 \pm 1.8) \times 10^{-4}$$

Source	Error on $Re(\epsilon'/\epsilon)$ $(\times 10^{-4})$ $K \to \pi^+\pi^-$	$K \to \pi^0\pi^0$
Trigger	0.23	0.20
CsI cluster reconstruction	—	0.75
Track reconstruction	0.22	—
Selection efficiency	0.23	0.34
Apertures	0.30	0.48
Acceptance	0.57	0.48
Backgrounds	0.20	1.07
MC statistics	0.20	0.25
Total	0.81	1.55
Fitting	0.31	
Total	1.78	

Reduced from 1.47

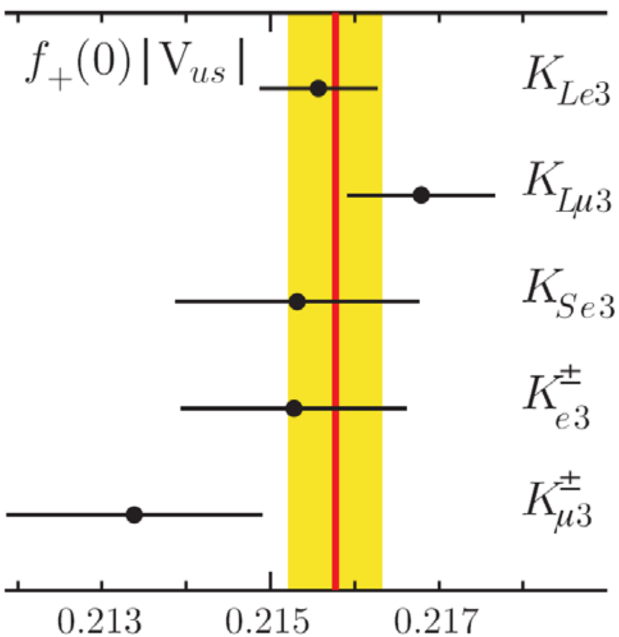
Table from E. Blucher, Kaon '09
(PRD in preparation)

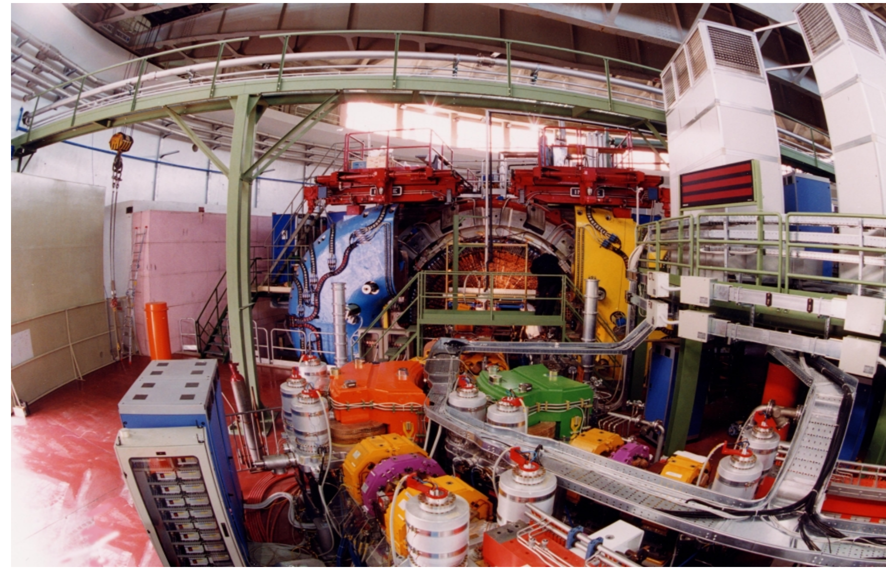


KLOE: V_{us}

- Use $K \to \pi \ell \nu$ decays to precisely measure V_{us}.
  - Fundamental test of CKM unitarity and the SM.

$\lvert f_+(0)\,V_{us}\rvert$
0.2155(7)
0.2167(9)
0.2153(14)
0.2152(13)
0.2132(15)





$$\left| f_+(0) V_{us}^{KLOE} \right| = 0.2157(6)$$

$$V_{us}^{WA} = 0.2237(13)$$

$$1 - V_{ud}^2 - V_{us}^2 = (9 \pm 8) \times 10^{-4}$$

- Results consistent with Unitarity of the CKM matrix & SM.

$f_+(0)$=0.9644 ±0.0049 from UKQCD/RBC.
$|V_{ud}|$=0.97418±0.00026 from $0^+ \to 0^+$ β decays.

JHEP 0804:059 (2008)

KLOE: R_K

- Test the SM with

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{\Gamma(K_{e2})}{\Gamma(K_{\mu 2})} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right) \cdot \left(1 + \delta R_K^{Rad.Corr.}\right)$$

Helicity Suppression factor

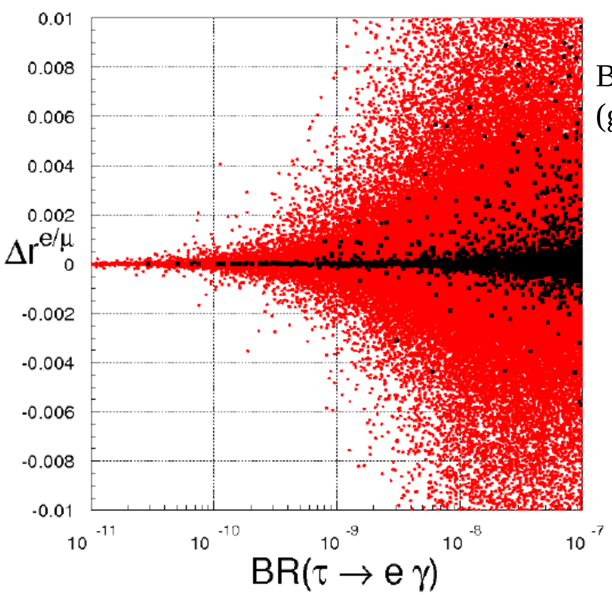
Rad. Corr. a few% from IB $K \to e\nu\gamma$

- Probe for NP models, RH currents, MSSM, 2HDM:
  - $R_K = 2.477(1) \times 10^{-5}$ in the SM. V. Cirigliano, I. Rossel, PRL **99** 231801 (2007)
  - 1% deviations from SM could signify NP.

$$R_K^{e/\mu} = \frac{\left(R_K^{e/\mu}\right)_{Expt.}}{\left(R_K^{e/\mu}\right)_{SM}} = 1 + \Delta R_K^{e/\mu}$$

  - Can be combined with LFV in τ decays to constrain NP.

A. Masiero, P. Paradisi, R. Petronzio, JHEP 0811:042 (2008).



Black dots indicate: $(g\text{-}2)_\mu = (1\text{-}5) \times 10^{-9}$

This is one example of a SUSY LFU breaking model, with overall conservation of L number.

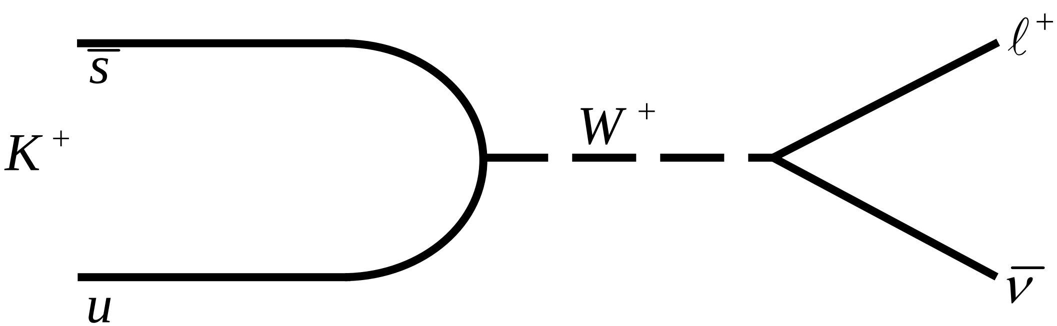
KLOE: R_K

- Test the SM with

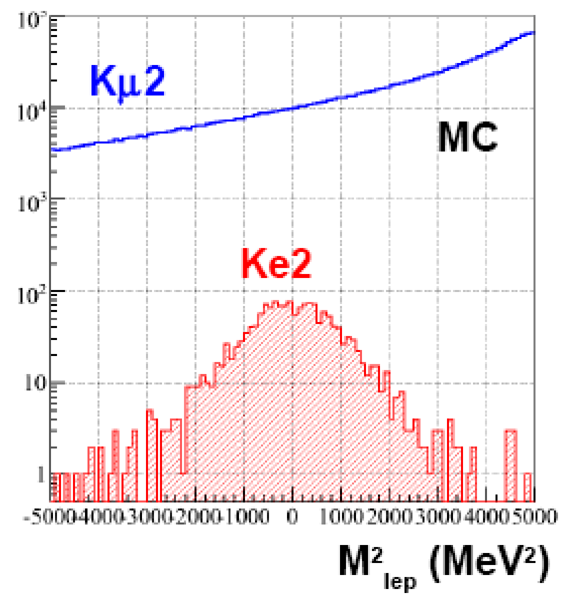
$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu)}{\Gamma(K^\pm \to \mu^\pm \nu)} = \frac{\Gamma(K_{e2})}{\Gamma(K_{\mu 2})} = \frac{m_e^2}{m_\mu^2} \cdot \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right) \cdot \left(1 + \delta R_K^{Rad.Corr.}\right)$$

Helicity Suppression factor

Rad. Corr. a few% from IB K→eνγ



- R_K tests Lepton Universality.
- Use data to determine $\delta R_K^{Rad.Corr.}$.



- Aim: 1% precision on R_K.
- Challenging measurement: 10^4 background rejection with O(50%) signal efficiency.
- $\phi \to K^+K^-$ topology helps signal identification.
- $N(K_{e2}) \sim 13.8K$ [limiting factor].

KLOE: R_K

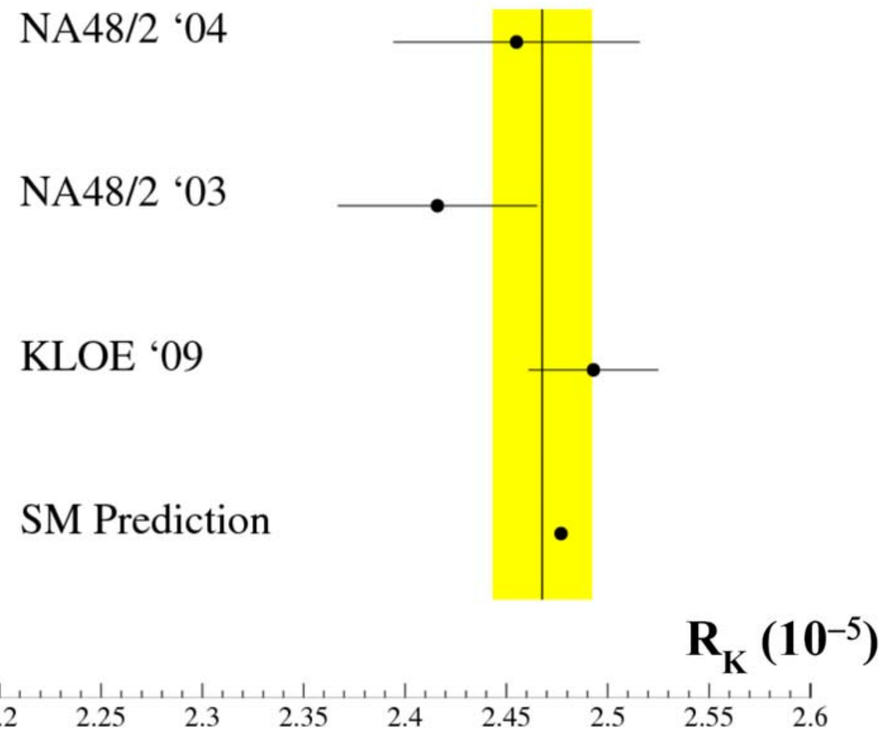
- Data collected between `01 and `05.
- 2.5fb-1 integrated at $\sqrt{s}=m_{\phi}$.
- ~2.5M $K_S K_L$ pairs.

Source	Systematic error [%] Stat	Systematic error [%] Syst	Main method
Reconstruction	0.4	0.4	Control samples
Trigger efficiency	0.4		Downscaled events
Bkg subtraction		0.3	Fit range variation
Ke2(DE) component	0.1		Measurement on data
Clustering for e, μ	0.3		KL control samples
Total	**0.6**	**0.5**	

- Statistical error dominated by K_{e2} yield and background subtraction.
- Systematic error limited by statistical effects.

$$R_K^{KLOE} = \left(2.493 \pm 0.025 \pm 0.019\right) \times 10^{-5}$$

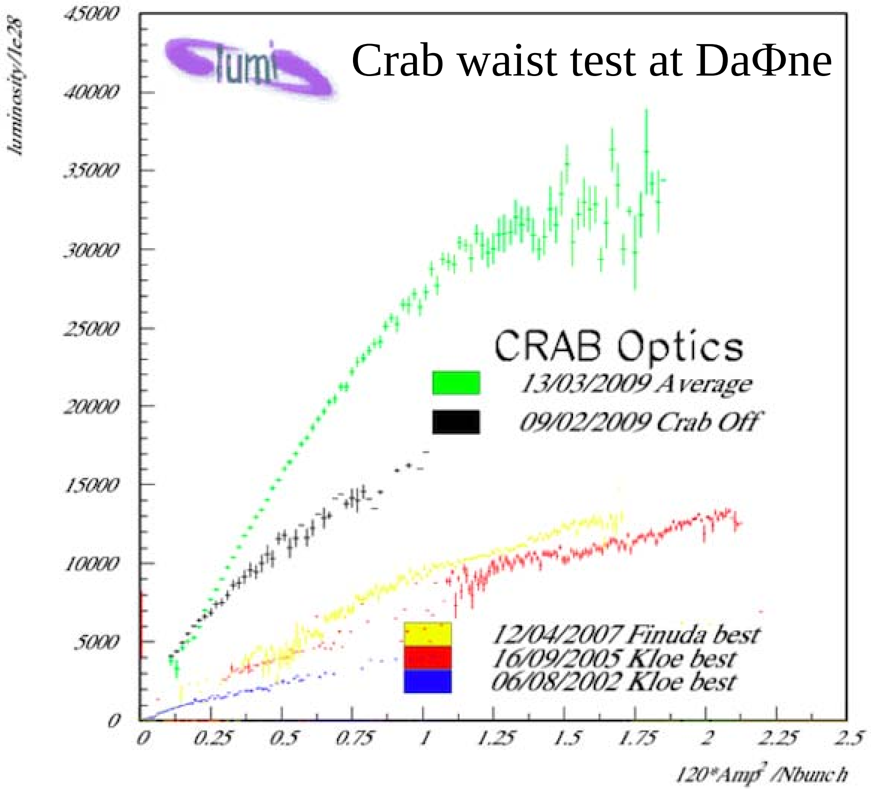
- Precision of ~1% reached.



KLOE-2

- SuperB beam tests at DaΦne give significant increase in $\mathcal{L}$.

Luminosity vs Current Product



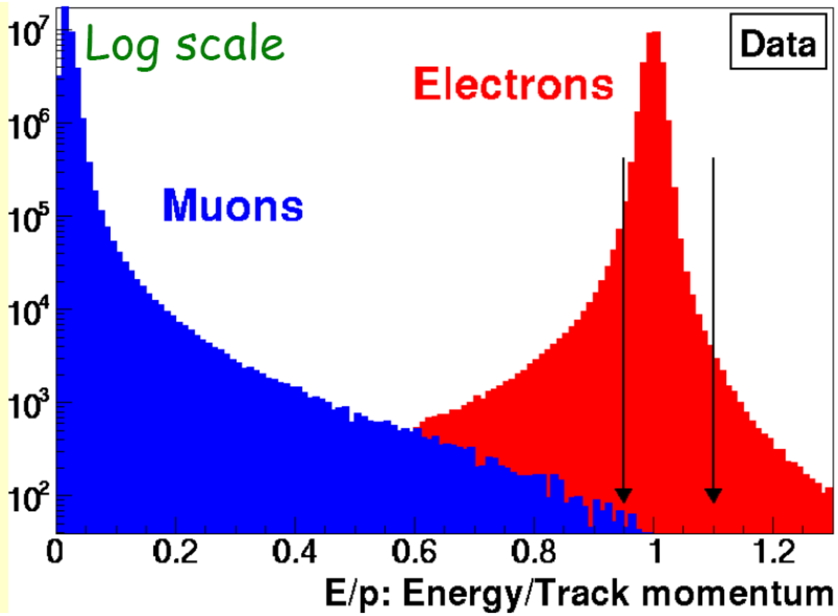
14th May 2009 Interactions Article
http://www.interactions.org/cms/?pid=1028098

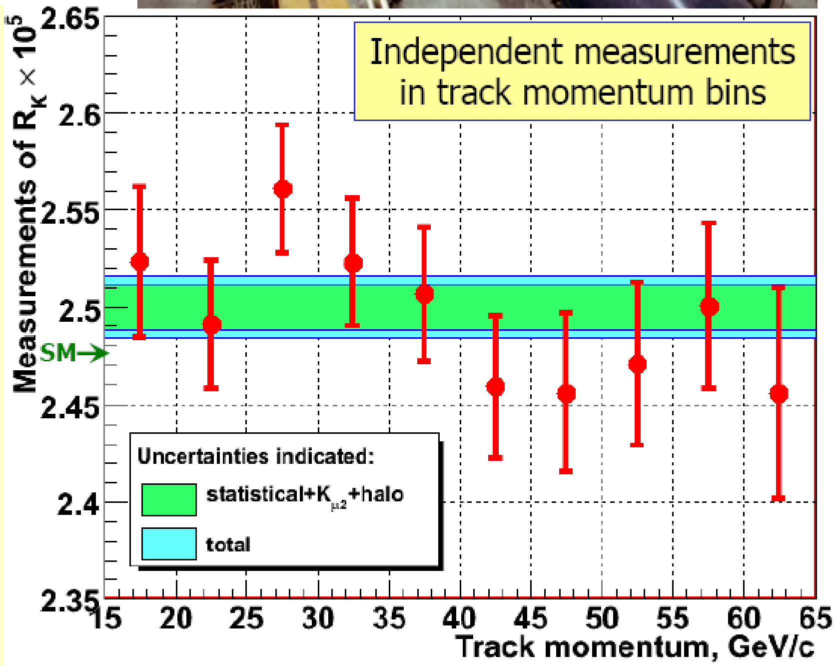
KLOE also showed a number of other results *including* tests of the ω effect (CPT), $\tau_{KS/L}$, and $K\rightarrow 3\pi$ decays.

- SuperB's Crab Waist scheme works well!
- KLOE will take data again ($\mathcal{L}$~ increased by ×3).
- New Inner Tracker detector (cylindrical GEMS) will give better acceptance for low p tracks.
- Physics goals include:
  - Improve LU tests and $|V_{us}|$.
  - Constrain CPT violation in kaon decay.
  - Measure K_{e2} to ~1 $^0/_{00}$.
  - Measure ε'/ε ~10^{-4}.
  - Study rare Ks, $\eta^{(')}$ decays.
  - Low energy spectroscopy (arXiv:0904.3815).
  - Will include a new γγ trigger.

NAG62 (2007/2008)

- Aim to measure R_K to ~0.3%.
- Analyzed 40% of the data.
- Data taking in 07/08.
- Excellent e–μ separation.
- N_{Ke2}= 51,089 [P=92%].
- $N_{K\mu2}=15.56\times10^6$ [P=99.75%].





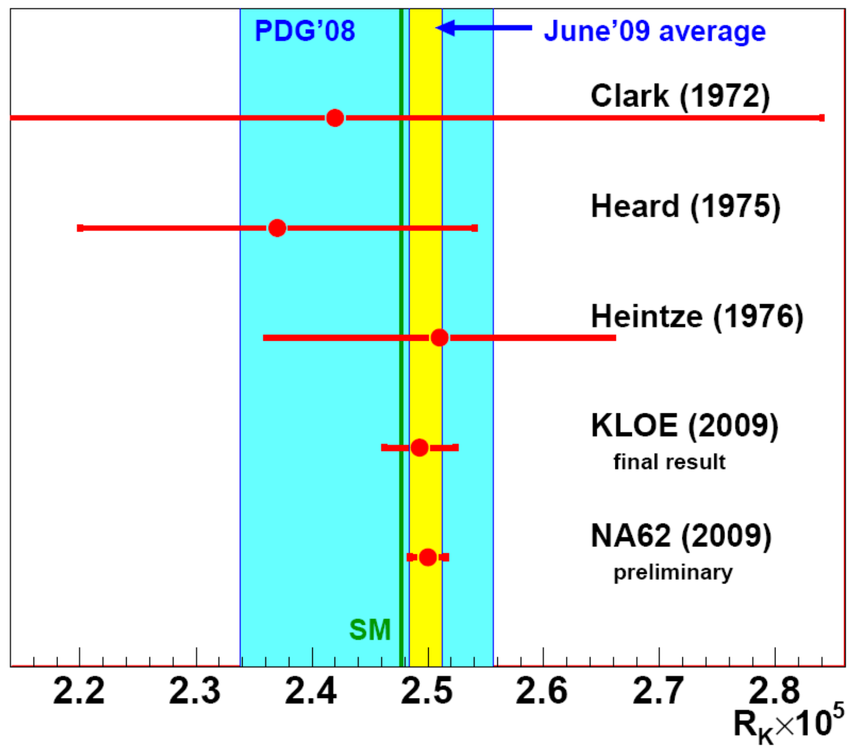
- Systematic error is dominated by statistical effects.

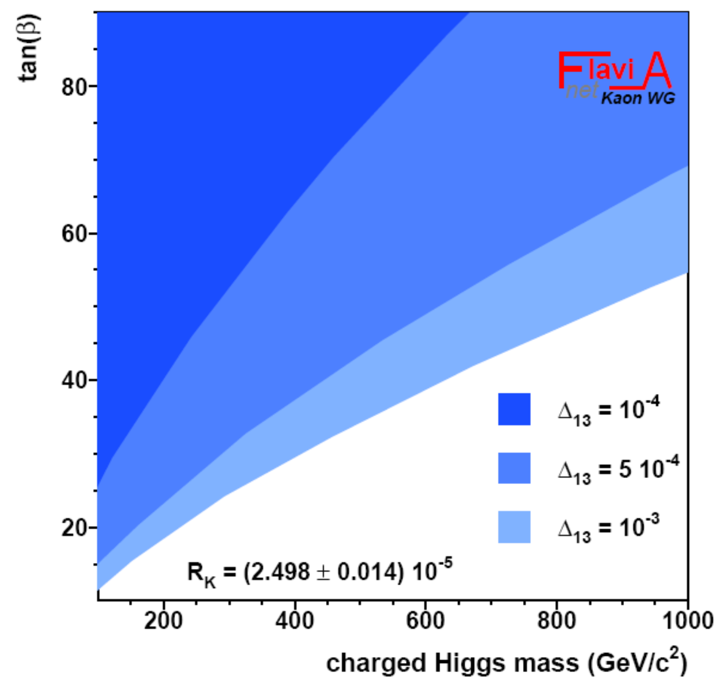
NA62 (2007/2008)

- Aim to measure R_K to ~0.3% with full data set.
- Preliminary result shown at Kaon '09:

$$R_K = (2.500 \pm 0.012 \pm 0.011) \times 10^{-5}$$ (0.64% precision)

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



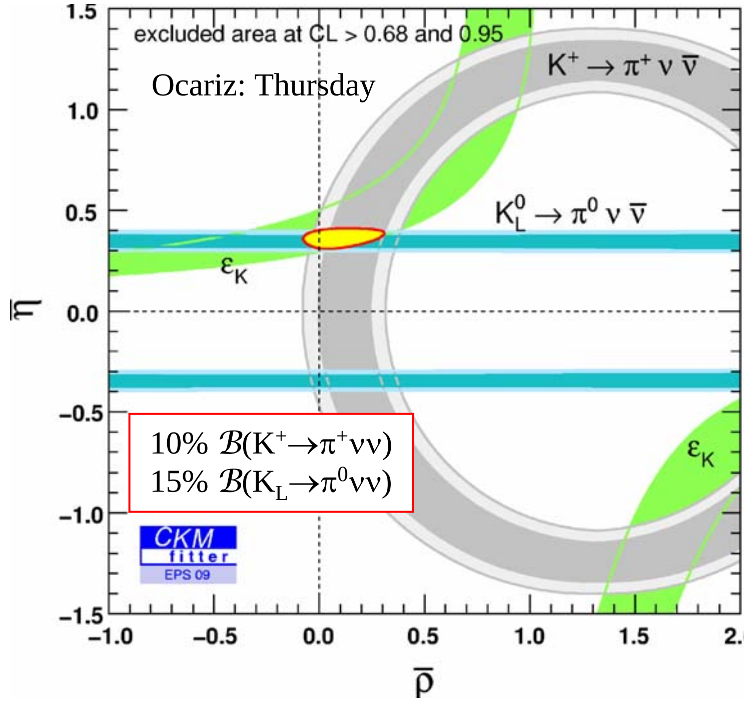


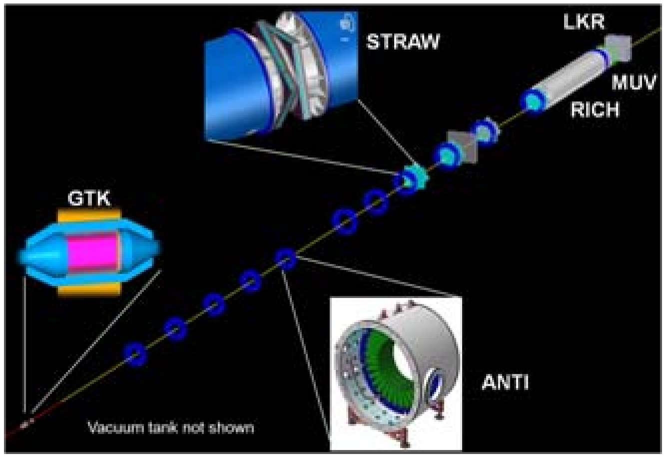
- This new result dominates the world average precision on R_K.

NA62 (In preparation)

- 2^{nd} phase of NA62:
  - 10% measurement of $K^+ \to \pi^+ \nu\bar{\nu}$.
  - 55 events/yr.
- Theoretically clean test of CKM and NP.
- Will give important constraints on CKM with $K^0_L \to \pi^0 \nu\bar{\nu}$ (from KOTO).
- Need to add:
  - PID system (RICH)
  - Silicon Pixel Tracker (GIGATRACKER)
  - veto anti-counters
  - new vacuum tube tracker (straw tube)

  to the existing apparatus.





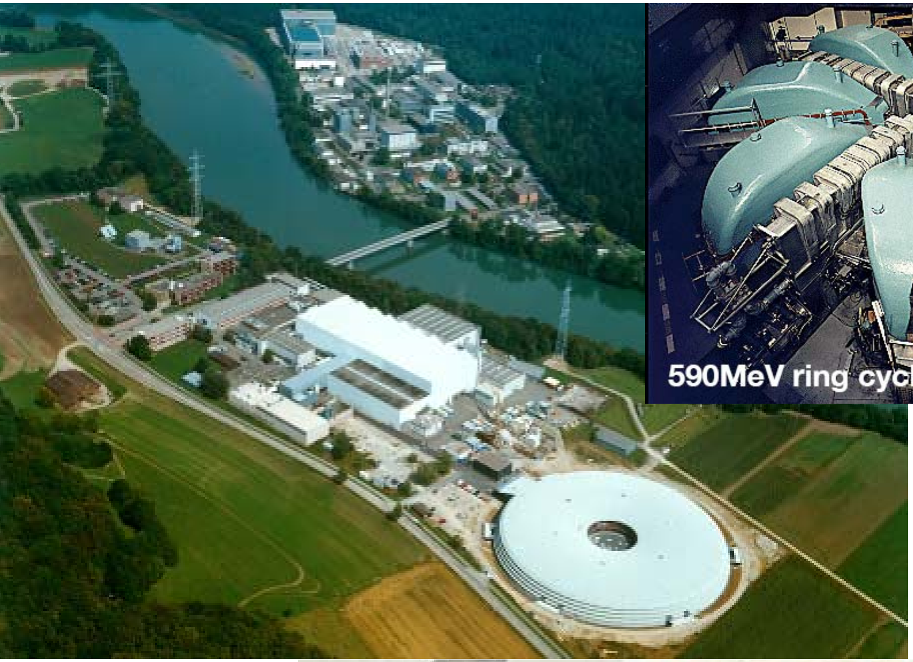
- Approved by CERN Research Board in December ’08.

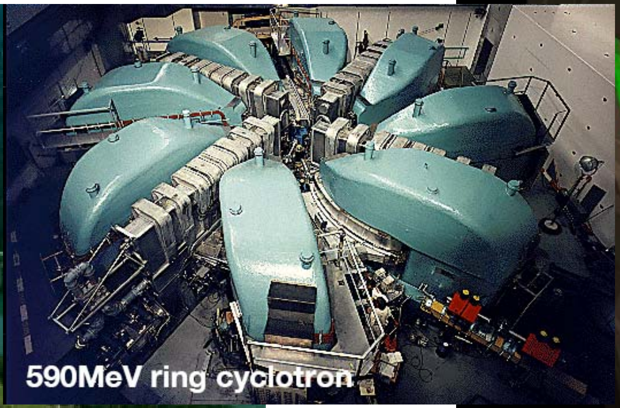
MEG

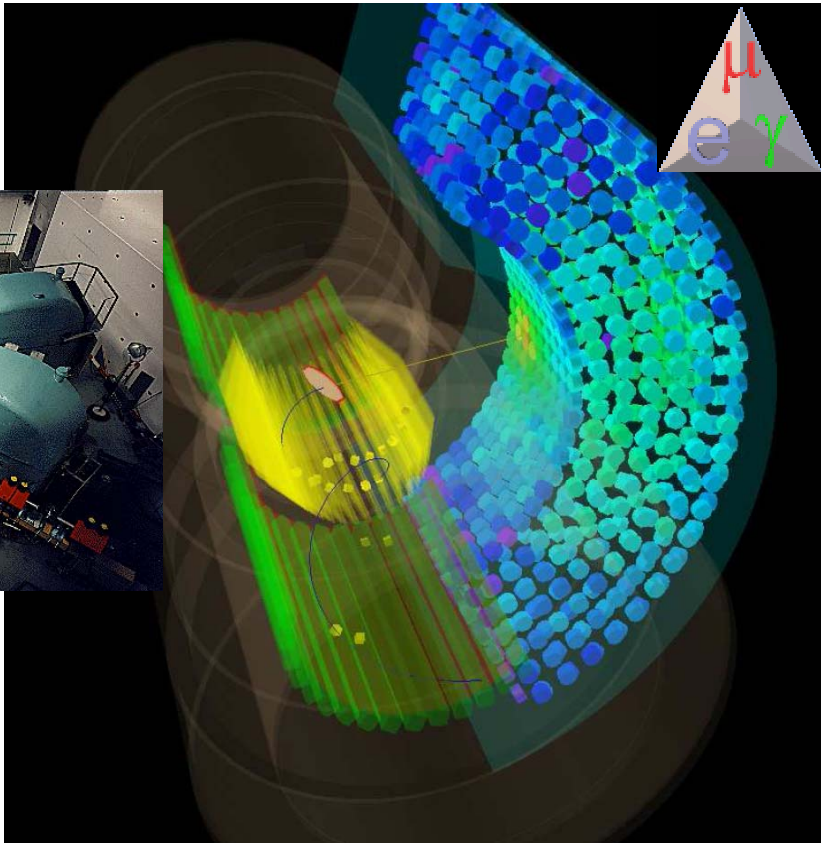
μ→eγ

Paul Scherrer Institut Based Experiment:

Use the worlds most powerful DC μ beam.

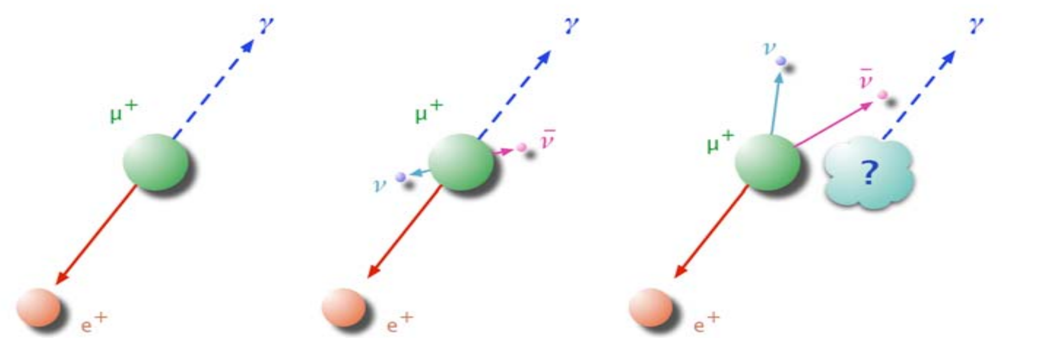






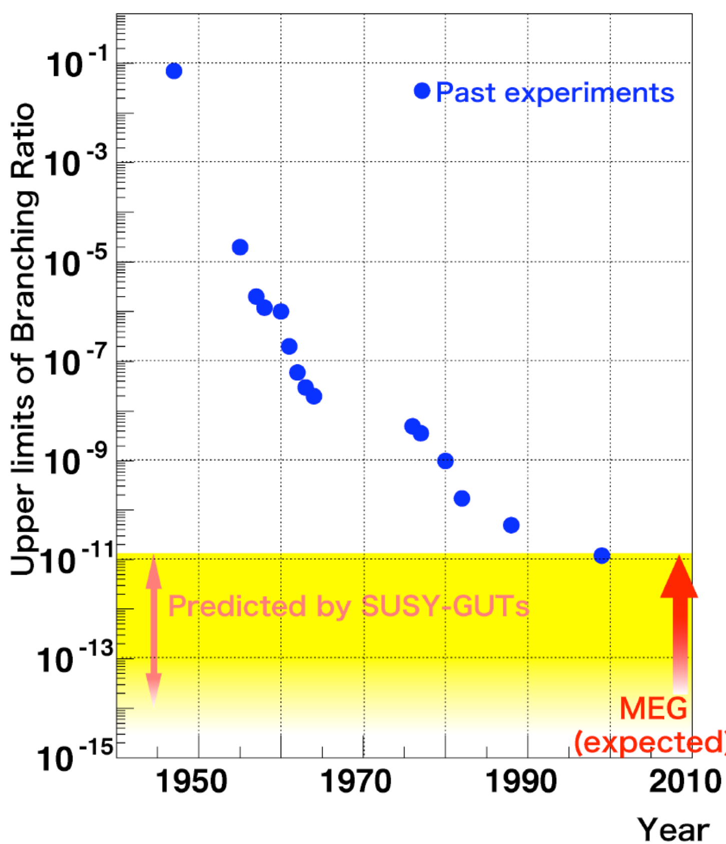
MEG

- Raison d'etre: search for $\mu^{\pm} \rightarrow e^{\pm}\gamma$.
  - Expected ultimate sensitivity reach ~ $\mathcal{B}<10^{-13}$ (90% CL).
  - SM expectation: ~ 10^{-50}.
    - Any signal would be a clear sign of new physics.
    - Complements θ_{13} measurements and $\tau\rightarrow\mu\gamma$ searches when interpreting new physics models.



Signal SM Background Accidental background

$\mu\rightarrow e\gamma$ search history



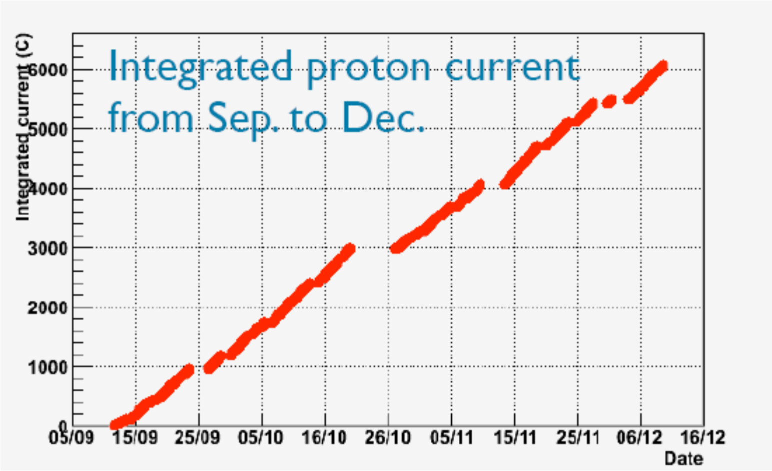
- Started taking data in 2008.
- Continue data taking later this year.

MEG

- 2008 Run:
  - Sept-Dec ’08.
  - 9.1×10^{13} μ on target.
  - 3.4×10^{6} (s) live time.
  - Experiment working well.
    - Some teething troubles being worked on for this year [related to DCH HV], and LXe purification helped improve response.
  - *Expected* single event sensitivities:

$$SES(2008) \leq (30-50)\times10^{-13}$$

$$SES(2009) \sim (3-5)\times10^{-13}$$



- Analysis of 2008 data is ongoing (still blind).
  - Hope to open the box soon, so watch this space!

See R. Sawada, CIPANP ‘09 for more details

μ→e conversion

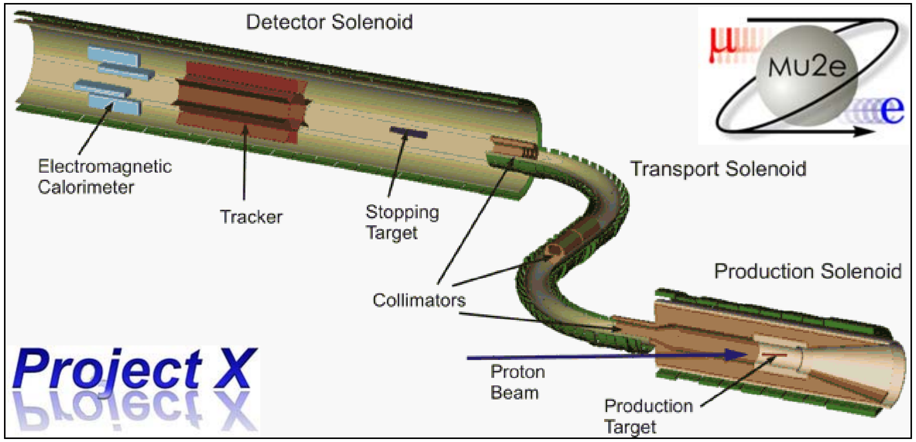
- The search for LFV via neutrinoless μ→e conversion.

$$\mu^- Al \rightarrow e^- Al$$

- Best limit from Sindrum-II.
- "Watch muonic Al decay".
- Sensitive to NP, in a complementary way to other LFV measurements.
- Present limit (Gold) is

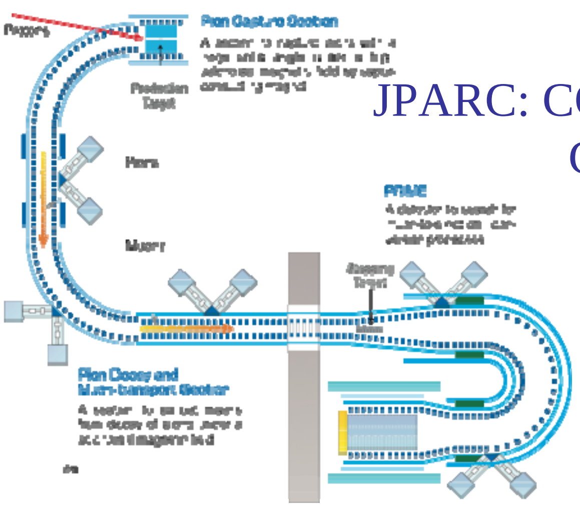
$$< 7\times 10^{-13}$$

- New experiments planned to surpass this by 10^3.



FNAL: Mu2e proposed in 2008
Construction from ~2013
Data taking from ~2017
Sensitivity $<10^{-16}$

Subsequent upgrade being planned (ProjectX).



JPARC: COMET proposed in 2007
Construction from ~2013
Data taking from ~2017
Sensitivity $<10^{-16}$

Subsequent upgrade being planned (PRISM).

Related talks from parallel sessions

BaBar + Belle:

J. Albert
E. Ben-Haim
P. Biassoni
C. Chavez
V. Druzhinin
M. Ebert
E. Guido
T. Hong
R. Kass
T. Latham
V. Lombardo
N. Lopez-March
A. Mokhtar
G. Onorato
M. Rotondo
J. Sundermann
V. Ziegler
C. Chiang
S. Choi
A. Drutskoy
W. Dungel
B. Golob
K. Hayasaka
S. Kyeong
C. Liu
R. Louvot
Y. Miyazaki
I. Nakamura
S. Nishida
A. Poluektov
B. Reisert
M. Wang
J. Wiechczynski
E. Won

KLOE(-2)/KTeV/ NA48/NA62:

P. Cenci
G. Collazuol
M. Dreucci
L. Erika
P. Gauzzi
S. Giovannella
G. Lamanna
E. de Lucia
E. Marinova
B. Di Micco
F. Nguyen
P. de Simone

CLEO:

D. Miller
S. Ricciardi
T. Skwarnicki

BES-III:

S. Jin

SuperB/SuperKEKB:

M. Sullivan
Z. Dolezal

KEDR:

S. Eidelman

MEG/Mu2e/COMET:

No talk at this conference, see CIPANP 2009

+ T. Nakada's ECFA/EPS summary of Super Flavour Factories.
+ UTFit/CKM Fitter talks (Tarantino & Ocariz)

Many excellent parallel session talks, please look at them for details!
Apologies if I did not cover your favourite topic.

Summary

- A good year for Flavour Physics!
  - A sample of the programme has been reviewed here!
- 45 years of CP violation studies have resulted in consistent descriptions of K and B decays.
  - What about CP violation/conservation in Charm?
- There is still room for new physics effects!
- Ever more precise constraints on LFV are being pursued via MEG and Super Flavour Factories.
  - Super Flavour Factories should also look for CP violation in τ decays!
- Kaon physics has a promising future programme with KLOE-2/NA62/…

Summary

- The next decade has a balanced flavour programme in B, D, K, τ, and μ decays.

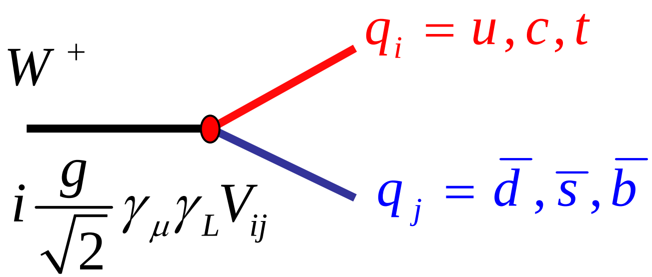
- We should recall that …
  - FCNC place strong constraints on the Standard Model.
  - So FCNC in the SUSY sector will do the same for new physics.

- ***This*** strong flavour programme (including hadron machines) is needed to elucidate the complex nature of high energy physics.
  - Flavour physics supports and strengthen the efforts of the LHC.
  - Complementarity to neutrino programme.
  - Each proposed and existing experiment provides a *unique set of measurements* to teach us something new about nature.

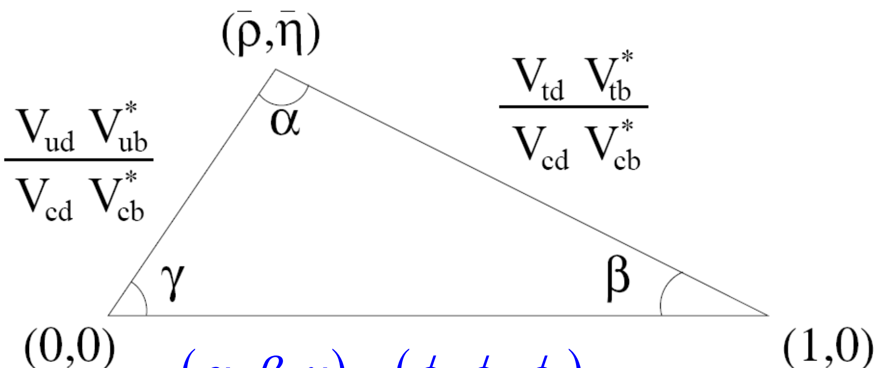
Thank you!

Additional Slides

CKM and the unitarity triangle



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



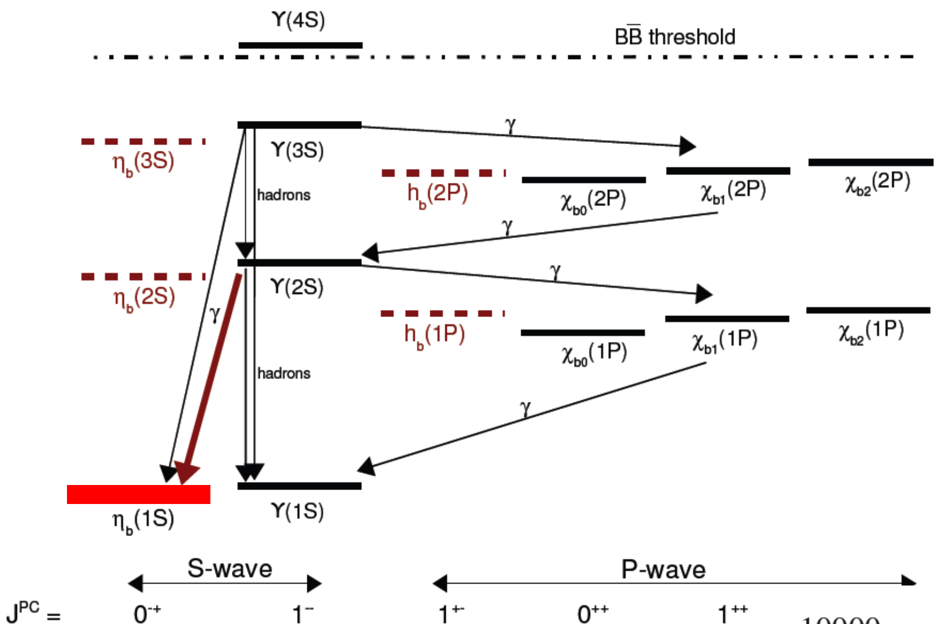
$$(\alpha,\beta,\gamma) = (\phi_1,\phi_2,\phi_3)$$

$$\alpha \equiv \arg\left[-V_{\rm td}V_{\rm tb}^*/V_{\rm ud}V_{\rm ub}^*\right]$$
$$\beta \equiv \arg\left[-V_{\rm cd}V_{\rm cb}^*/V_{\rm td}V_{\rm tb}^*\right]$$
$$\gamma \equiv \arg\left[-V_{\rm ud}V_{\rm ub}^*/V_{\rm cd}V_{\rm cb}^*\right]$$

$$\mathcal{A}(\Delta t) = \frac{\Gamma(\Delta t) - \overline{\Gamma}(\Delta t)}{\Gamma(\Delta t) + \overline{\Gamma}(\Delta t)}$$

$$\mathcal{A}(\Delta t) = S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$$

An end to the 30 year search for η_B



observed
predicted but unobserved

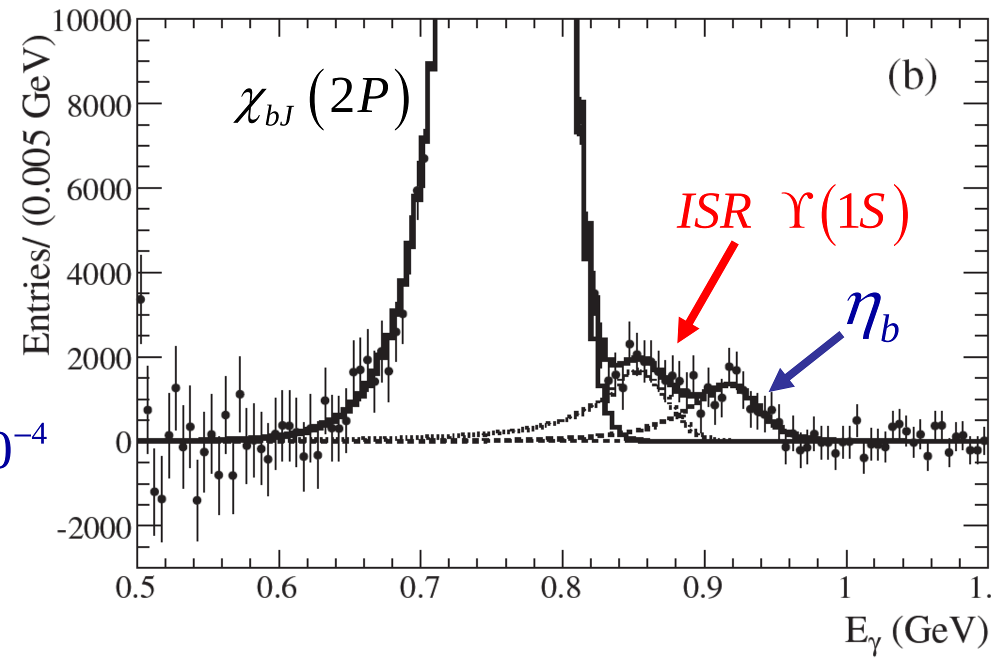
- After 30 years of searching, a candidate for the ground state of the bb system has been found.

$$m_{\eta_b} = 9388.9^{+2.3}_{-3.1} \pm 2.7 \text{ MeV/c}^2$$

$$m_{\Upsilon(1S)} - m_{\eta_b} = 71.4^{+2.3}_{-3.1} \pm 2.7 \text{ MeV/c}^2$$

$$B(\Upsilon(3S) \to \gamma\eta_b) = (4.8 \pm 0.5 \pm 1.2) \times 10^{-4}$$

Phys. Rev. Lett. 101, 071801 (2008)



Charm Mixing

- Define mass eigen-states:

$$|D_1\rangle = p|D^0\rangle + q|\overline{D}^0\rangle$$
$$|D_2\rangle = p|D^0\rangle - q|\overline{D}^0\rangle$$

- Mixing occurs if Δm or $\Delta\Gamma \neq 0$

$$x = \frac{\Delta M}{\Gamma}, \quad y = \frac{\Delta\Gamma}{2\Gamma} \qquad \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

- Short distance terms are GIM or CKM suppressed.
- Long distance terms dominate and are hard to calculate.

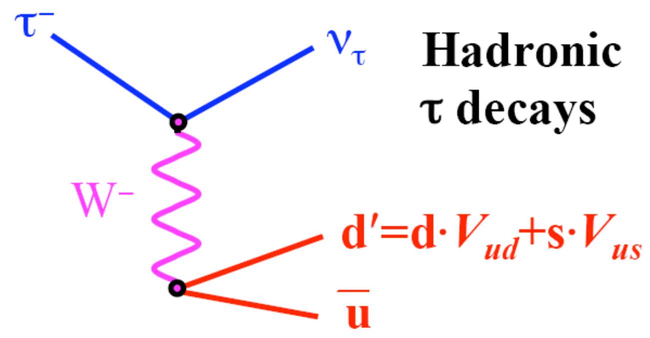
*BABAR: PRL **98** 211802 (2007)*	*$D^0 \to K^+\pi^-$ decay time analysis, BABAR*	3.9σ
*BELLE: PRL **98** 211803 (2007)*	*$D^0 \to K^+K^-$, $\pi^+\pi^-$ vs $K^+\pi^-$ lifetime difference analysis, BELLE*	3.2σ
*BELLE: PRL **99** 131803 (2007)*	*$D^0 \to K_s\pi^+\pi^-$ time dependent amplitude analysis, BELLE*	2.2σ
*CDF: PRL **100**, 121802 (2008)*	*$D^0 \to K^+\pi^-$ decay time analysis, CDF*	3.8σ
*BABAR: PRD **78**, 011105 R (2008)*	*$D^0 \to K^+K^-$, $\pi^+\pi^-$ vs $K^+\pi^-$ lifetime difference analysis, BABAR*	3σ
BABAR: arXiv:0807, 4544 (2008)	*$D^0 \to K^+\pi^-\pi^0$ time dependent amplitude analysis, BABAR*	3.1σ
CLEO-c PRD 78, 012001, (2008)	*$D^0 \to K^+\pi^-$ Relative Strong Phase Using Quantum-Correlated Measurements in $e^+e^- \to D^0 D^0$ at CLEO*	
Significance of all mixing results combined by Heavy Flavor Averaging Group ICHEP2008:		**$\sim 9.8\sigma$**

τ Physics: V_{us}

τ Lepton analogue of the KLOE Unitarity test

- Use ΔS=1 decays of $\tau^{\pm}$.
- Rates sensitive to $|V_{us}|$:

(1)
$$|V_{us}|^2 = \frac{R_{\tau,strange}}{R_{\tau,non-strange}/|V_{us}|^2 + \delta R_{OPE}}$$

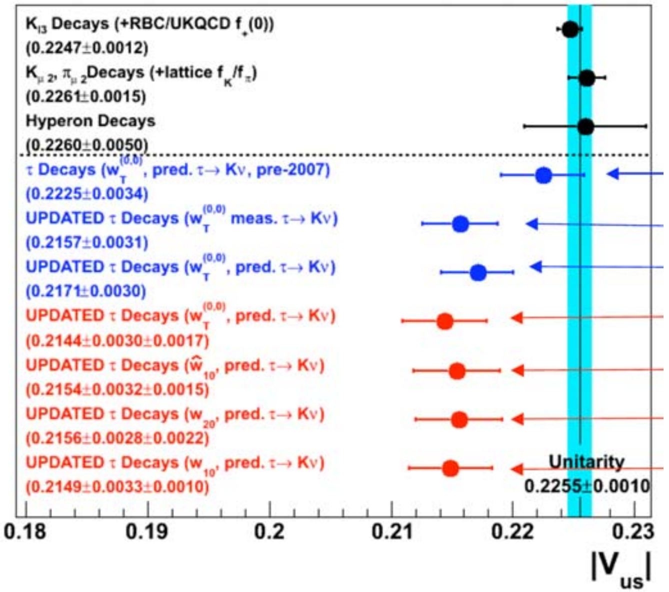


Hadronic τ decays

δR_{OPE} is a small SU(3) breaking correction: $<0.1\times R_{\tau,non-strange}/|V_{ud}|^2$

- R_τ=ratio of hadronic decay rate: $\tau^{\pm}\to e^{\pm}\nu_e\nu_\mu$.
- 9 modes with recent results relevant for this measurement.

3 σ discrepancy from R_τ measurements



(2)
$$\frac{\Gamma(\tau\to K\nu)}{\Gamma(\tau\to\pi\nu)} = \frac{|V_{us}|^2}{|V_{ud}|^2}\frac{f_K^2}{f_\pi^2}\left(\frac{1-m_K^2/m_\tau^2}{1-m_\pi^2/m_\tau^2}\right)^2\left(1+\delta_{RC}^{\tau}\right)$$

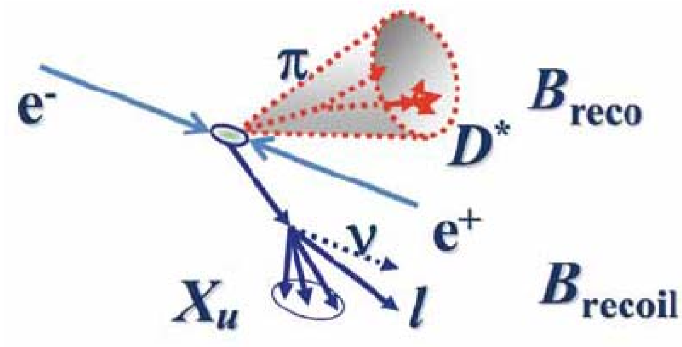
$$\frac{B(\tau^-\to K^-\nu)}{B(\tau^-\to\pi^-\nu)} = 0.06531\pm0.00056\pm0.00093$$

$$|V_{us}| = 0.2255\pm0.0019\pm0.0014$$

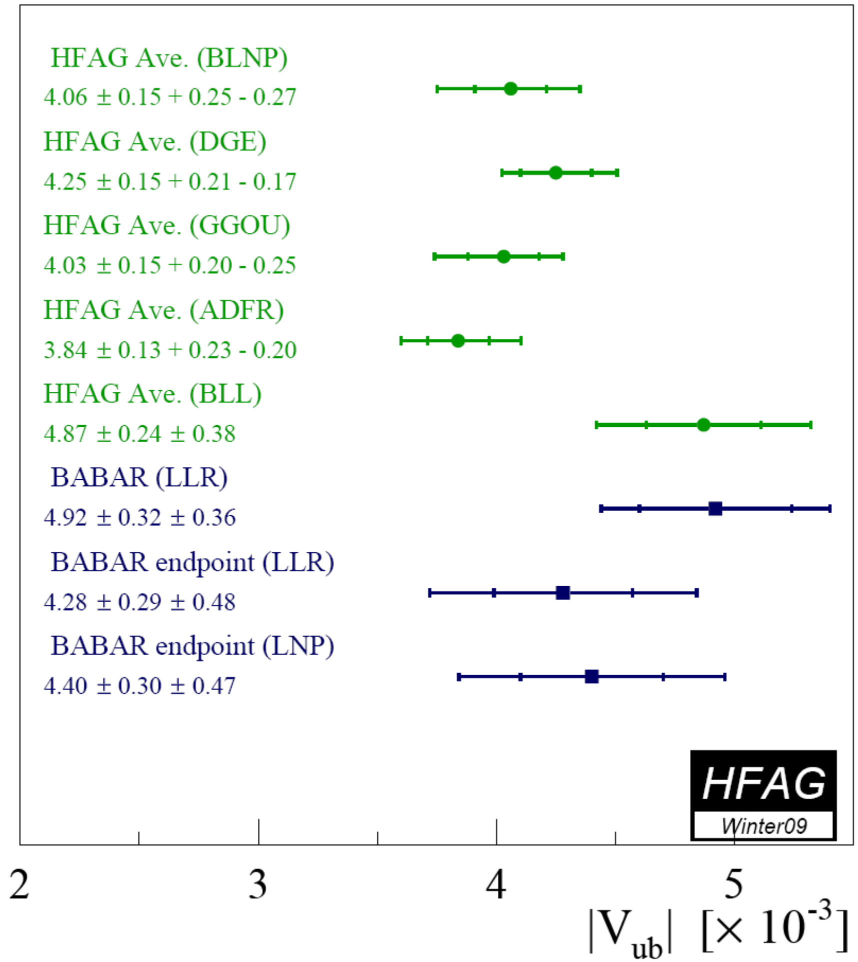
The ratio determination of |Vus| is in good agreement with Unitarity!

V_{ub}

- Inclusive $|V_{ub}|$:
- Use the semi-leptonic decay rate to obtain $|V_{ub}|^2 \propto \mathcal{B}(B \to X_u l \nu)$.
  - Measure as a function of a kinematic quantity: $q^2(\ell\nu), m_X, E_\ell$.

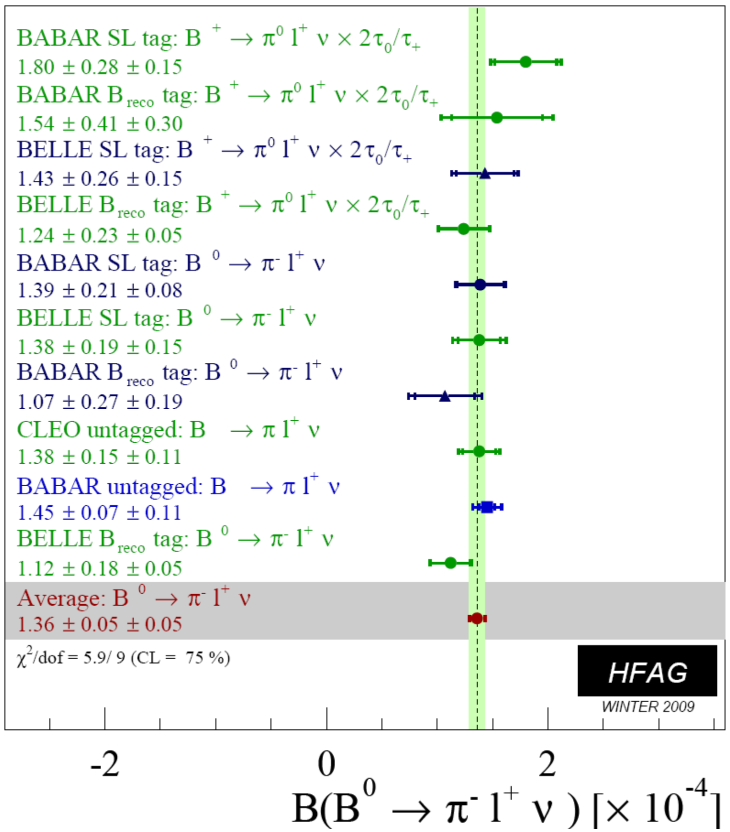


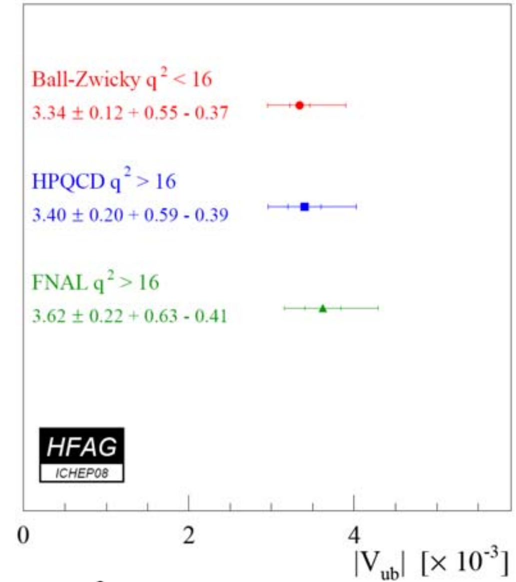
- Interpret measured rate with your favourite theory.
- There are many schemes on the market.
- Results obtained are consistent.
- Can be compared with an exclusively reconstructed X_u system (π, ρ, etc.).

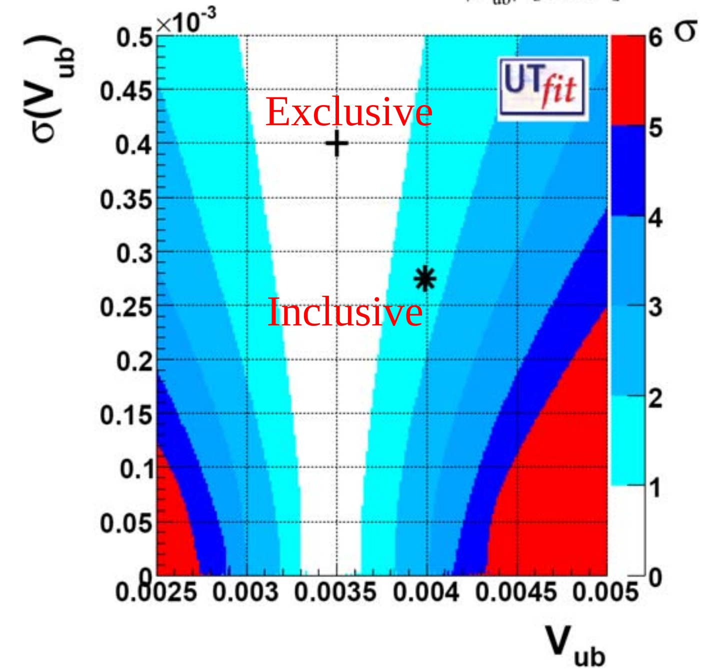


V_{ub}

- Exclusive $|V_{ub}|$:
  - Tension exists between inclusive and exclusive results.





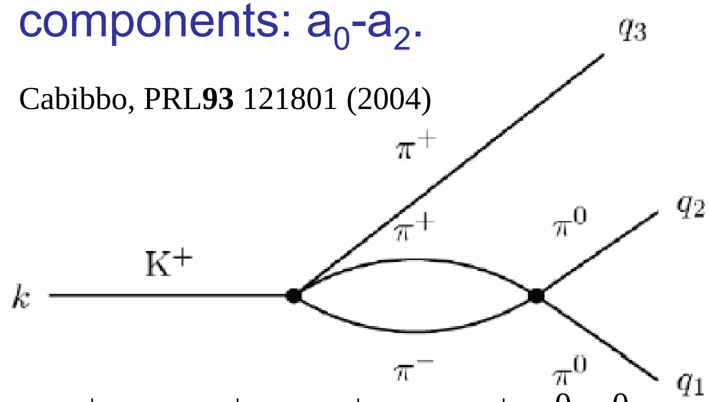


- Small tension between $|V_{ub}|$ and $\sin 2\beta$ persists: $\sim 1.5\ \sigma$.

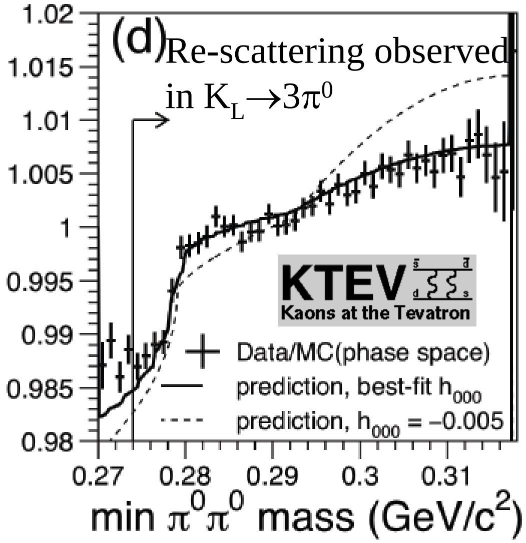
KTeV and NA48/2: ππ scattering

- Use the $m_{\pi^0\pi^0}$ distribution in 3π decay to measure re-scattering lengths between I=0 and I=2 components: a_0-a_2.

Cabibbo, PRL**93** 121801 (2004)

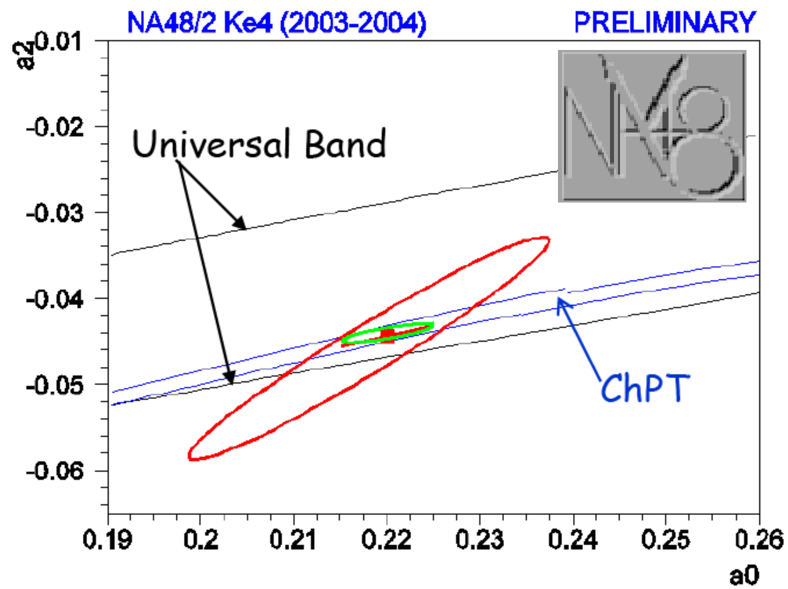


$$K^+ \to \pi^+\pi^-\pi^+ \to \pi^+\pi^0\pi^0$$



PRD 78 032009 (2008)

- NA48-2 have results on 3π and $K^+ \to \pi^+\pi^- e^+\nu$.
- Again parameterize I=0,2 scattering lengths: a_0 and a_2.



- Impressive statistics: 1.1M Ke4, and 60M 3π decays.
- Scattering lengths measured in perfect agreement with χPT.

KTeV: Blucher; NA48-2: Bloch @ Kaon '09

KTeV and NA48/2: ππ scattering

KTEV Kaons at the Tevatron

2. Floating both h_{000} and a_0-a_2:

$$h_{000} = (-2.09 \pm 0.62_{stat} \pm 0.72_{syst} \pm 0.28_{ext}) \times 10^{-3} = (-2.09 \pm 0.99) \times 10^{-3}$$

$$m_{\pi^+}(a_0 - a_2) = 0.215 \pm 0.014_{stat} \pm 0.025_{syst} \pm 0.006_{ext} = 0.215 \pm 0.031$$

$$\chi^2 / dof = 2790.6 / 2764 \text{ (all pixels)}$$

$$\chi^2 / dof = 126.3 / 130 \text{ (edge pixels)}$$

ChPT (Colangelo et al.): $m_{\pi^+}(a_0 - a_2) = 0.265 \pm 0.004$

ChPT best prediction $a_0 = 0.220 \pm 0.005$, $a_2 = -0.0444 \pm 0.0008$, $a_0-a_2 = 0.264 \pm 0.004$

(ChPT cusp) $a_0-a_2 = 0.2633 \pm 0.0024_{stat} \pm 0.0014_{syst} \pm 0.0019_{ext} \pm 0.0053_{th}$

(ChPT Ke4) $a_0 = 0.2206 \pm 0.0049_{stat} \pm 0.0018_{syst} \pm 0.0064_{th}$

(ChPT combined) $a_0 = 0.2196 \pm 0.0027_{stat} \pm 0.0021_{syst} \pm 0.0048_{th}$

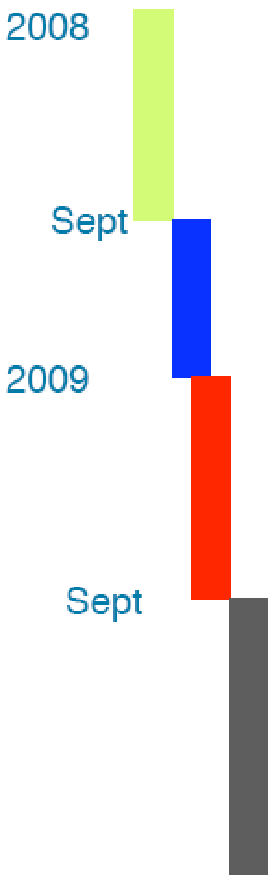
$a_2 = -0.0444 \pm 0.0007_{stat} \pm 0.0005_{syst} \pm 0.0012_{th}$

$a_0 - a_2 = 0.2640 \pm 0.0020_{stat} \pm 0.0017_{syst} \pm 0.0035_{th}$

- KTeV and NA48-2 agree well on the observed level of ππ re-scattering in K→3π decays.
- Excellent agreement with expectations from χPT.

KTeV: Blucher; NA48-2: Bloch @ Kaon '09

Timeline of MEG



-2008.sep : R&D, Installation, calibration and engineering runs (+ very few physics data)

2008.sep : Physics data taking

2009 : Analysis of 2008 data

2009.sep-2011? : Physics data taking

Now, we are working for analysis of 2008 data, and hardware upgrades for 2009 run

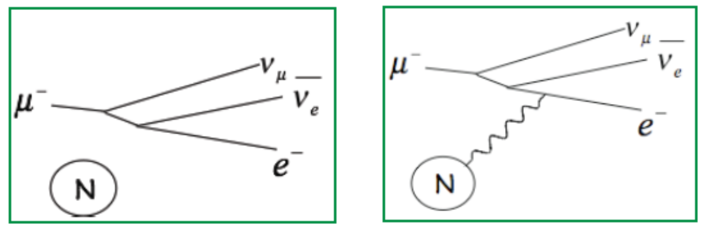
μ→e conversion

Mu2e in One Page

- Make muonic Al.
- Watch it decay:
  - Decay-in-orbit (DIO): 40%
    - Continuous E_e spectrum.
  - Muon capture on nucleus: 60%
    - Nuclear breakup: p, n, γ
  - Neutrino-less μ to e conversion
    - Mono-energetic $E_e \approx 105$ MeV
    - At endpoint of continuous spectrum.
- Measure E_e spectrum.

Bohr radius ≈ 20 fm
Al nuclear radius ≈ 4 fm
Lifetime: 864 ns

Decay-in-Orbit: Dominant Background



1.5×10^{-15} DIO e⁻ are with 2 MeV of endpoint.