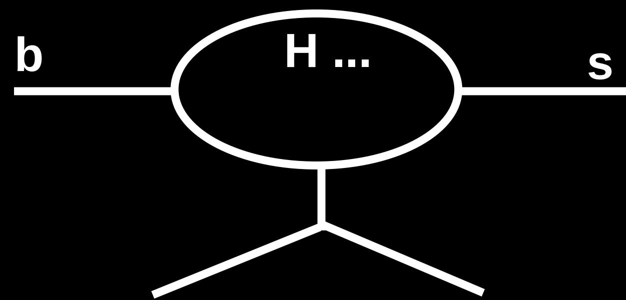
The Super Flavor Factory

B_u B_d B_s D τ ...

Probing the terascale



Adrian Bevan

9th November 2006

Queen Mary
University of London

Outline

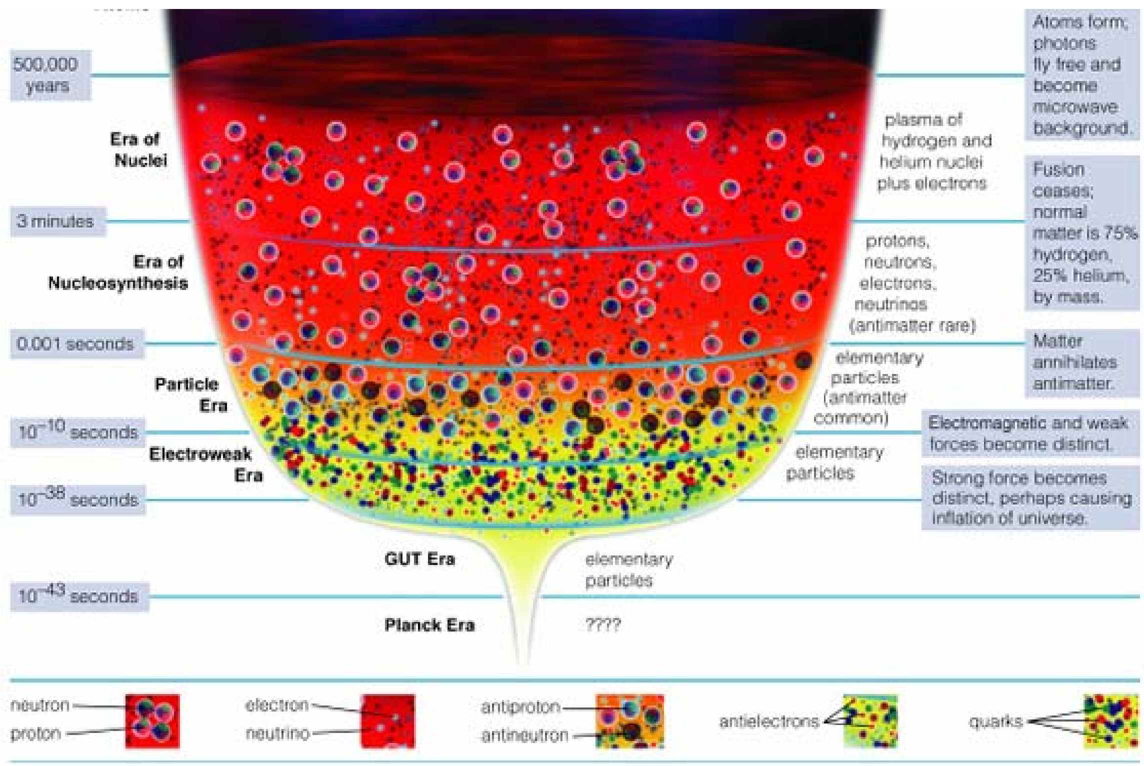
- Motivation
- Recent Activity
- The Luminosity Frontier
  - Studies of $B_{u,d}$ decays
  - Running at the $\Upsilon(5S)$: B_s decays
  - Potential for charm
  - Lepton Flavor Violation in τ decay
  - Testing Lepton Universality & studying dark matter.
- Detector concepts
- Accelerator design and R&D
- Complimentarity
- Next Steps
- Summary

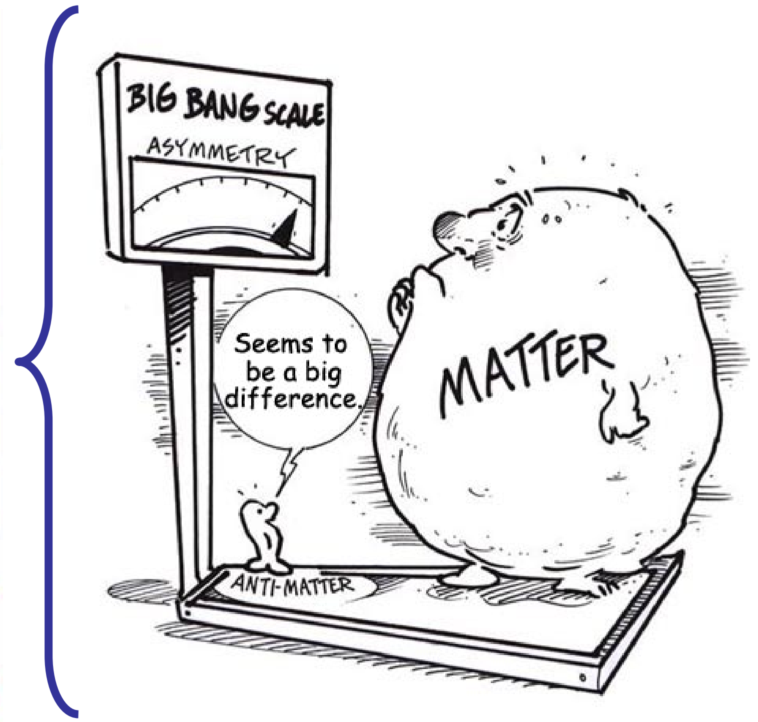
This talk covers a fraction of the total physics accessible to a Super Flavor Factory…

… and a quick tour of current accelerator designs/parameters

Motivation 1/2

- What fundamental questions are we looking to answer with a Super Flavor Factory (SFF)?

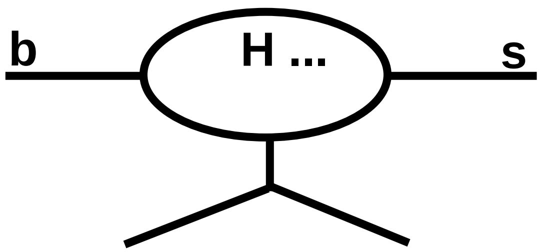




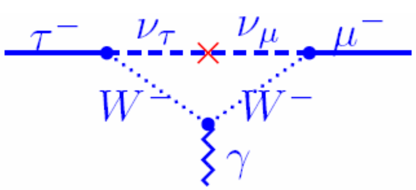
- Why is our universe matter dominated?

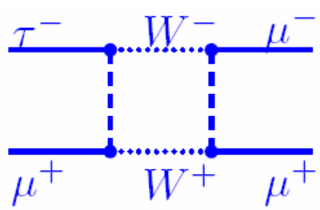
Motivation 2/2

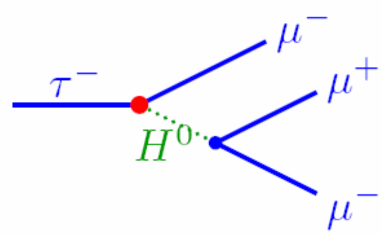
- How can we learn about the flavor physics of the mass generation mechanism and BSM particles?
  - Through penguin loops and FCNC.
  - Precision studies of rare loop/FCNC dominated processes. i.e. TeV scale interferometry of virtual particles in loops.

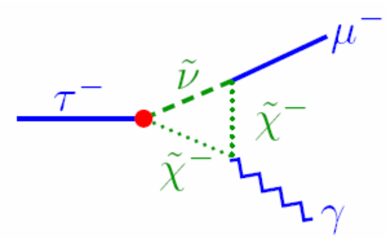


- Search for LFV enhancements.





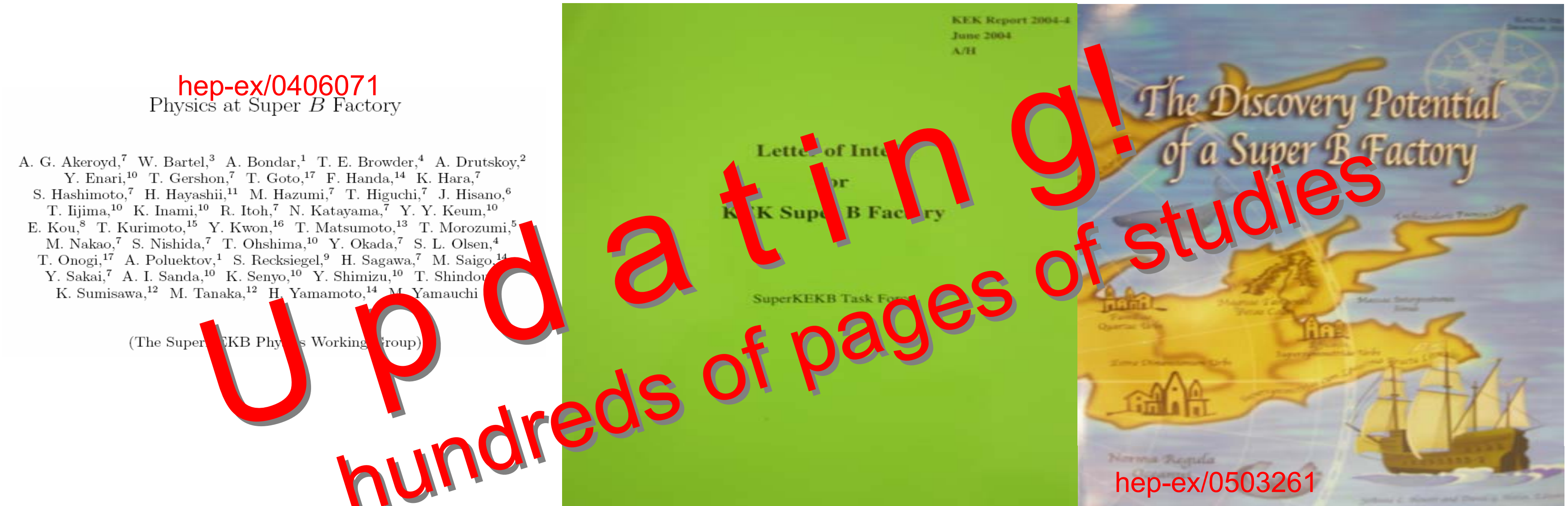




- …

A lot of recent activity in the field

hep-ex/0406071



hep-ex/0503261

Updating!

hundreds of pages of studies

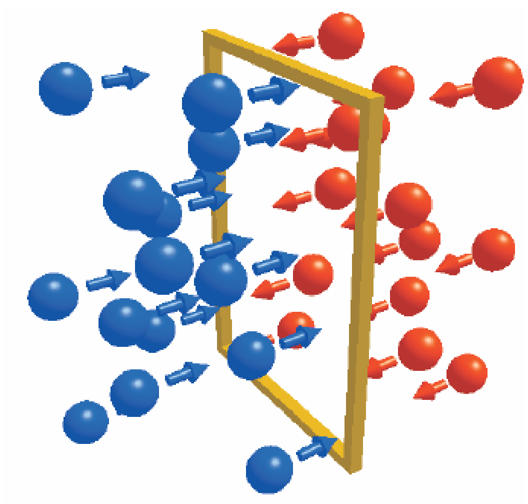
- Many recent workshops at SLAC, KEK, Frascati, ITEP and elsewhere.
- Strong collaboration on MDI.
- many reports at recent conferences: FPCP, EPAC, ICHEP...

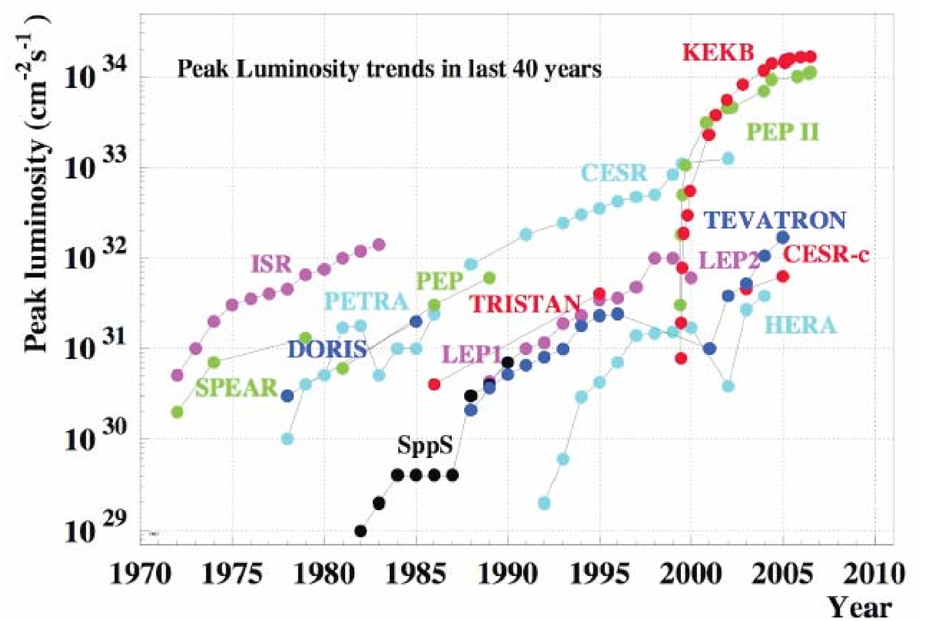
More details can be found at:

http://belle.kek.jp/superb/
http://www.pi.infn.it/SuperB/

The Luminosity Frontier

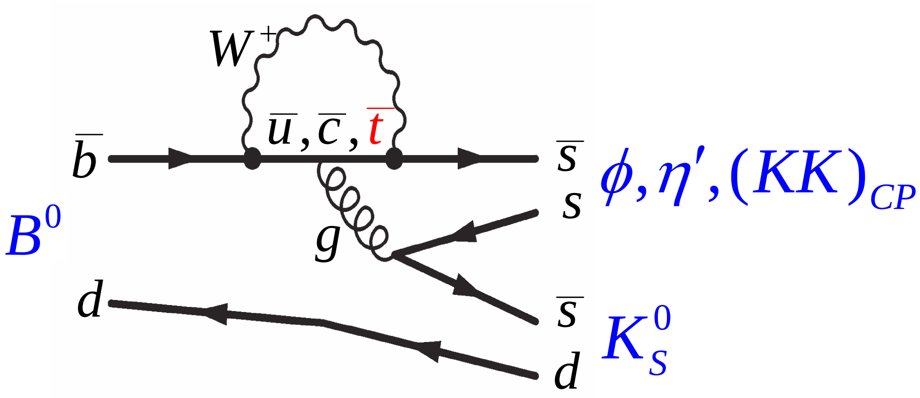
- The current generation of experiments have pushed back our understanding of Flavor Physics.
- All measurements of the CKM mechanism are compatible with the SM.
- Deviations, if any must be smaller than current constraints.
- We know that there is a gap in our knowledge from Cosmology.
- Need more precision (more luminosity) to push back our understanding of the CKM mechanism, and its equivalent BSM.



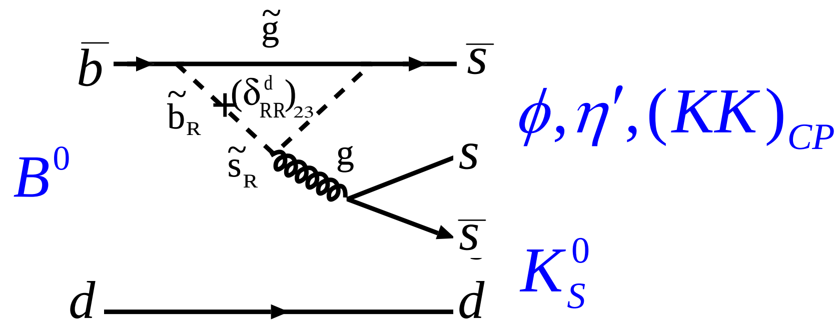


Probing new physics at the $\Upsilon(4S)$

- Time dependent CP asymmetry measurements can constrain possible NP contributions.

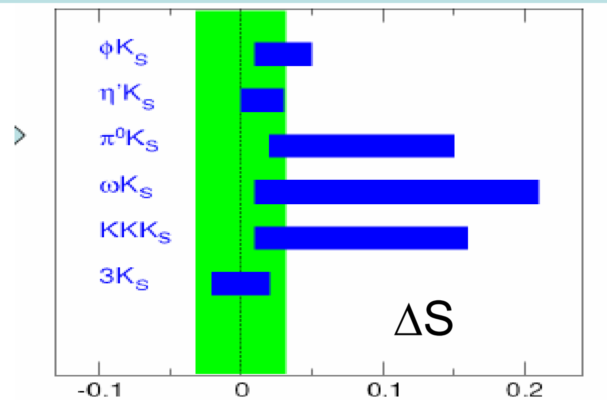


SM: measure β



New phases from SUSY?

- ΔS-sin2β≠0 signals NP.
- SM Deviations from sin2β from J/ψK_s are mode dependent.
- Need interaction with theorists.



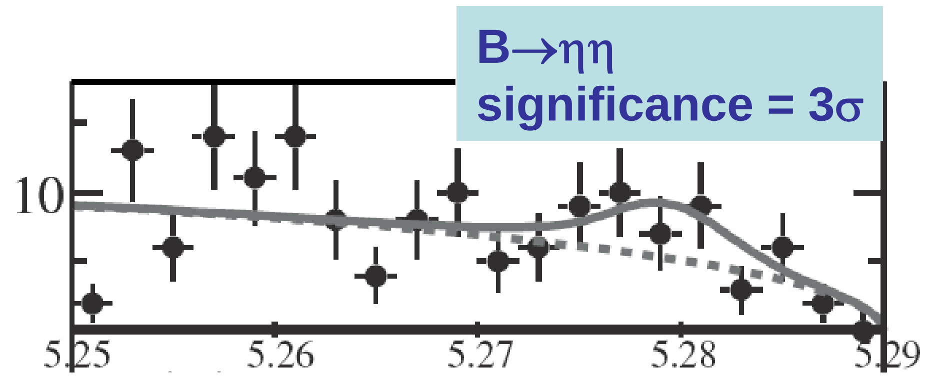
QCDF: (Beneke, PLB620 (2005). 143-150, Cheng et al., PRD72 (2005) 094003 etc.
SCET: (Williamson & Zupan, hep-ph/0601214)
Can estimate ΔS and mostly see a positive shift.

SU(3): Grossman *et al*, PRD68 (2003) 015004; Gronau *et al*, PRD71 (2005) 074019; …).

Standard Model corrections to ΔS

- Can use $B\to\eta\eta$, $\eta'\eta'$, $\eta'\eta$, $\eta'\pi^0$, $\eta\pi^0$ to bound $\Delta S = \sin 2\beta - \sin 2\beta_{eff}$ in the golden s-penguin modes $B\to\eta' K^0$ and ϕK^0.
- All final states have neutrals to reconstruct.

$$B(\eta\eta) = (1.1^{+0.5}_{-0.4} \pm 0.1)\times 10^{-6}$$
$$B(\eta'\eta') < 2.4\times 10^{-6}$$
$$B(\eta'\eta) < 1.7\times 10^{-6}$$
$$B(\eta\pi^0) < 1.3\times 10^{-6}$$
$$B(\eta'\pi^0) < 2.1\times 10^{-6}$$



PRD **73** 071102 (2006)
PRD **74** 051106 (2006)

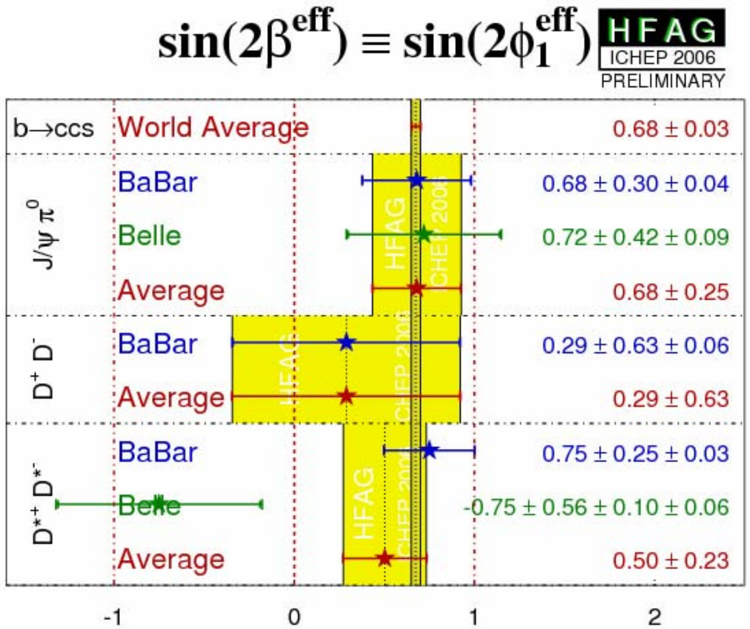
- SM bound is sub 0.1, and a little larger than experimental precision.

$$-0.046 < \Delta S(\eta' K^0) < 0.094$$
$$|\Delta S(\phi K^0)| < 0.38$$

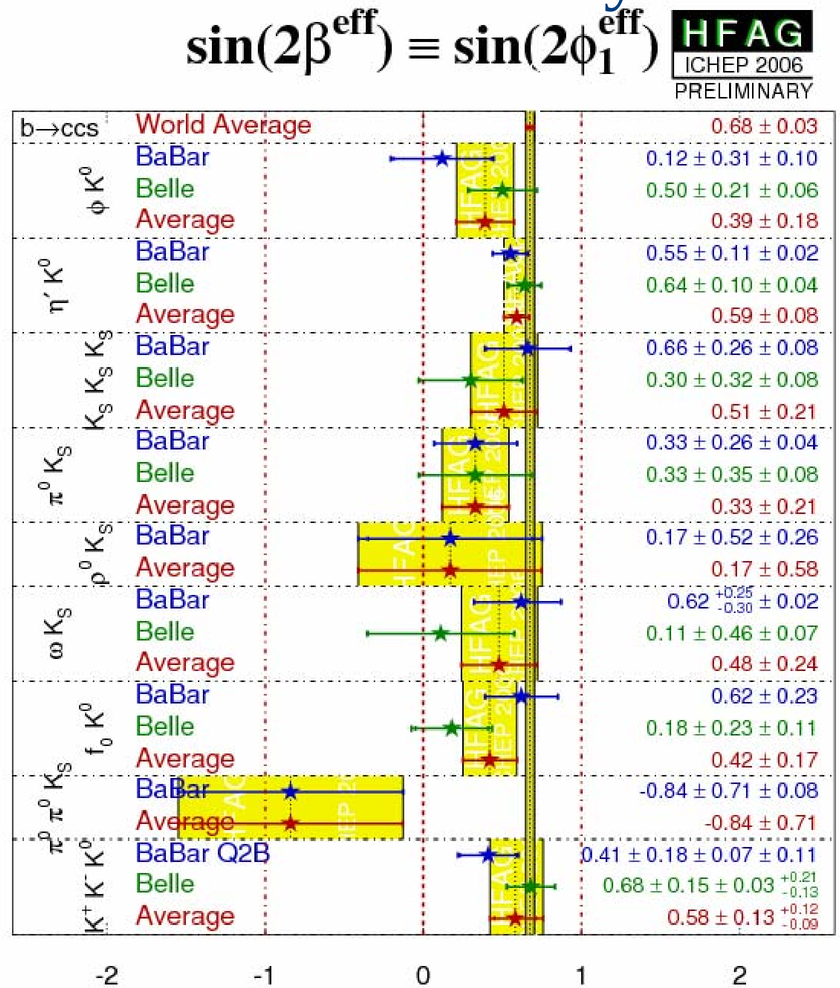
e.g. see Gronau et al., hep-ph/0608085

Current constraints on ΔS

$b \to c\bar{c}d$ decays



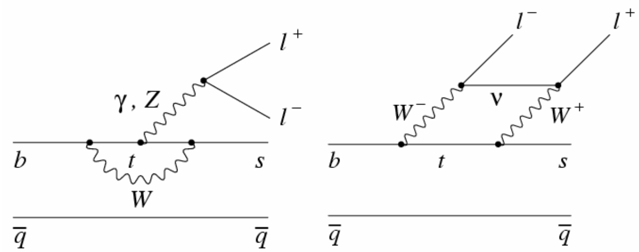
$b \to c\bar{c}s$ decays



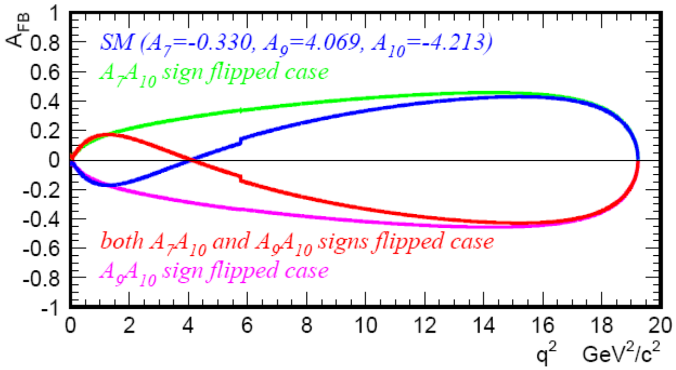
- ΔS is consistent with zero for $c\bar{c}s$ and $c\bar{c}d$ decays.
- However the average for ccs decays is 2.6σ away from sin2β.
- Need a SFF to elucidate this intriguing pattern.

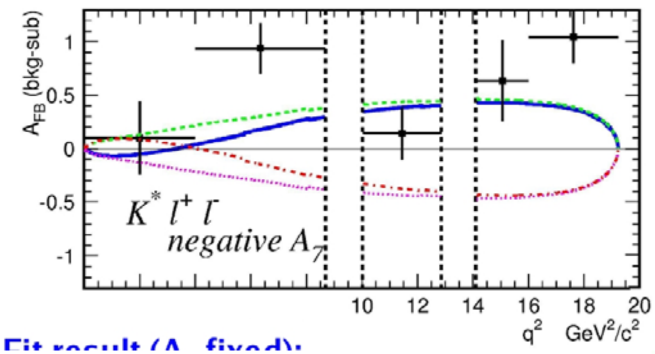
Examples of probing new physics at the $\Upsilon(4S)$

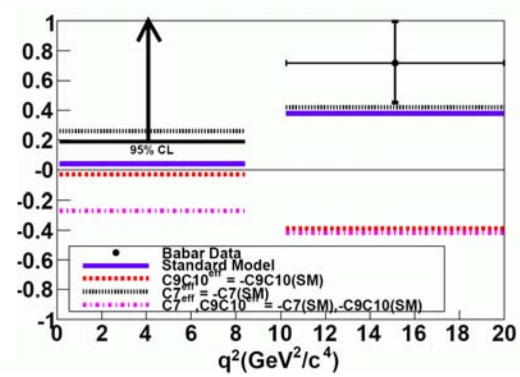
- Kinematic distribution in B→K*ll sensitive to new physics in loops.



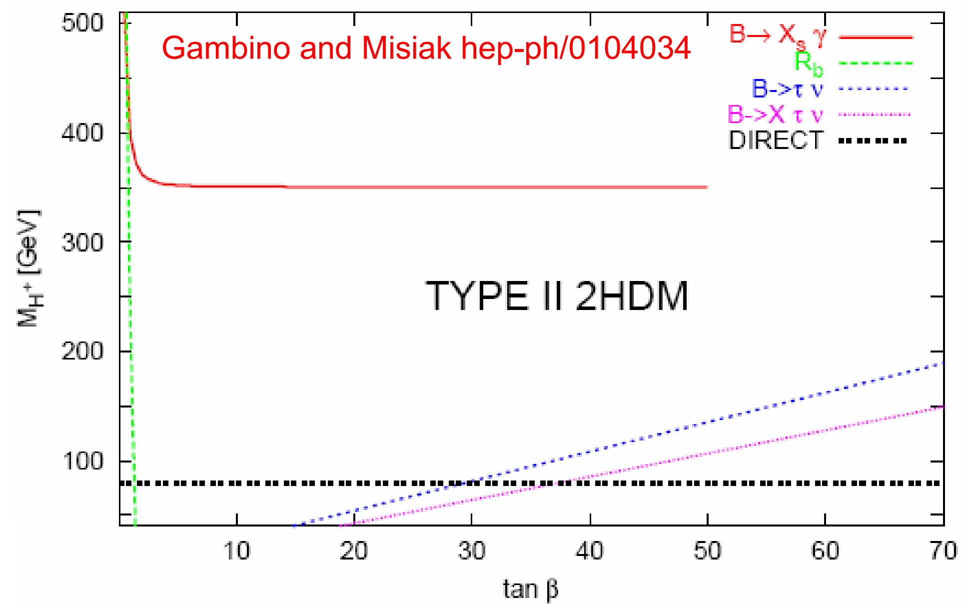
Latest Experimental Results:
PRL 96 (2006) 251801
hep-ex/0507005





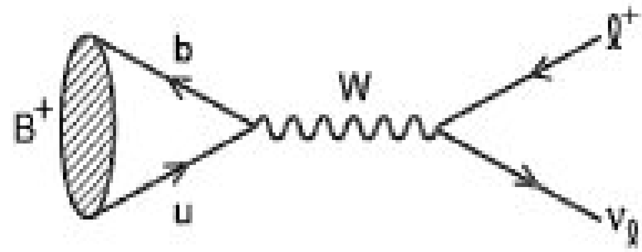


- B→K*γ can be a more stringent constraint than direct searches at colliders.
- This trend continues for LHC vs SFF.



$B^+ \to \tau^+ \nu$

- Supressed by V_{ub} in the SM
- Can replace W^+ with H^+



SM prediction
$(1.59 \pm 0.40) \times 10^{-4}$
(depends on f_B and V_{ub})

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

- Difficult measurement: missing the ν.

BELLE: tag with fully reconstructed B mesons (180 channels) (revised). 3.5 σ significance

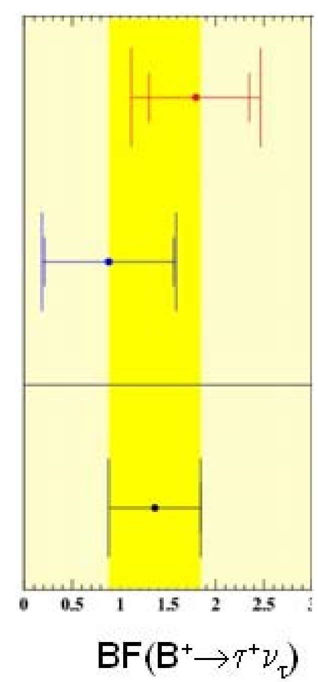
$$\mathrm{BF}(B^+ \to \tau^+ \nu_\tau) = (1.79^{+0.56+0.39}_{-0.49-0.46}) \times 10^{-4}$$

BABAR (new) Tag with $B \to D(^*) l \nu$

$$\mathrm{BF}(B^+ \to \tau^+ \nu_\tau) = (0.88^{+0.68}_{-0.67} \pm 0.11) \times 10^{-4}$$

BF<1.80@90%CL

Averaged (1.36 ± 0.48)x10-4

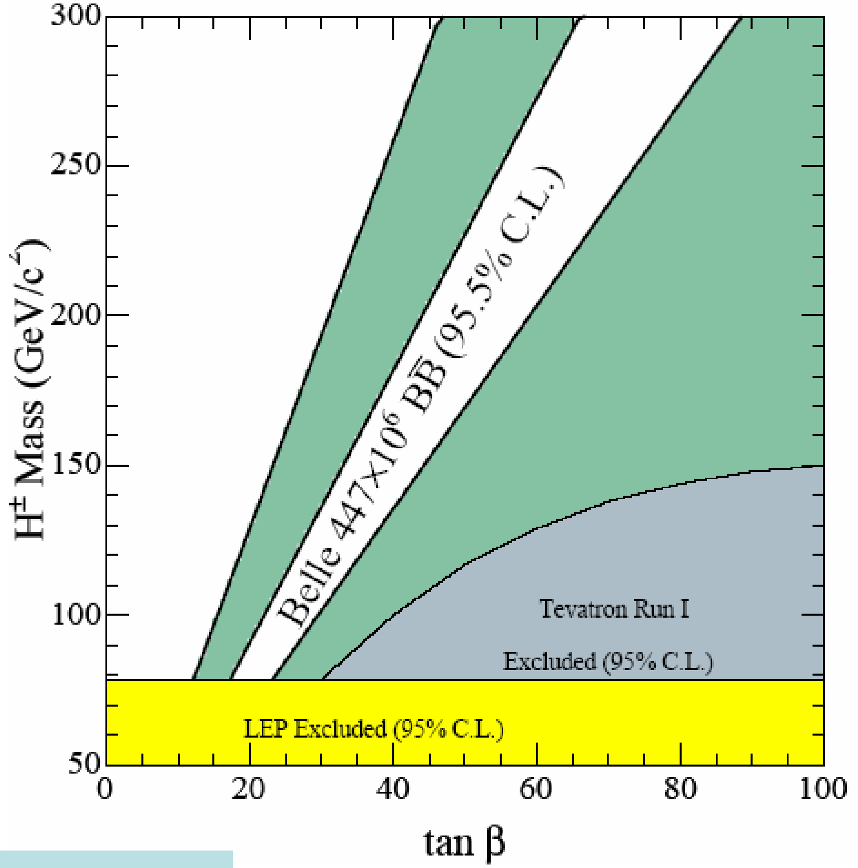


Constraints from $B^+ \to \tau^+ \nu$

- Provides limits: e.g. the 2HDM of W.S. Hou, PRD **48**, 2342 (1993).
- SM prediction can be enhanced/reduced by a factor r_H:

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

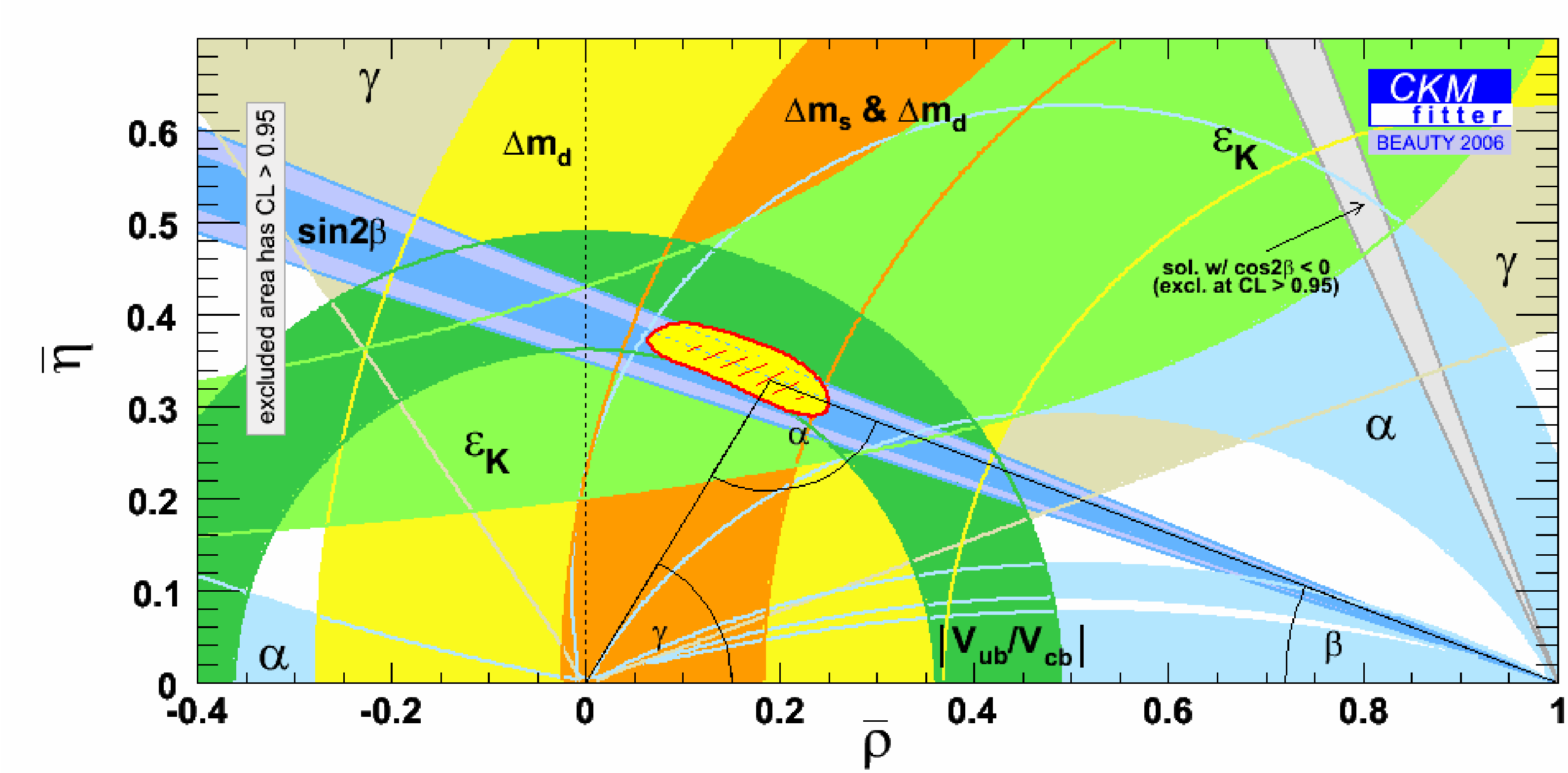
- Within the SM we can use this measurement to constrain f_B.



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

Elucidating the CKM mechanism

- With 0.8 ab^{-1} of data (combining both experiments)



Stat of the art in CKM Metrology today

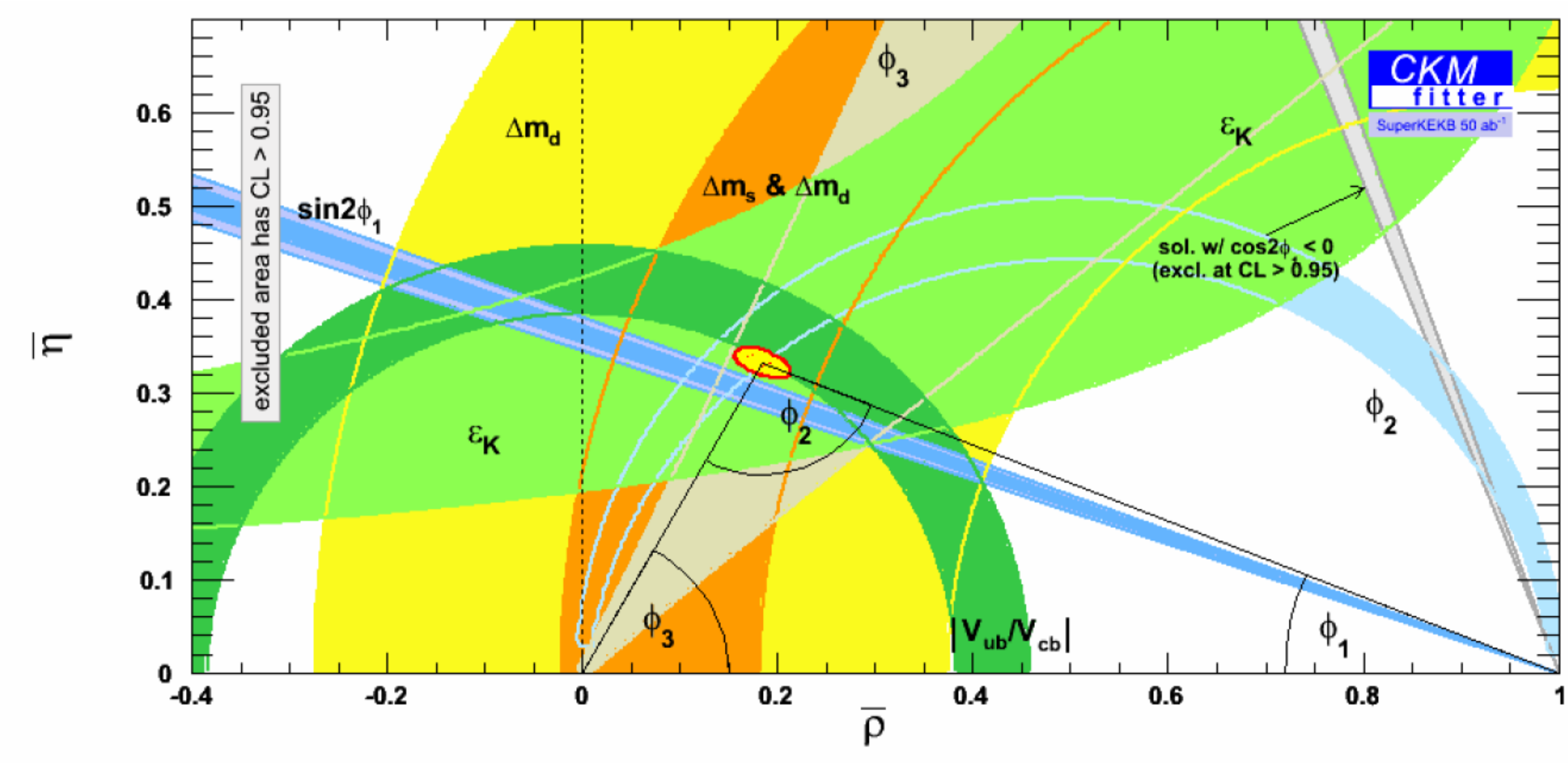
$$\alpha \sim 10^\circ$$

$$\beta \sim 0.7^\circ$$

$$\gamma \sim 10^\circ$$

Elucidating the CKM mechanism

- With 50 ab^{-1} of data we can expect precision over-constraint of the UT!



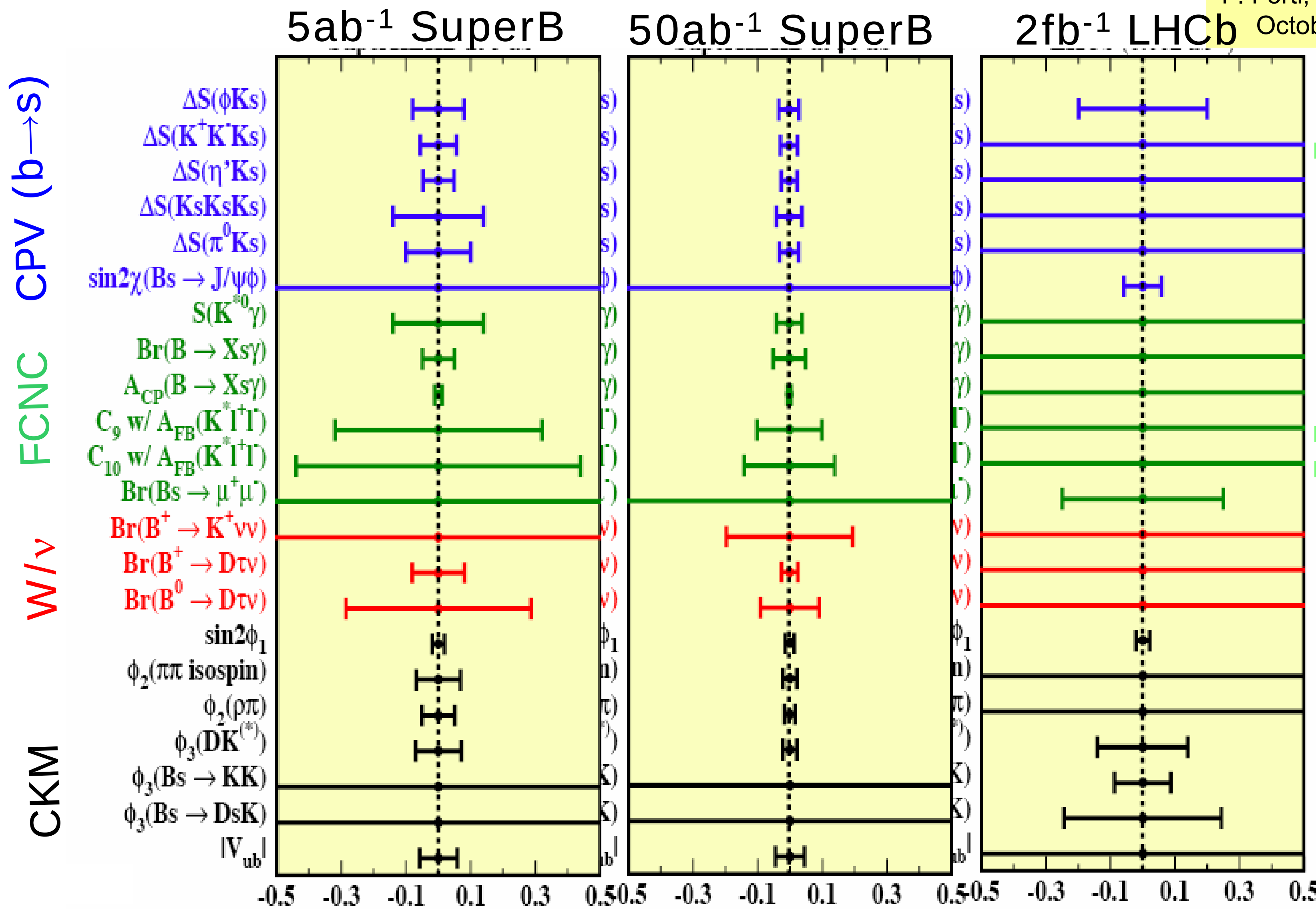
CKM Metrology with unprecedented precision

$$\alpha \sim 2^\circ$$
$$\beta \sim 0.012$$
$$\gamma \sim 2^\circ$$

$$V_{ub}(\text{inclusive}) \sim 6.1\%$$
$$V_{ub}(\text{exclusive}) \sim 5\%$$

Projected Sensitivities

Projections from
F. Forti, CERN WS
October 2006



N.B. Uses old LHC-b projections and only comparing with 2fb-1 from LHC-b!

The SFF gives the best NP reach in a wide range of measurements!
Also provides a number of ancillary measurements to pin down theory.

Projected Sensitivities for Upgraded LHC-b

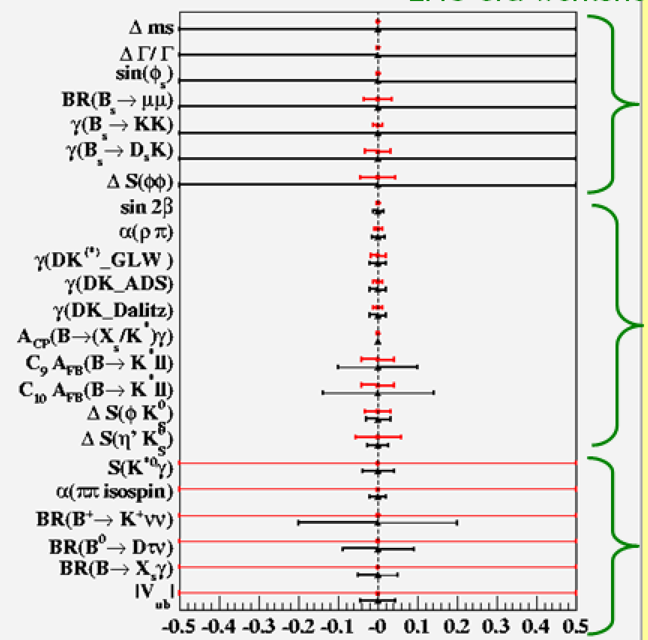
Comparison with Super-B factory

LHCb

Sensitivity Comparison ~2020

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

M Hazumi - Flavour in LHC era workshop



~~B_s only accessible at LHCb~~

W R O N G!

Common

No IP Neutrals, ν

Preliminary

Beauty 2006 Oxford, 29 Sept 2006 F. Muheim

- Some BS results will only come from LHC-b.
- Some BS results will only come from SFF!
- Some overlap exists in the physics coverage of both experiments.

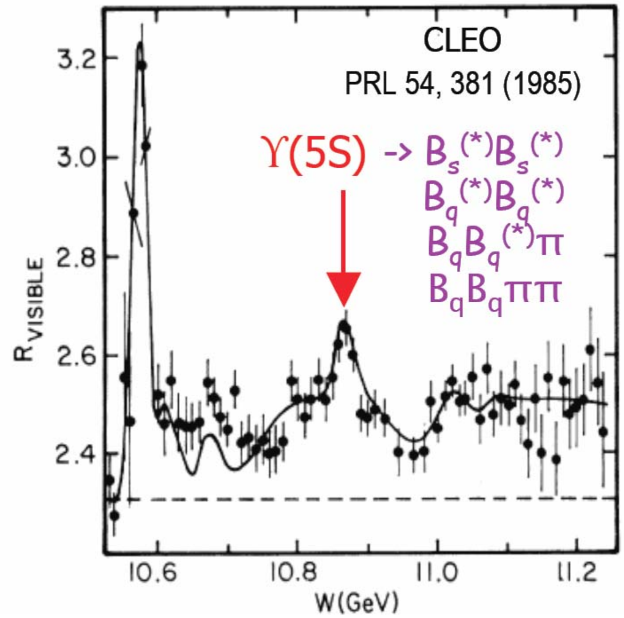
Running at Υ(5S)

- $e^+e^- \to \Upsilon(5S)$ creates mostly $B^*_s B^*_s$.
- Belle have recorded 23.6fb^{-1} at the 5S.
- e.g. $B_s \to \gamma\gamma$, $\phi\gamma$ are unique probes beyond the SM that are available at a SFF.
- Testing the ratio

$$\frac{BR(B_s \to K^*\gamma)}{BR(B_s \to \phi\gamma)} = \frac{V_{td}}{V_{ts}} \frac{1}{\xi^2}$$

SU(3) breaking term from Lattice QCD & sum rules

can constrain new physics in loops.



- Semileptonic decays $B_s^{\pm} \to l^{\pm}X$ can be used to constrain possible new physics.
- Measure $\Delta\Gamma/\Gamma$ using $B_s \to D_s^{(*)} D_s^{(*)}$ decays. $\Delta\Gamma/\Gamma$ ~O(10%) in the SM.
- + reach of TDCPV measurements under study.

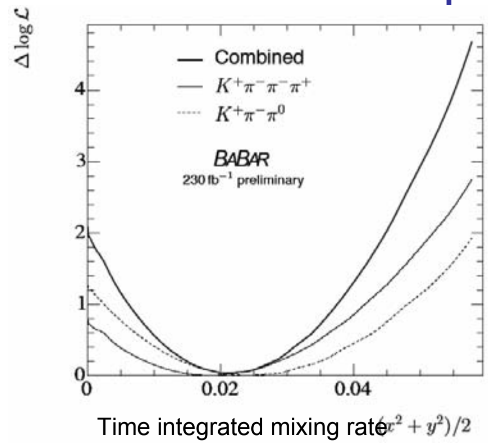
(see proceedings of BNM2006: Pierini, Drutskiv), and hep-ex/0608015.

Charm physics

e.g. see Bigi, hep-ph/0608225

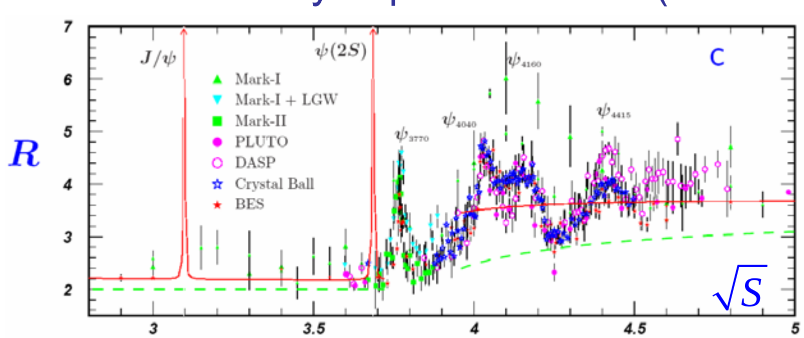
- Charm sector is unique: only up type quark to give access to the full range of NP effects.
- Provides tools to validate QCD and theoretical tools B-physics studies.
- Search for D^0-$\bar{D}^0$ mixing.
  - Box diagram contribution is small.
  - long distance effects can dominate.

$$x \equiv 2\frac{m_B - m_A}{\Gamma_B + \Gamma_A}, \qquad y \equiv \frac{\Gamma_B - \Gamma_A}{\Gamma_B + \Gamma_A}$$



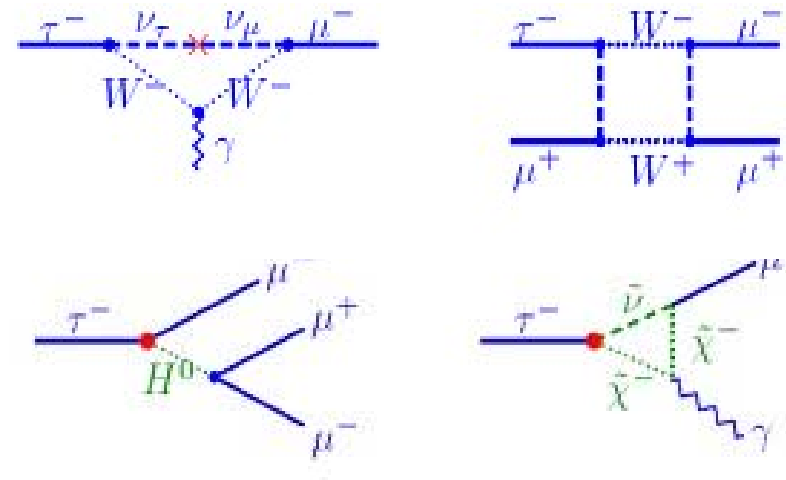
Results consistent with no mixing at 2.1% C.L.

- Search for CPV in D decay.
  - Rich structure in D→PP, PV, VV decays (c.f. B decays).
    - $\Delta C=1$ and $\Delta C=2$ transitions.
    - VV decays sensitive to T-odd triple products and provide windows on the dynamics of the processes involved.
    - Time dependent Dalitz plots needed to fully exploit this area (c.f. $B\to\pi^+\pi^-\pi^0$).
- Charm baryons.
  - Λ_c branching fractions.
- precision R scan.
- ...



LFV in $\tau \rightarrow l\gamma$

- The B-factories are τ factories.
- $\sigma(\tau^+\tau^-)=0.89$ nb at $\Upsilon(4S)$
- $N_\tau=1.5\times10^9$



90% confidence levels:

Belle:

$$\mathcal{B}(\tau \rightarrow e\gamma) < 12\times10^{-8}$$

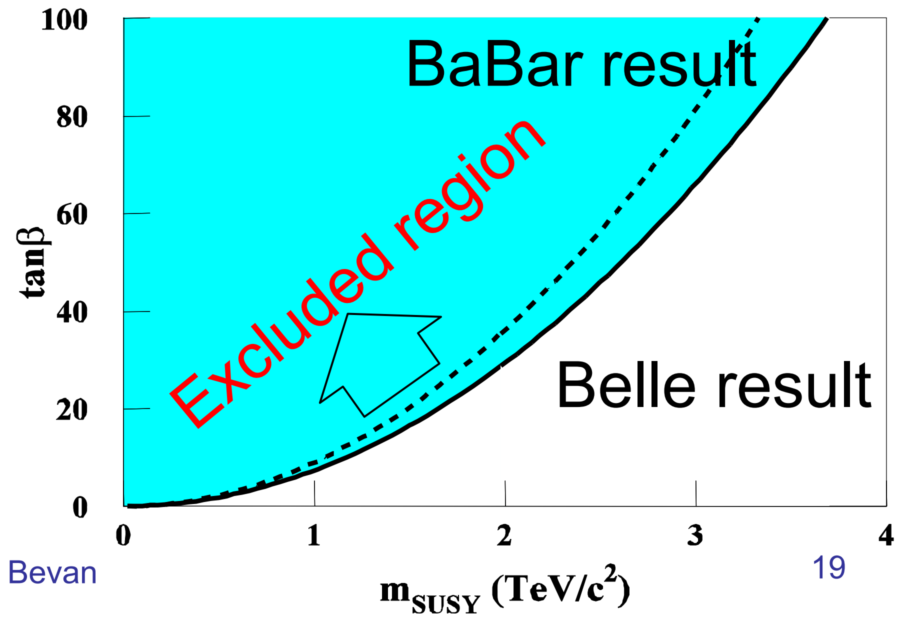
$$\mathcal{B}(\tau \rightarrow \mu\gamma) < 4.1\times10^{-8}$$

BaBar:

$$\mathcal{B}(\tau \rightarrow e\gamma) < 11\times10^{-8}$$

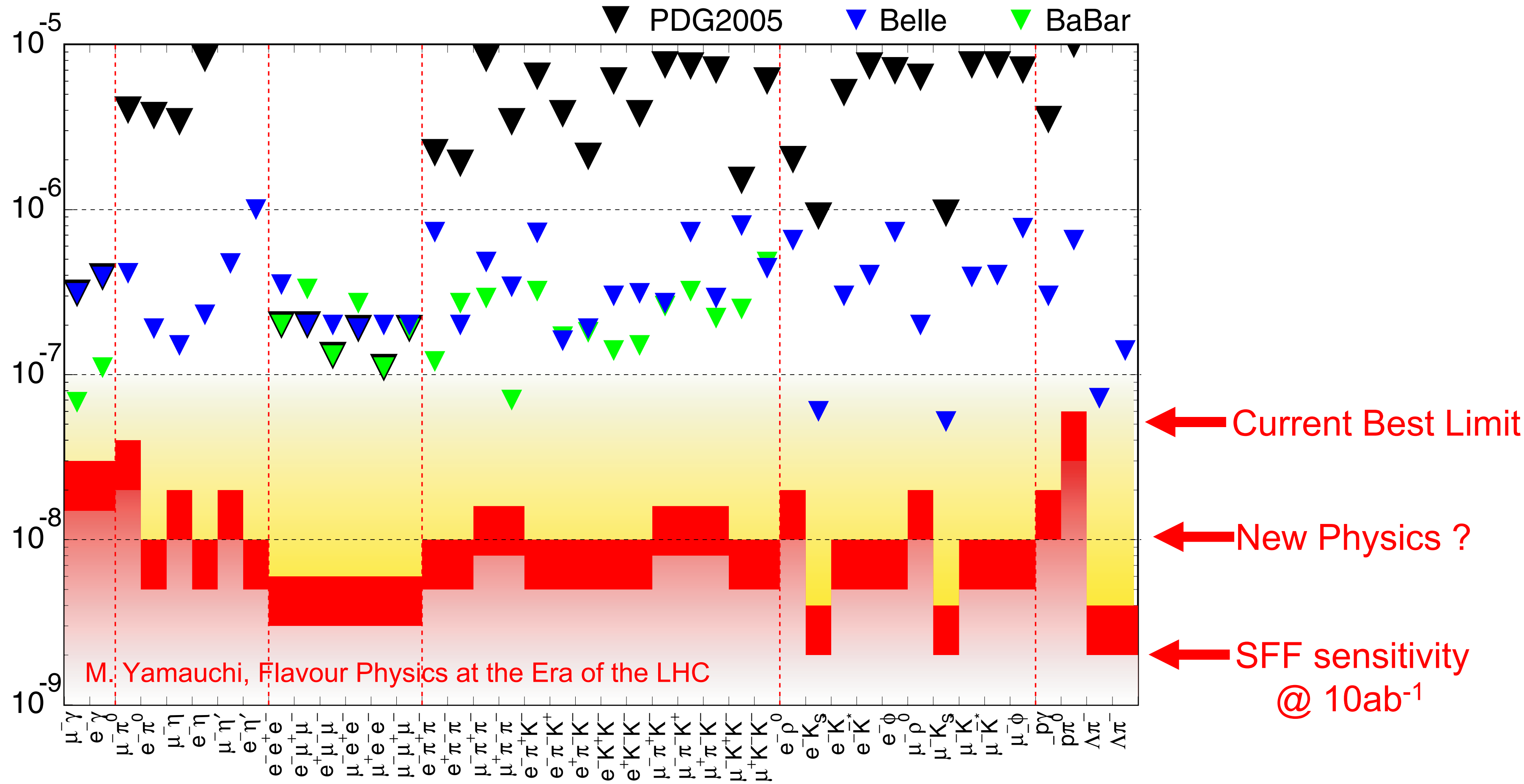
$$\mathcal{B}(\tau \rightarrow \mu\gamma) < 6.7\times10^{-8}$$

$$Br(\tau \rightarrow \mu\gamma) = 3.0\times10^{-6}\times\left(\frac{\tan\beta}{60}\right)^2\times\left(\frac{M_{SUSY}}{1\text{TeV}}\right)^{-4}$$



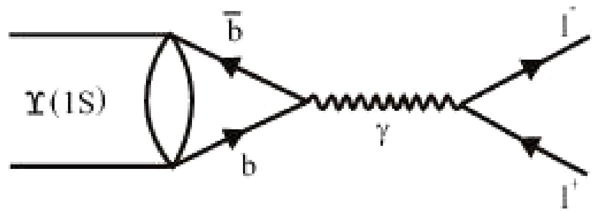
LFV in τ lepton decay

- Search for LFV with 50 fold increase in statistics at a SFF.
- SUSY breaking at low energies should result in large FCNC [e.g. $\tau \to \mu\gamma$, $\mu \to e\gamma$].



Test Lepton Universality

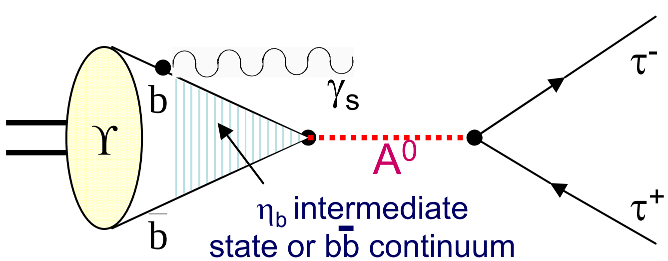
- Use Y(3S) decays to test lepton universality



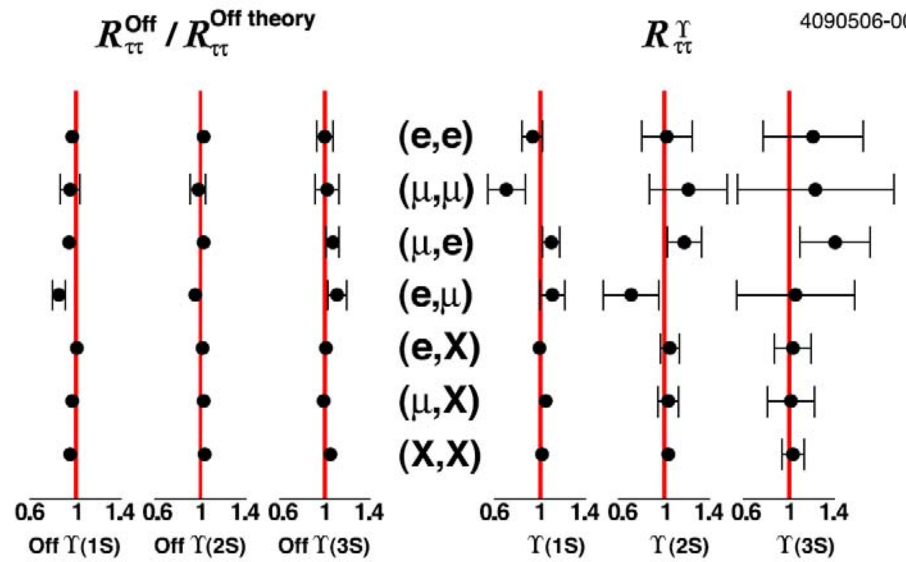
$$R_{\tau/\ell} = \frac{\Gamma_{\Upsilon(nS)\to\gamma_s\tau\tau}}{\Gamma^{(em)}_{\ell\ell}} = \frac{B_{\tau\tau} - B_{\ell\ell}}{B_{\ell\ell}} = \frac{B_{\tau\tau}}{B_{\ell\ell}} - 1$$

= 0 if lepton universality holds

- Light H and H doublets can break universality.



- Current experimental data is from CLEO:



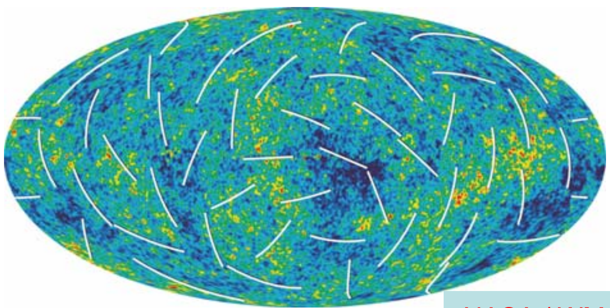
- The data are consistent at a level of 2.6σ with LU.
- Precision of this test is O(10%).
- SFF could perform a precision test of LU.

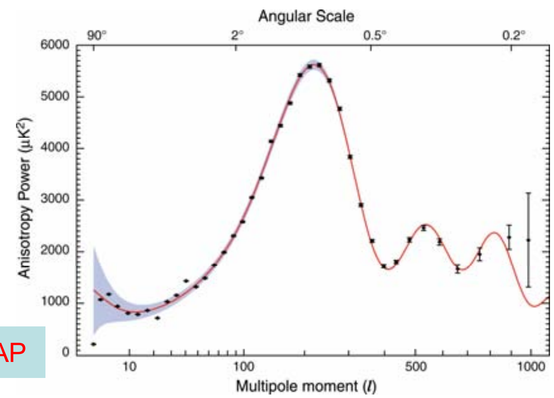
M. A. Sanchis-Lozano, hep-ph/0610046, hep-ph/0510374, Int. J. Mod. Phys. A19 (2004) 2183

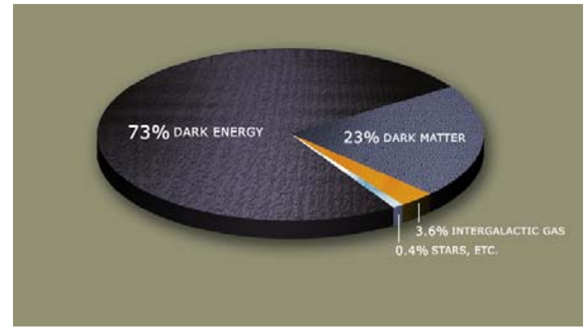
CLEO: hep-ex/0607019

Study Dark Matter

- Dark matter consitutes ~1/4 of of the energy in the universe:







NASA / WMAP

- Most models have a SM-dark matter interaction that can be probed by experiment:

$$
\begin{array}{rl}
\Upsilon \rightarrow invisible & J/\Psi \rightarrow invisible \\
\eta \rightarrow invisible & \Upsilon \rightarrow \gamma + invisible \\
B^+ \rightarrow K^+ + invisible & \Upsilon \rightarrow \gamma A_1, A_1 \rightarrow \tau^+\tau^- \\
K^+ \rightarrow \pi^+ + invisible & J/\Psi \rightarrow \gamma A_1
\end{array}
$$

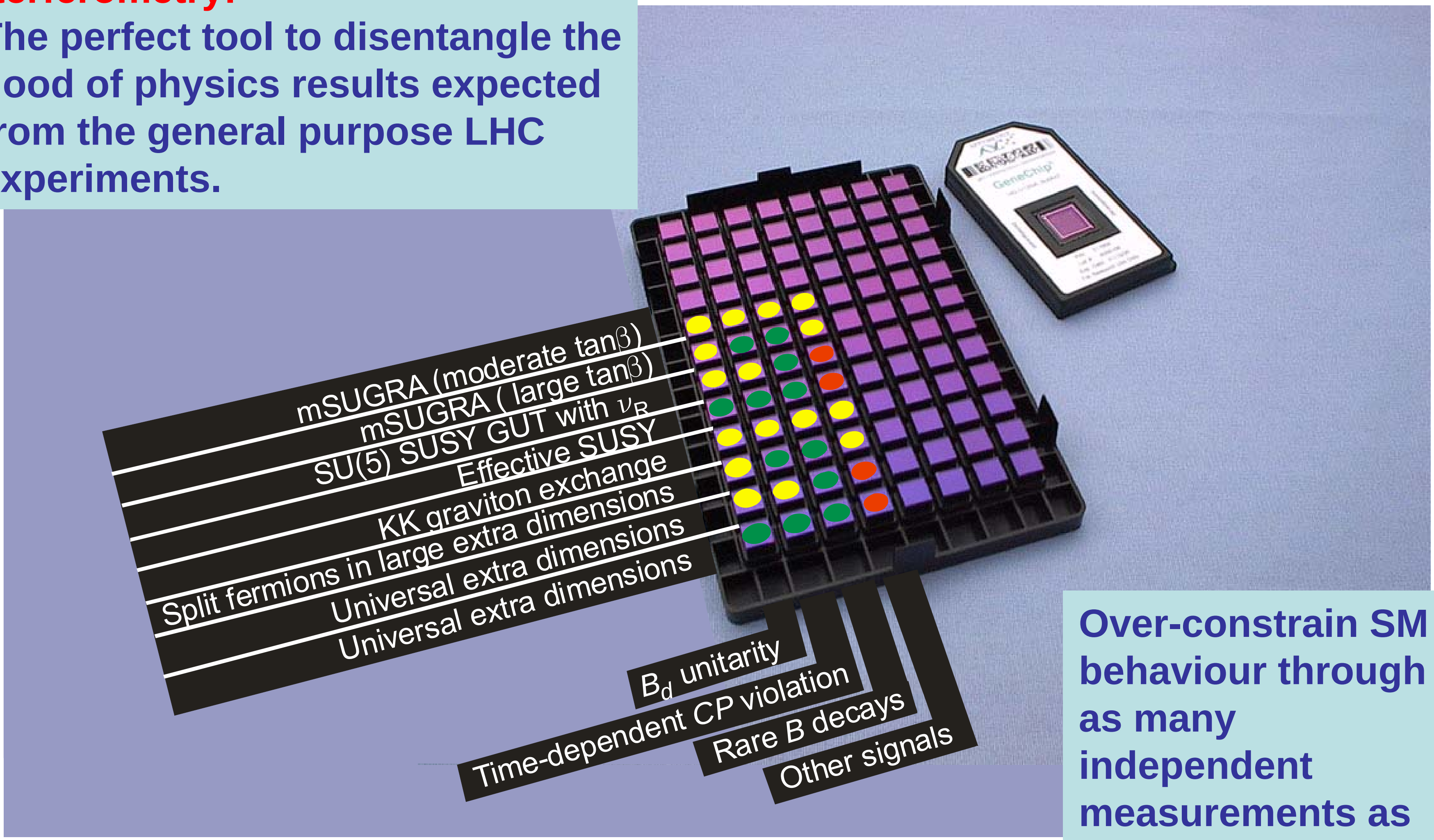
hep-ph/0506151, hep-ph/0509024, hep-ph/0401195, hep-ph/0601090, hep-ph/0509024, hep-ex/0403036 ...

- Use radiative return to the Υ(3S) to gain stats.

Demystifying new physics scenarios

Interferometry:

The perfect tool to disentangle the flood of physics results expected from the general purpose LHC experiments.



Over-constrain SM behaviour through as many independent measurements as possible in order to elucidate NP.

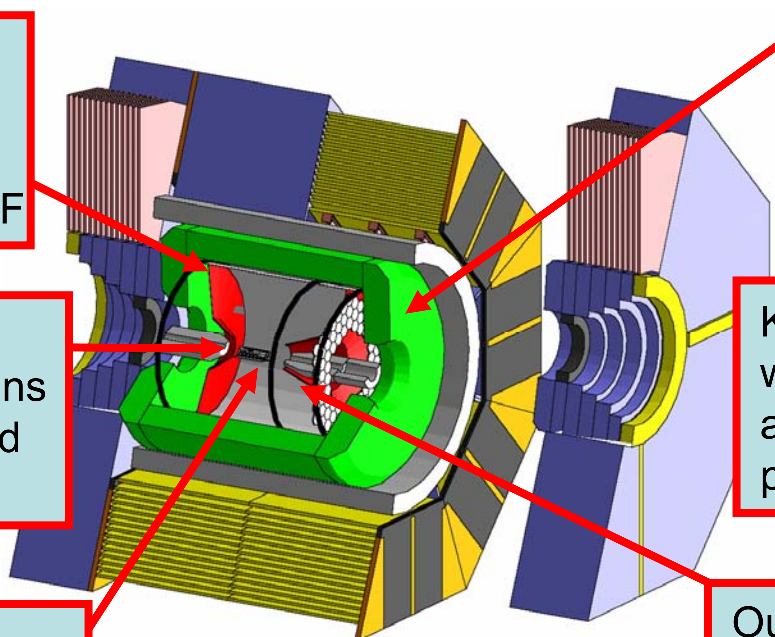
Detector Concepts I

- Detector technology research ongoing.
- Need to improve upon Belle and BaBar to operate at the higher occupancy environment of a 10^{36} machine.
- Several viable technologies to choose from.
- Possibility to get more efficient PID detector than at Babar.

PID:
Super DIRC
AEROGEL Rich
Combine RICH with TOF

Beam pipe:
Smaller beam pipe, means tracking closer to IP, and better S/N.

Si:
Inner pixel detector surrounding a small radius beam pipe needs R&D.



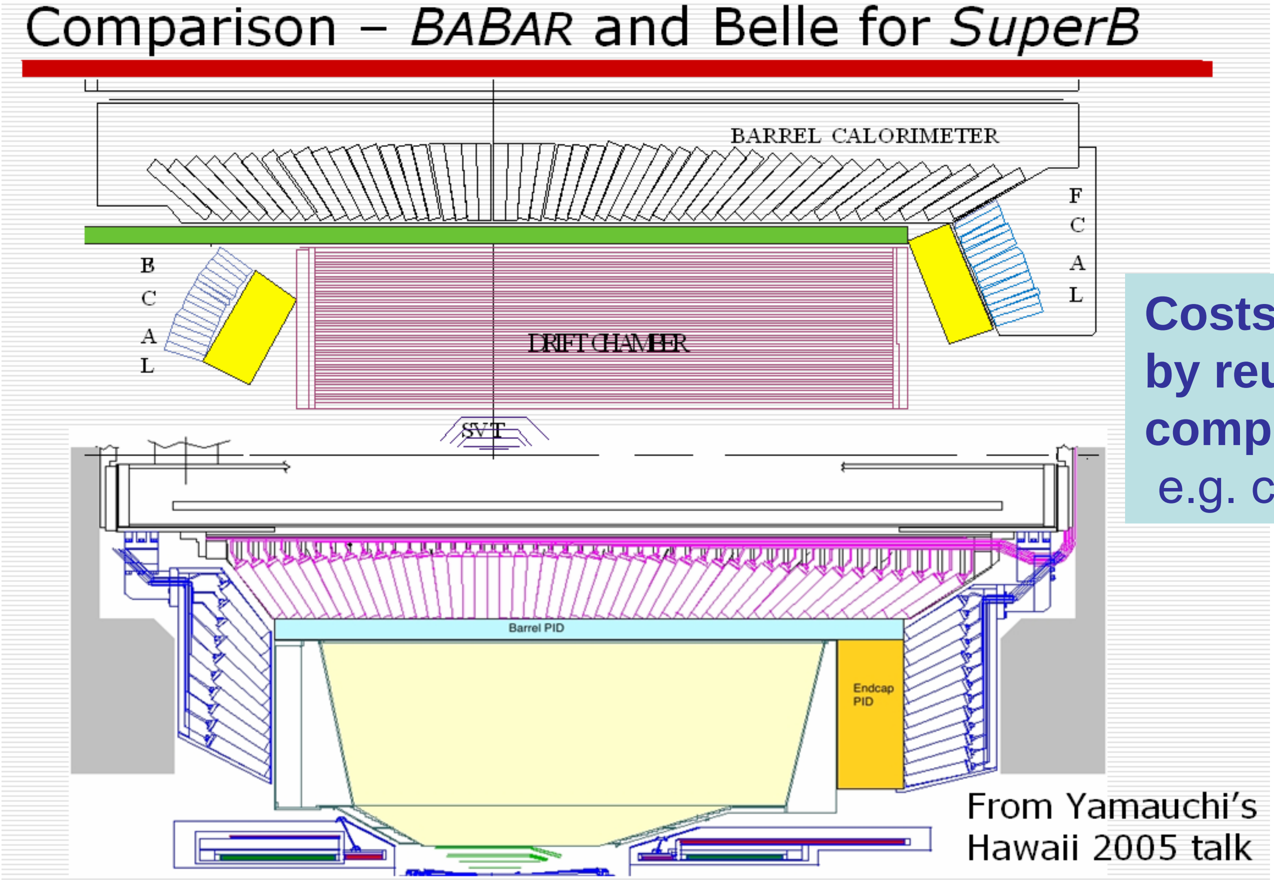
Fast calorimetry:
LSO
Pure CsI end-cap
(reuse CsI(Tl) barrel)

K_L/μ detection:
with scintillator and new generation photon sensors

Outer tracker:
Thin silicon wafers
Small cell tracking detector

Detector Concepts II

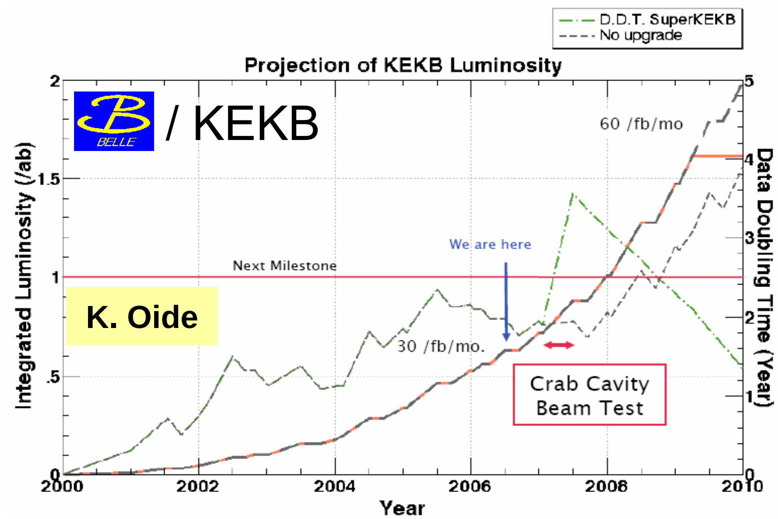
- Some R&D required e.g. doing pixel R&D now, but most technologies are already proven.

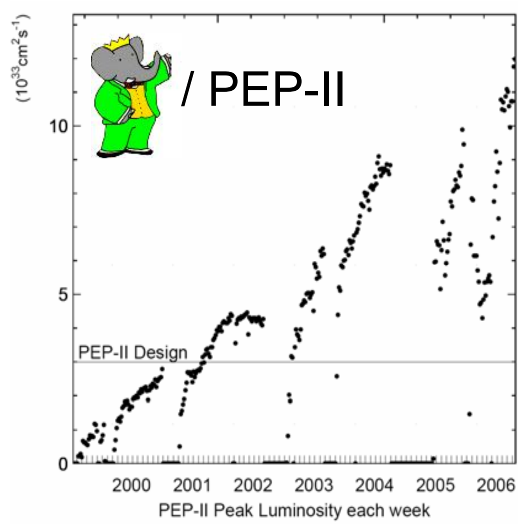


Costs will be kept down by reusing some existing components:
e.g. calorimeter barrel

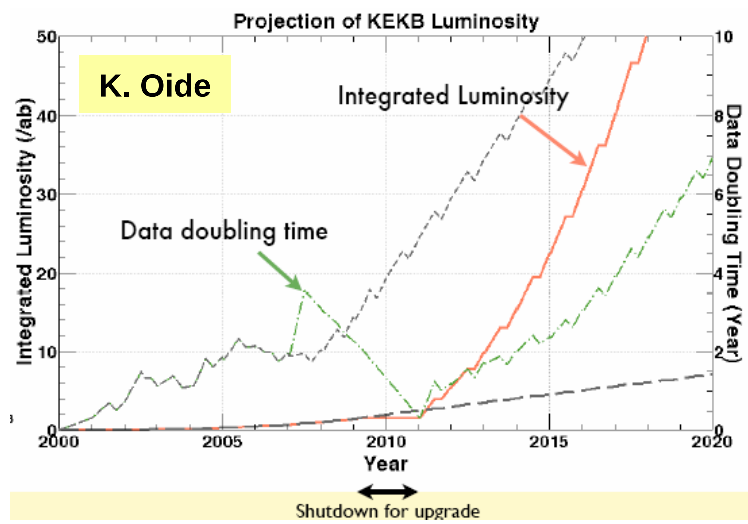
B-factory Performance

- Both B-factories continue to increase their peak luminosity delivered and have reliable integrated luminosity predictions.



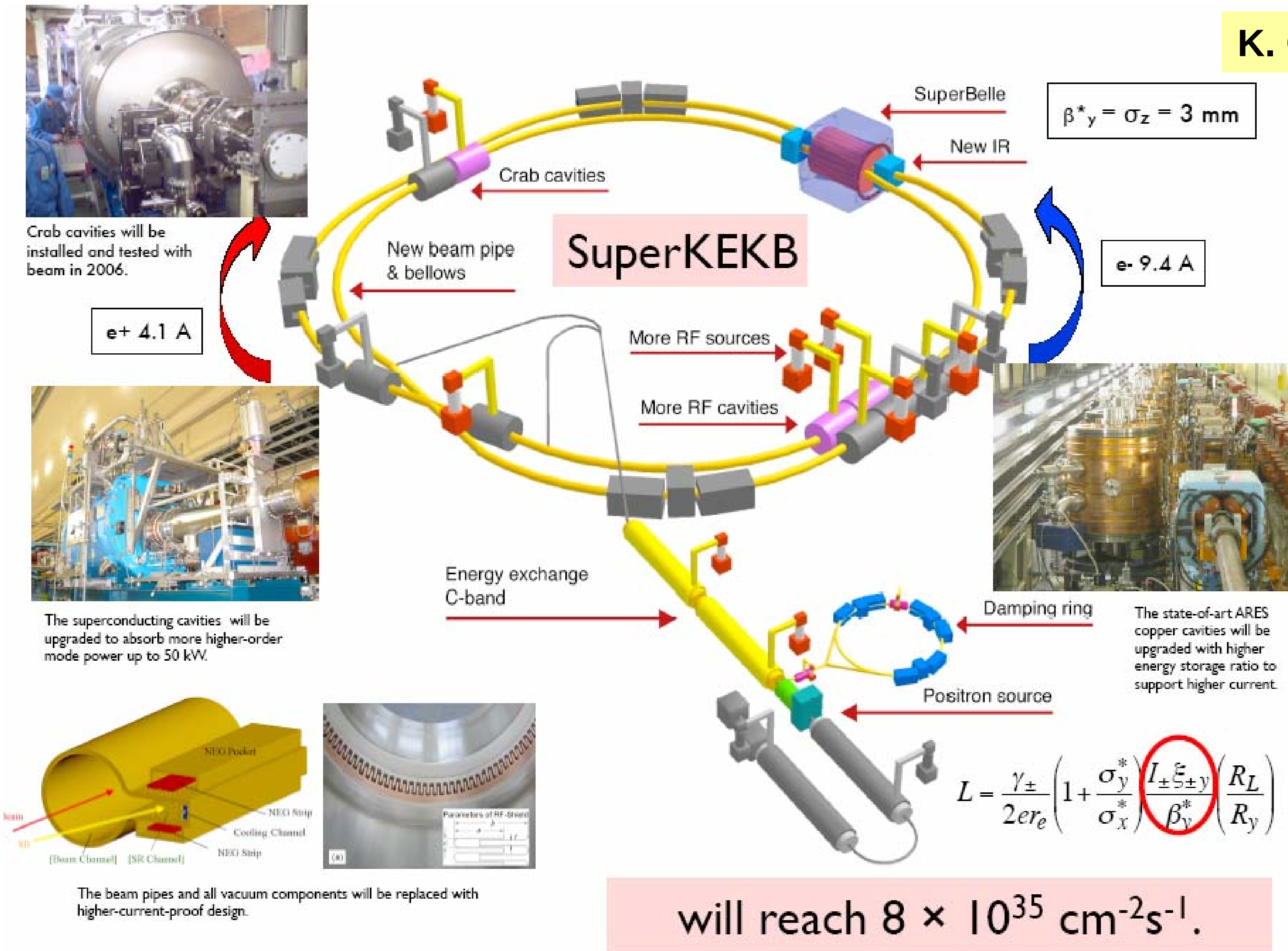


- Belle and BaBar now have a combined total integrated luminosity in excess of $1ab^{-1}$.
- A next generation machine aims to integrate at least $50ab^{-1}$ on a timescale interesting for physics.



Super KEK-B: Overview

K. Oide



Super KEKB: Luminosity predictions

- The luminosity is given by:

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

Lorentz factor, classical $e^{\pm}$ radius and ratio of beam sizes

Beam current: I
beam-beam parameter: ξ
vertical β function at IP

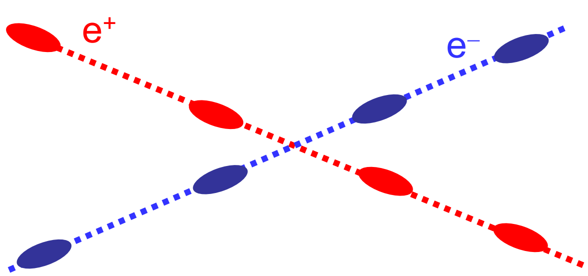
Reduction factor from crossing angle and the hourglass effect

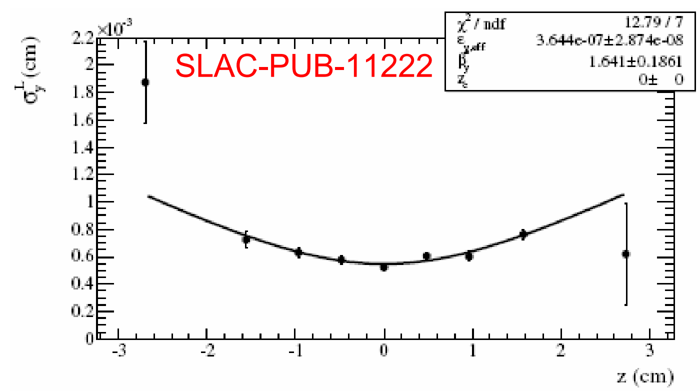
The beam beam parameter ξ is the result of a transverse kick of an incoming e^+ bunch against an outgoing e^- bunch.

$$\varepsilon = \sigma\sigma'$$

$$\beta = \sigma / \sigma'$$

Where σ is the beam spread and σ' is the angular divergence



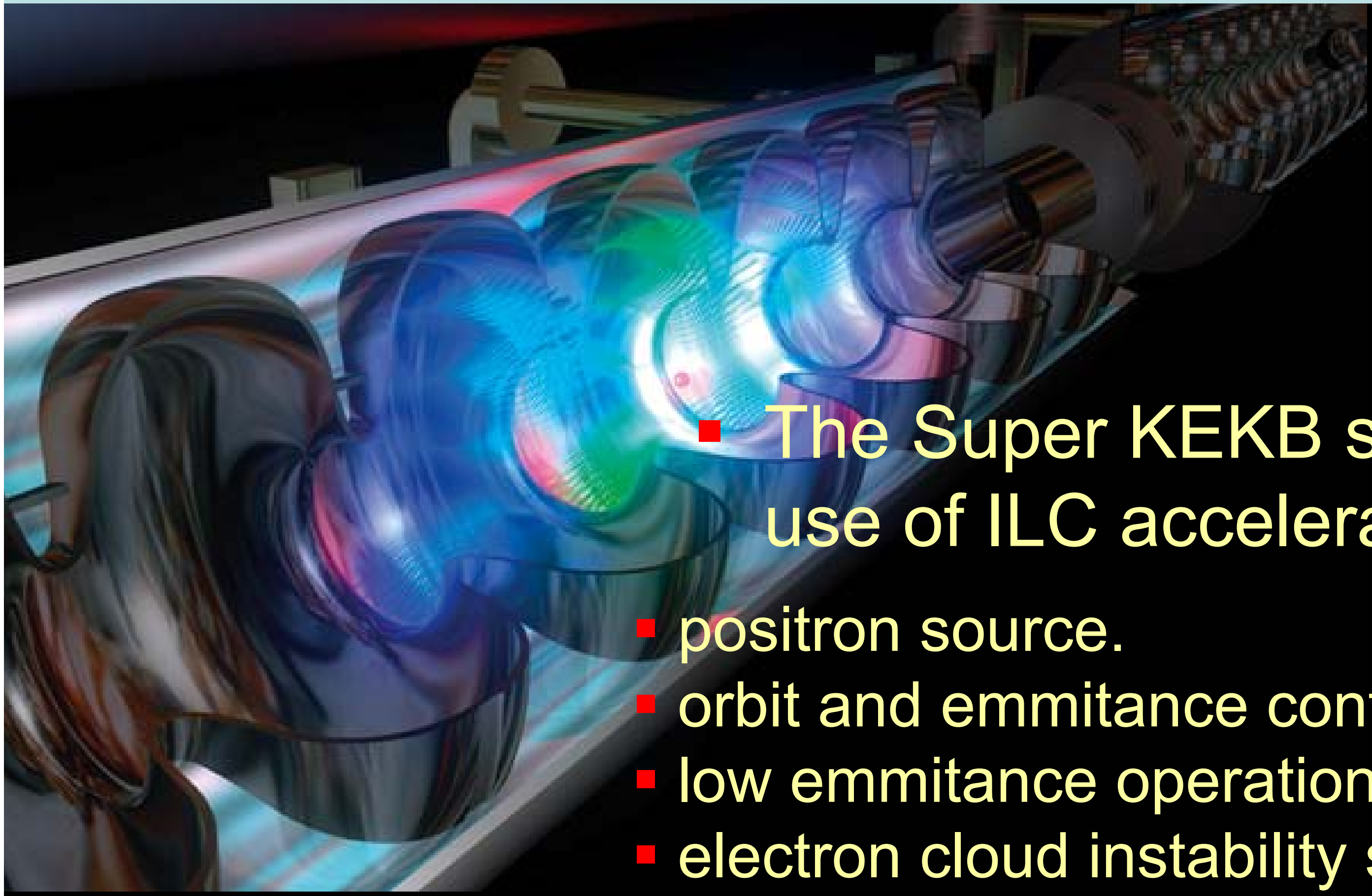


SLAC-PUB-8699

The hourglass effect leads to ~6% luminosity reduction for PEP-II

- The solution to gain a factor of 100 in luminosity at Super KEKB comes from $\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}$.

Synergy with ILC R&D



- The Super KEKB scheme makes use of ILC accelerator R&D
  - positron source.
  - orbit and emmitance control in linac.
  - low emmitance operation of LER.
  - electron cloud instability studies.
  - effect of wiggler.
  - development of ring RF system with ILC specs and klystrons for the ring.
  - next generation bunch-by-bunch feedback.
  - detector component R&D.

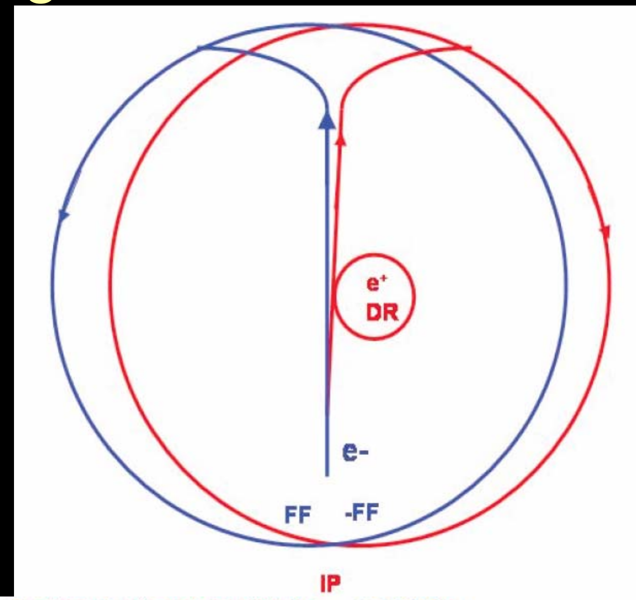
Image courtesy of interactions.org
An ILC image of the field within superconducting RF cavities.

List taken from a talk by K. Oide

“ILC inspired design” collider

- Rapidly evolved through several configurations from PEP-II through to the current design.
- Low emmitance operation to push up luminosity.
- ILC like final focus.
- Don’t need strong damping.
- ILC technology for the storage rings.
- Site independent design.

Image courtesy of interactions.org
An ILC image of the field within superconducting RF cavities.



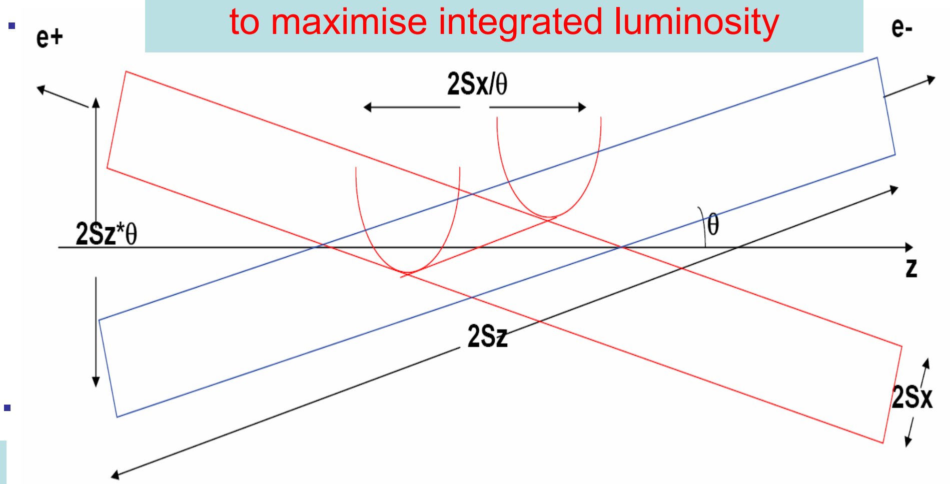
Tor Vergata site between 3.0 Km and 2.2 Km

One potential site being investigated is just outside Rome near Frascatti.

Luminosity goal of the accelerator

- Target is to reach 1×10^{36} cm^2s^{-1}.
- Novel ideas are being used to improve the design performance.
- e.g. Crabbed waist to maximise overlap of the colliding bunches.

twist bunch waists during bunch collision to maximise integrated luminosity



Parameter	Super KEKB	Linear Inspired
ε_x (nm)	9.0	0.8
ε_y (nm)	0.045	0.002
β_x (mm)	200.0	20.0
β_y (mm)	3.0	0.2
σ_z (mm)	3.0	7.0
I (e^-) A	9.4	2.5
I (e^+) A	4.1	1.4
lumi (10^36 $cm^{-2}s^{-1}$)	0.8	1.0
2θ (mrad)	15?	30.0

- Both designs are expected to deliver a luminosity of ~10^{36} $cm^{-2}s^{-1}$.
- This will deliver
  - 1.25×10^{10} $B\overline{B}$ per year,
  - 1.0×10^{10} $\tau^+\tau^-$ per year.
- Total data sample x50 improvement over current generation of e^+e^- experiments.

Complimentarity with existing experiments

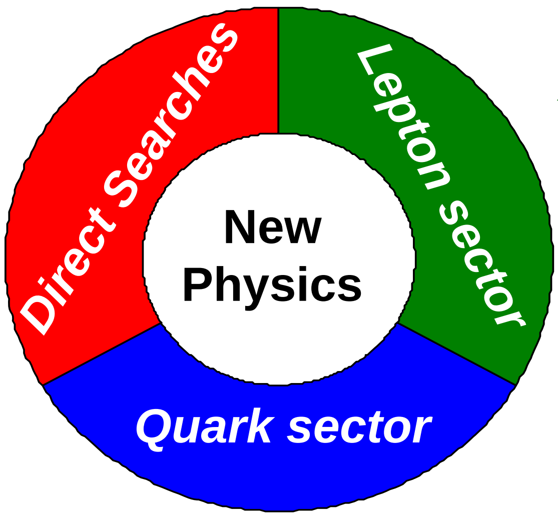
- A crucial part of a unified effort to understand new physics!

LHC, ILC

Higgs boson mass and couplings. New particle searches

ν experiments, g_μ-2, $\mu \rightarrow e\gamma$, etc.

ν mass hierarchy and mixing, CPV, and LFV



τ LFV,
τ CPV,
lepton universality

Flavor mixing,
CPV phases,
CPT

Only the SFF delivers all of this!

Super Flavor Factory,
LHC-b, Rare K experiments, BESIII…

Next steps

- ILC inspired design:
  - CDR in preparation for INFN. Will be completed by the end of the year and submitted Feb 07.
- Super KEK B design:
  - Update LOI case in the new year.
- Upcoming workshops:
  - 13th-15th November, Monte Porzio Catone, Italy.
  - 18th-19th December, Nara, Japan.
- Converge on a single proposal for the SFF.

UK Involvement

- Longstanding interest in UK's BaBar community
- Developments over the last few years have increased interest above critical mass.
- Recently submitted a proposal to PPARC for PRD funding toward travel, physics studies, accelerator and detector R&D for a SFF.
- 8 UK institutes involved
  - ***Brunel, Cockcroft Institute, Edinburgh, Liverpool, Manchester, RAL, QMUL and Warwick.***

Case for a Super Flavor Factory

- TeV scale quantum interferometry in $B_{u,d,s}$ decays.
  - Over constrain NP models with many independent measurements.
  - Fundamental requirement to understand the nature of any new physics uncovered at the LHC.
  - Precision understanding of SM processes.
- LFV/CPV searches in τ decays.
- Search for mixing, CPV and NP in D decays.
- Test lepton universality at the $\Upsilon(3S)$.
- Improve constraints on CPT in correlated $P^0\overline{P}^0$ systems.
- Update measurements of R for g-2, $\sin\theta_W$, search for DM and much *much* more!
- A growing interest from the B-physics community.
- Several available sites around the world for Super FF.
- Synergy with ILC detector and accelerator R&D.

Towards the European Strategy for Particle Physics: The Briefing Book

hep-ph/0609216

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Owing to the complementarity of e^+e^- B-factories and B physics at hadron colliders, the physics case for a Super B-factory is well motivated, even when considering that LHCb will make major contributions to the field. The Super B-factory will benefit from a clean environment, allowing for measurements that nobody else can do, such as the leptonic decays $B \to \tau(\mu)\nu$, sensitive to $|V_{ub}|$ and to a BSM-charged Higgs (see Fig. VI-4 for the MSSM), or the rare decay $B \to K\nu\nu$, which is complementary to the corresponding rare- kaon decay and sensitive to many SM extensions. A Super B-factory will also outperform LHCb on CKM metrology: a precision measurement of α is only possible at an e^+e^- machine, and also the measurements of β and γ will benefit from a better control of systematic uncertainties. High-precision measurements of time-dependent CP-violating asymmetries in such important hadronic penguin modes as $B_d \to \phi K^0$ and $B_d \to K^*\gamma$ are only possible at a Super B-factory. New types of asymmetries, such as the above-mentioned forward–backward asymmetry in various $b \to s\, \ell^+\ell^-$ decays, can be studied in greater detail. Finally, the full range of interesting τ and charm physics analyses can be exploited with unprecedented statistics. We shall emphasize in particular the search for the lepton-flavour-violating decay $\tau \to \mu\gamma$, for which sensitivities of the order of 10^{-9}–10^{-10} can be achieved at a Super B-factory. Such sensitivities are well within the reach of the most prominent BSM physics scenarios.

Additional Material

- Target Luminosity: 10^{36} cm^2s^{-1}.
- 12.5 Billion B pairs per year.
- 10 Billion $\tau^+\tau^-$ pairs per year.