Imperial College
London

CKM 2008

Summary WG3 – Rare decays

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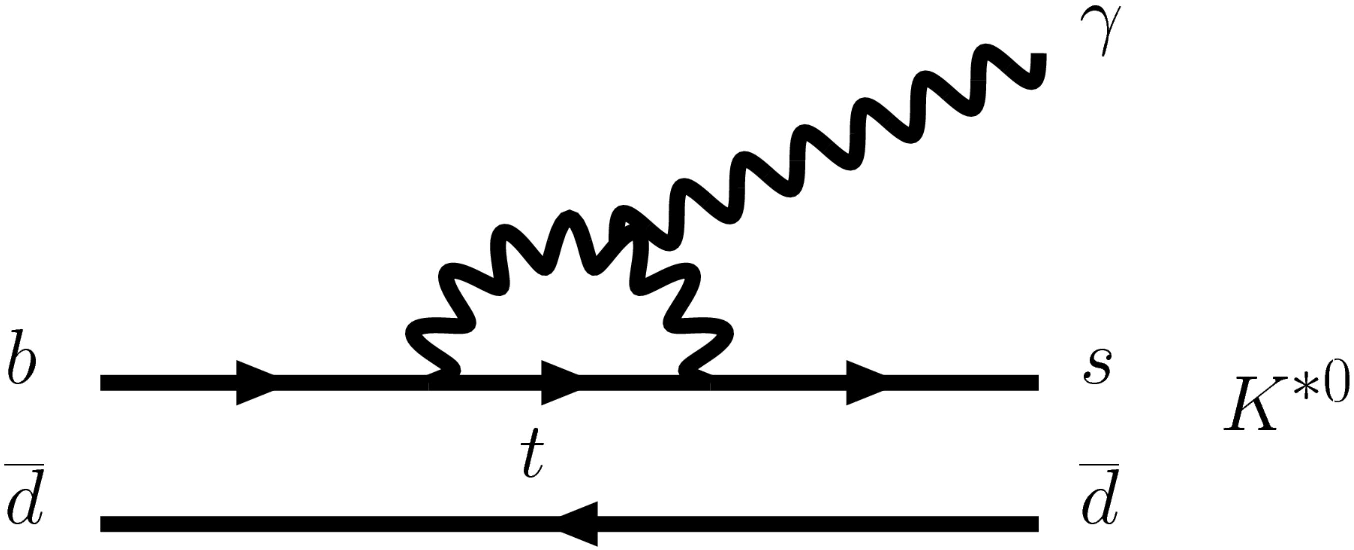
Scope

InWG3 we covered the area of “Rare Decays”

- b → s/d γ inclusive and exclusive
- b → s $l^+ l^-$ inclusive and exclusive
- B → $\mu^+\mu^-$



Participants

Presentations were given by

Shohei Nishida, Vanya Belayev, Ben Pecjak, Matthew Wingate, Bruce Schumm, Antonio Limosani, Christoph Greub, Diego Guadagnoli, Einan Gardi, Bob Harr, Sergey Sivoklokov, Paride Paradisi, Chris Schilling, Enrico Lunghi, Mitesh Patel, Thorsten Feldmann, Tobias Hurth

Many others active in discussions.

A pick of interesting points and discussions during the week.

My fault if something essential has been missed or misunderstood.

Estimate of B → X_s γ

First estimate at NNLO

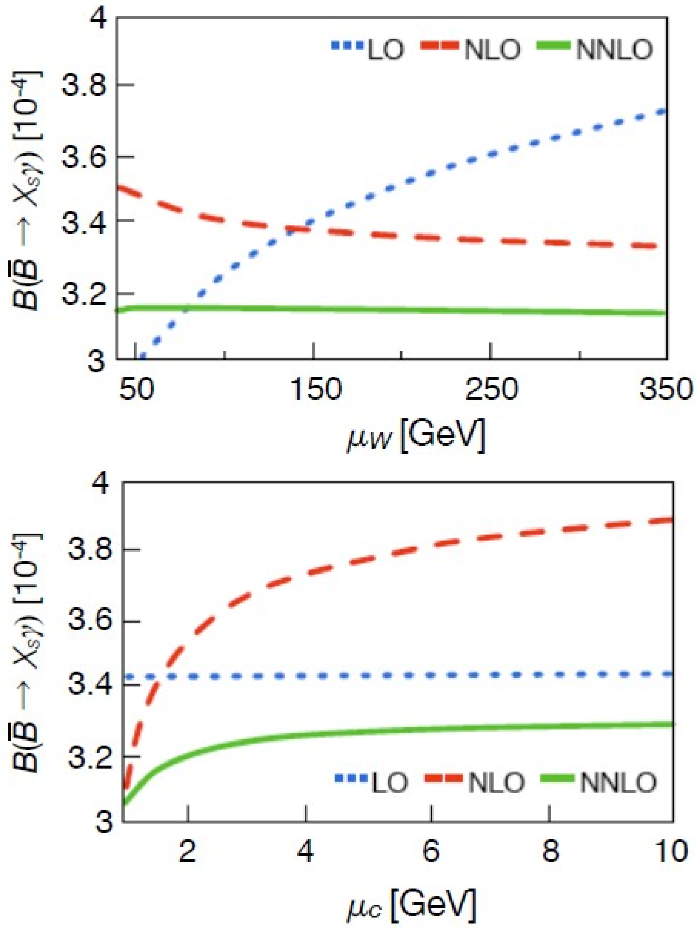
$$\mathcal{B}(\bar{B} \to X_s\gamma)^{E_\gamma > 1.6\,\mathrm{GeV}}_{\mathrm{NNLO}} = (3.15 \pm 0.23) \times 10^{-4}$$

To be compared to

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{E_\gamma > 1.6\,\mathrm{GeV}}_{\mathrm{exp}} = (3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$$

Inclusion of NNLO corrections leads to a notable reduction of renormalization scale dependences.

Most pronounced effect occurs for charm quark mass scale that was main source of uncertainty at NLO.

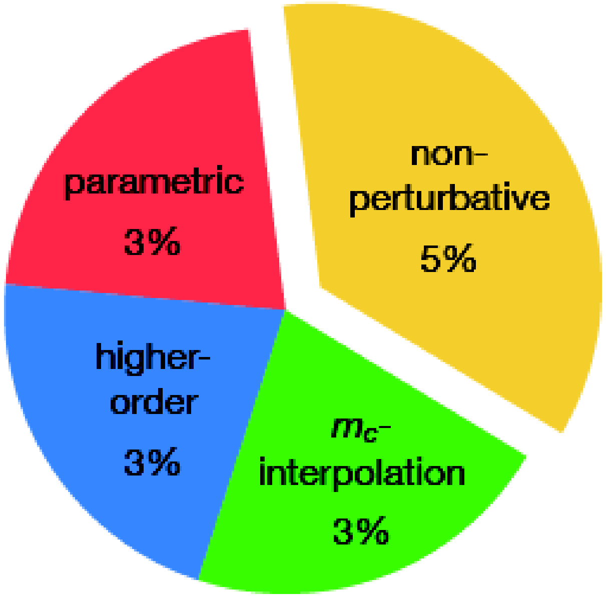


M. Misiak *et al.* ‘06

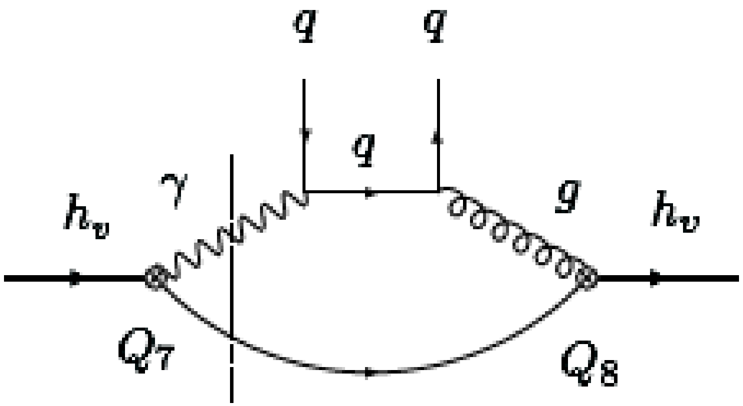
Estimate of $B \to X_s \gamma$

Dominant theoretical error due to non-perturbative corrections of order $\alpha_s \Lambda_{QCD}/m_b$.

To estimate precise impact of these enhanced non-local power corrections will remain notoriously difficult



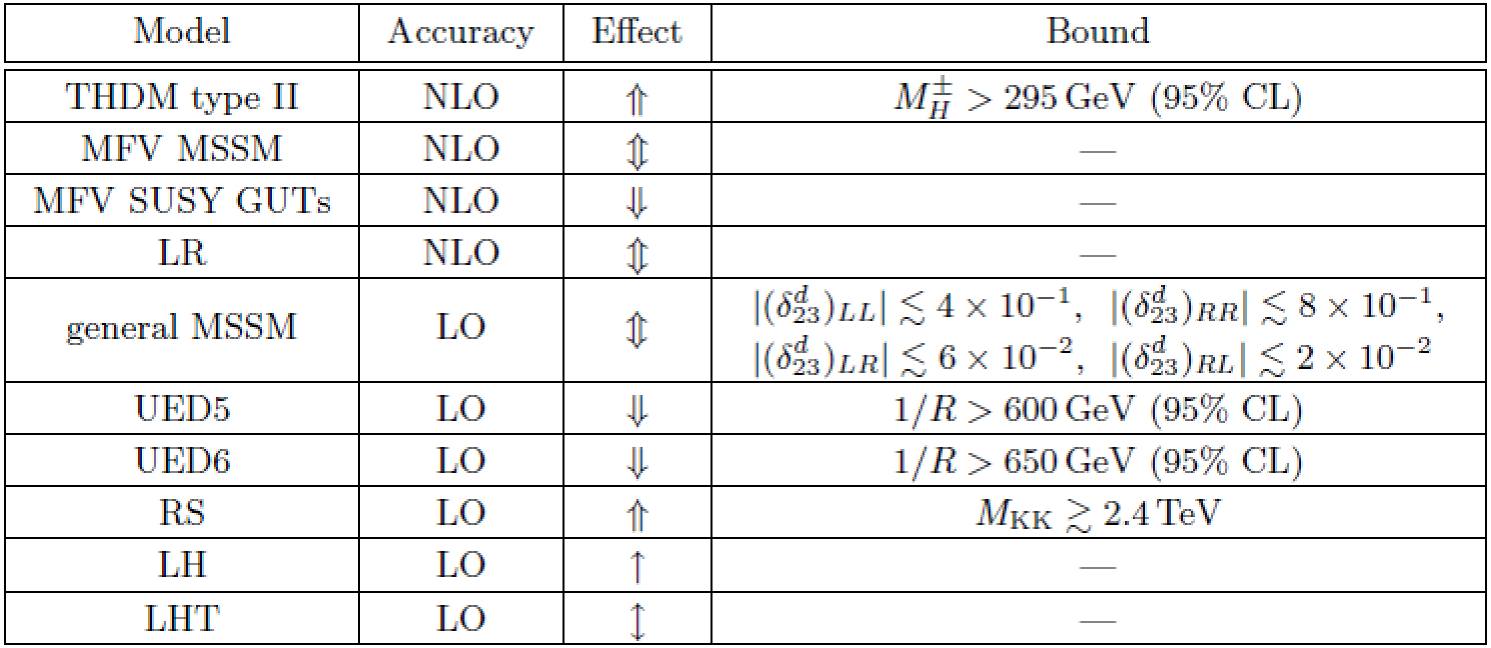
individual sources of errors on branching ratio at NNLO



Inclusive b → s γ

Provides stringent bounds on many models of NP at EW scale

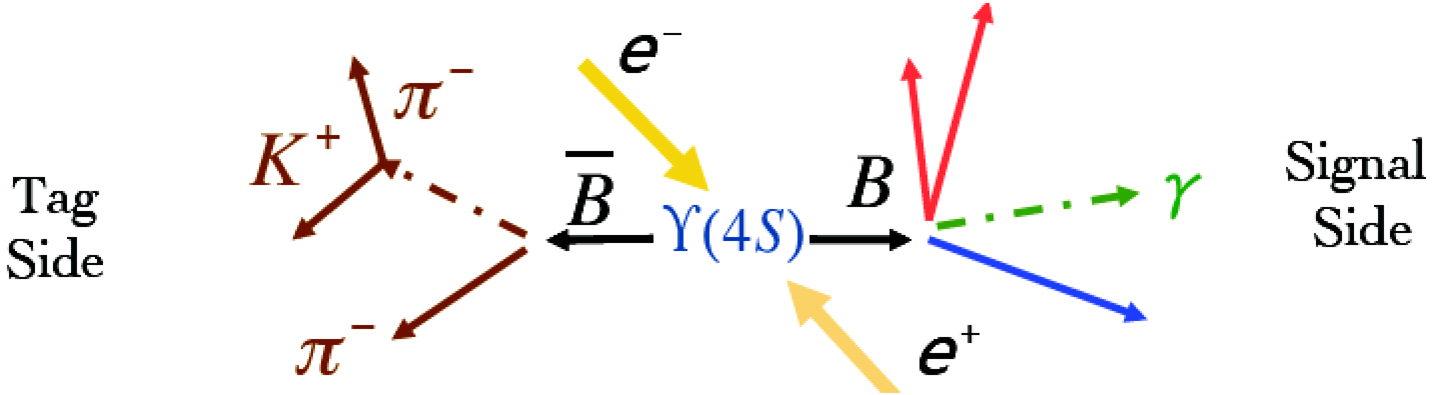
Important role in any study of beyond SM physics within and outside flavour sector



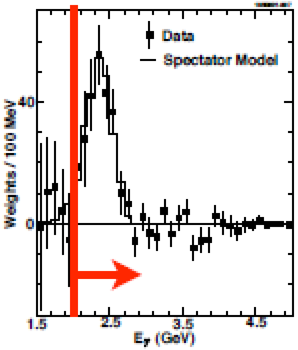
Model	Accuracy	Effect	Bound
THDM type II	NLO	$\Uparrow$	$M_H^{\pm} > 295\,\mathrm{GeV}$ (95% CL)
MFV MSSM	NLO	$\Updownarrow$	—
MFV SUSY GUTs	NLO	$\Downarrow$	—
LR	NLO	$\Updownarrow$	—
general MSSM	LO	$\Updownarrow$	$\lvert(\delta_{23}^d)_{LL}\rvert \lesssim 4 \times 10^{-1}$, $\lvert(\delta_{23}^d)_{RR}\rvert \lesssim 8 \times 10^{-1}$, $\lvert(\delta_{23}^d)_{LR}\rvert \lesssim 6 \times 10^{-2}$, $\lvert(\delta_{23}^d)_{RL}\rvert \lesssim 2 \times 10^{-2}$
UED5	LO	$\Downarrow$	$1/R > 600\,\mathrm{GeV}$ (95% CL)
UED6	LO	$\Downarrow$	$1/R > 650\,\mathrm{GeV}$ (95% CL)
RS	LO	$\Uparrow$	$M_{\mathrm{KK}} \gtrsim 2.4\,\mathrm{TeV}$
LH	LO	$\uparrow$	—
LHT	LO	$\updownarrow$	—

Inclusive measurements

- 3 different methods in use
  - Fully inclusive
  - Sum over many exclusive modes
  - B-recoil method
    - Method to decrease systematics in the future

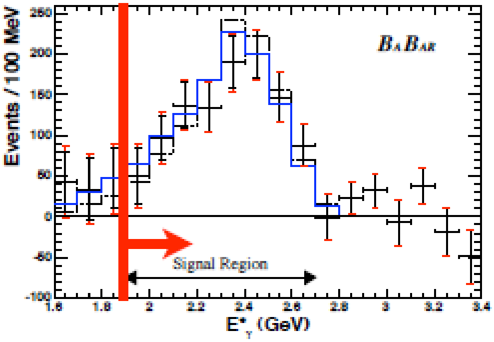


Inclusive measurements



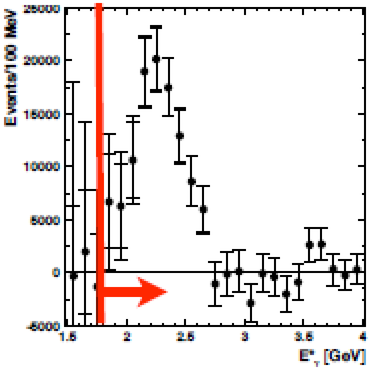
CLEO
9.1/fb ON
4.4/fb OFF
Eγ > 2.0 GeV

PRL87, 251807
(2001)



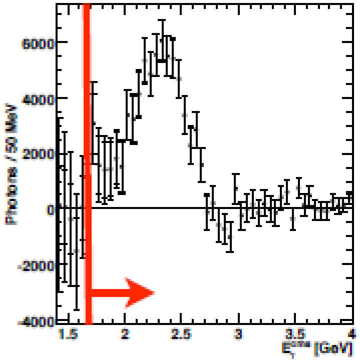
BABAR
81.5/fb ON
9.6/fb OFF
Eγ > 1.9 GeV

PRL97, 171803
(2006)



Belle
140/fb ON
15/fb OFF
Eγ > 1.8 GeV

PRL93, 061803
(2004)



Belle
605/fb ON
68/fb OFF
Eγ > 1.7 GeV

arXiv:0804.1580
(2008)

More data, lower the photon energy cut

Matching experimental measurement

Matching the experimental measurement not trivial

- At the moment theory and experiment “meet” at cutoff E_0=1.6 GeV
- Experiment use extrapolation to get down to 1.6 GeV.
- Theory calculate fraction T from 1 GeV to 1.6 GeV

● $1 - T = 0.04 \pm 0.01_{\text{pert}}$

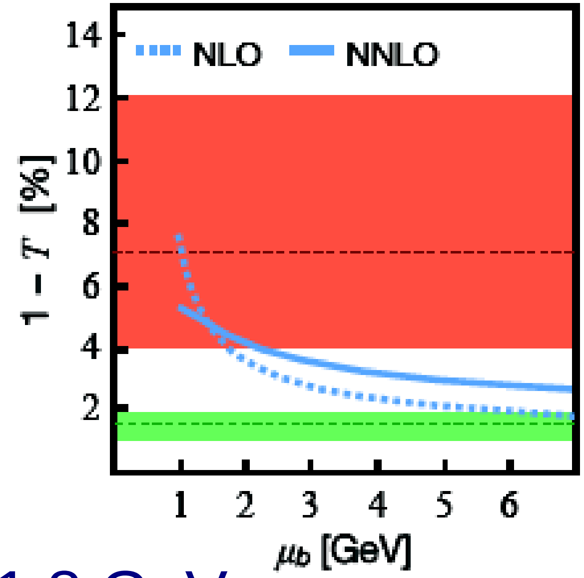
M. Misiak *et al.* '06

● $1 - T = 0.07^{+0.05}_{-0.03}{}_{\text{pert}} \pm 0.02_{\text{hadr}} \pm 0.02_{\text{pars}}$

T. Becher and M. Neubert '06

● $1 - T = 0.016 \pm 0.003_{\text{pert}}$

J. Andersen and E. Gardi '06



Recommendation to move matching to 1.8 GeV

Matching experimental measurement

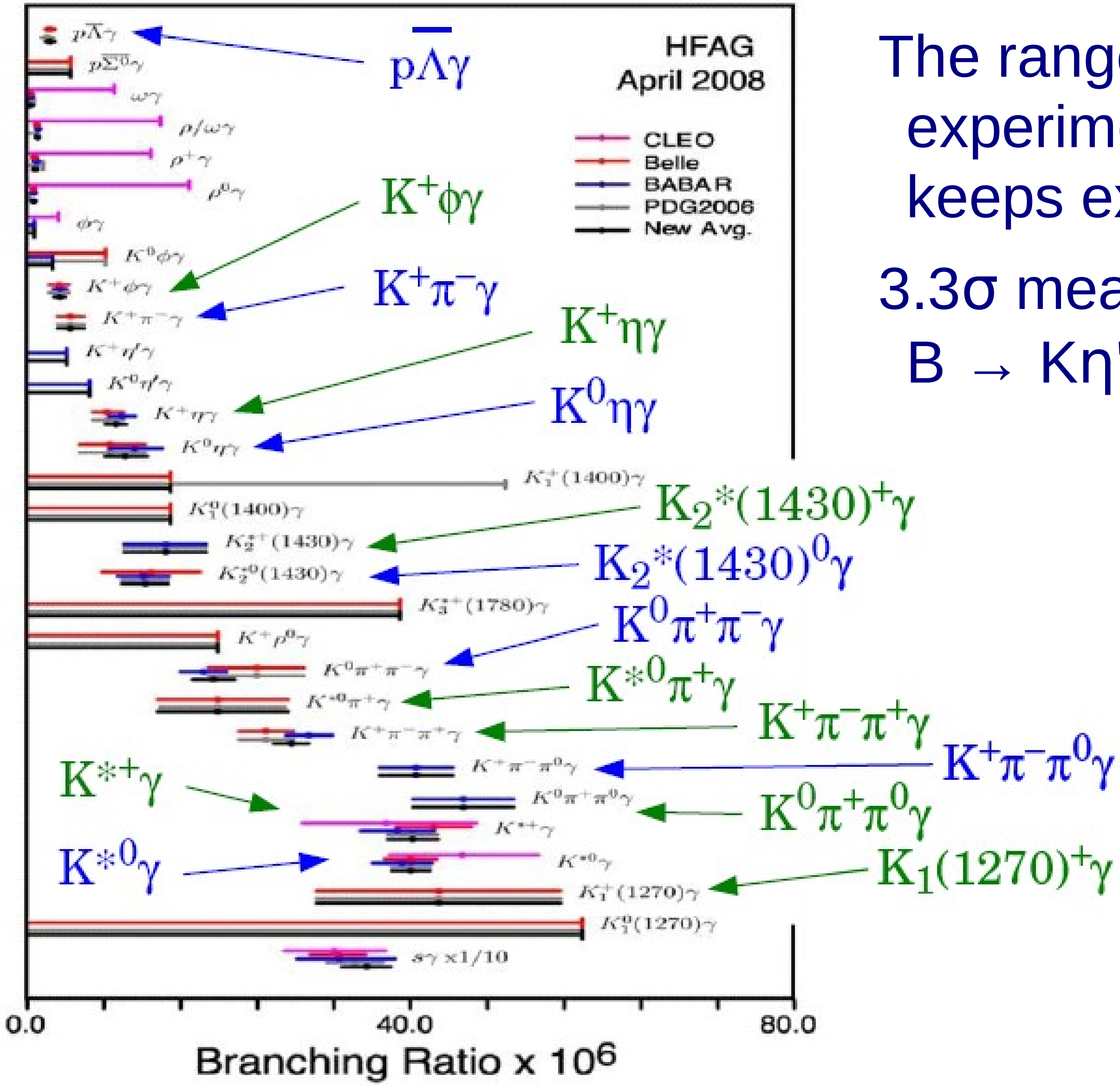
Matching to fixed-order might not be sufficient to guarantee a good approximation away from the Sudakov region.

In particular, resummation artifacts can alter the asymptotic behaviour of spectrum of (Q_i, Q_j) interference term in limit

$$\frac{d\Gamma_{ij}}{dE_\gamma} \sim \begin{cases} E_\gamma^{-1}\,, & i = j = 8\,, \\ E_\gamma\,, & i = 7 \ \text{and} \ j = 8\,, \\ E_\gamma^3\,, & \text{otherwise} \end{cases}$$

In order to get a good theoretical control over tail of spectrum, it might not be enough to consider only interference of (Q_7, Q_7)

Exclusive experimental results



The range of experimental results keeps expanding

3.3σ measurement of B → Kη'γ the latest

Direct CP and isospin asymmetries

Charge asymmetry

$$A_{CP}=\frac{\Gamma(\bar{B}\rightarrow\bar{K}^{*}\gamma)-\Gamma(B\rightarrow K^{*}\gamma)}{\Gamma(\bar{B}\rightarrow\bar{K}^{*}\gamma)+\Gamma(B\rightarrow K^{*}\gamma)}$$

BaBar

-0.009 ± 0.017 ± 0.011

BELLE

-0.015 ± 0.044 ± 0.012

Isospin asymmetry

$$\Delta_{0+}=\frac{\Gamma(B^{0}\rightarrow K^{*0}\gamma)-\Gamma(B^{+}\rightarrow K^{*+}\gamma)}{\Gamma(B^{0}\rightarrow K^{*0}\gamma)+\Gamma(B^{+}\rightarrow K^{*+}\gamma)}$$

BaBar

0.029 ± 0.019 ± 0.016 ± 0.018

BELLE

0.034 ± 0.044 ± 0.026 ± 0.025

This number becomes interesting in comparison with measurement in $B \rightarrow K^{(*)} l^{+}l^{-}$

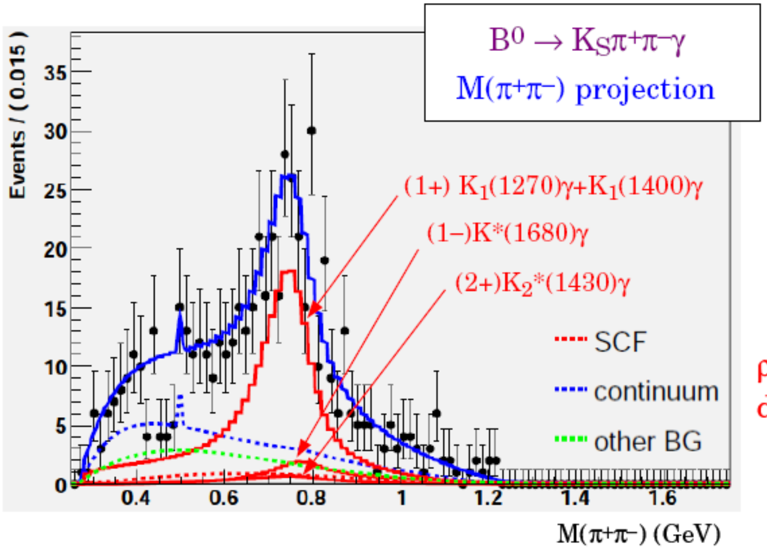
Time dependent CP violation

Time dependent analysis

- Rely on CP eigenstate. Expect suppression of m_s/m_b with respect to $B_d \to J/\Psi\ K^0_s$
- Main results from $B_d \to K^{*0}\ \gamma$, $K^{*0} \to K^0_s\pi^0$

Results are compatible with no CPV so far

New result from BELLE in $B_d \to K^0_s\rho^0\gamma$



looks O.K.

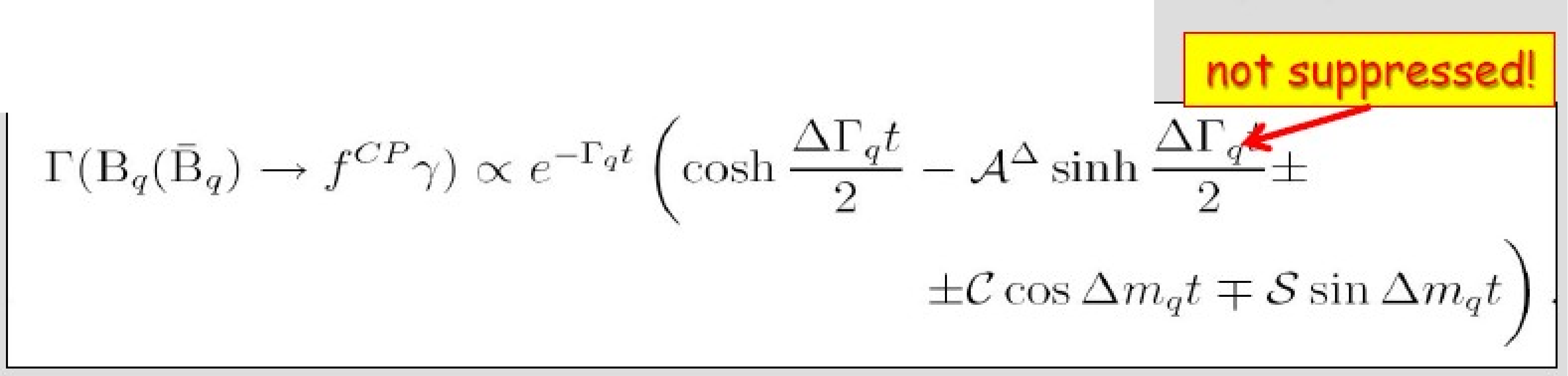
ρ^0 component is dominant

Complications with contamination of non-CP final state.

- Dilution factor determined using isospin assumption.

$B_s \to \varphi\gamma$

CP eigenstate as $B_d \to K^{*0}\gamma$ but now with advantage of sizeable ΔΓ



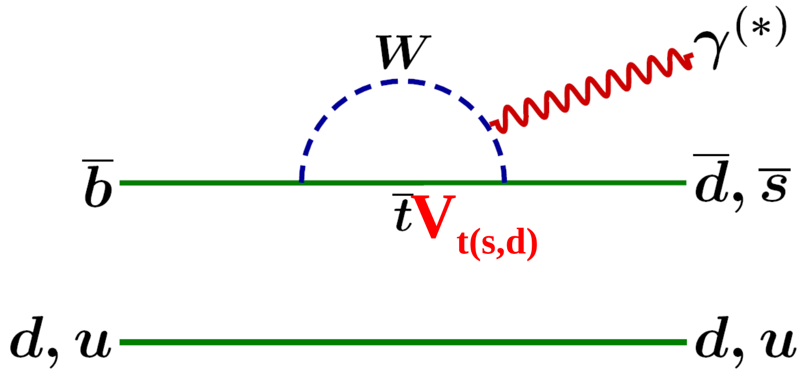
not suppressed!

$$\Gamma(\mathrm{B}_q(\bar{\mathrm{B}}_q) \to f^{CP}\gamma) \propto e^{-\Gamma_q t}\left(\cosh\frac{\Delta\Gamma_q t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_q t}{2} \pm \right.$$
$$\left. \pm\mathcal{C}\cos\Delta m_q t \mp \mathcal{S}\sin\Delta m_q t\right).$$

Resolution from 2 fb^{-1} at LHCb comparable to current B-factory results.

Discussion raised issue of $\Gamma(B_s \to \varphi\gamma)/\Gamma(B_d \to K^{*0}\gamma)$ as a test of theoretical predictions.

Measurement of $|V_{td}/V_{ts}|$



Exclusive approach

2008 results from both BaBar and BELLE

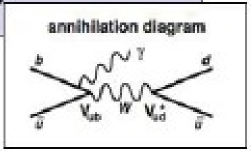
isopin factor: 1(.5) for ρ±(ρ0)(and ω)

form factor ratio

$$\frac{\mathcal{B}(B\to\rho\gamma)}{\mathcal{B}(B\to K^*\gamma)} = S_\rho \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1-m_\rho^2/M_B^2}{1-m_{K^*}^2/M_B^2)}\right)^3 \zeta^2[1+\Delta R]$$

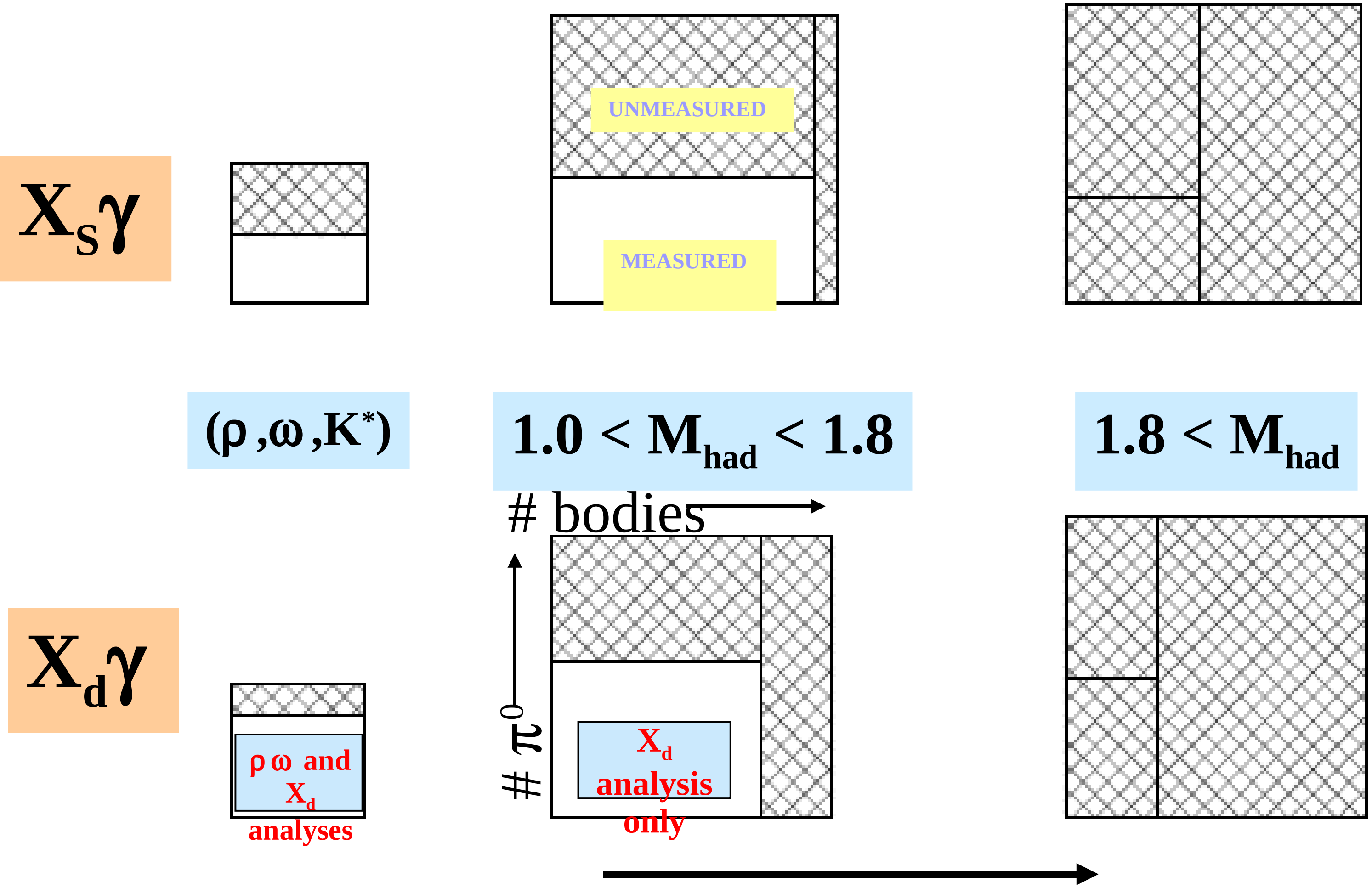
well measured

annihilation amplitude corrections



Measurement of $|V_{td}/V_{ts}|$

New semi-inclusive result from BaBar



$X_S\gamma$

UNMEASURED

MEASURED

(ρ, ω, K^*)

$1.0 < M_{had} < 1.8$

$1.8 < M_{had}$

bodies

$\# \pi^0$

$X_d\gamma$

$\rho\ \omega$ and X_d analyses

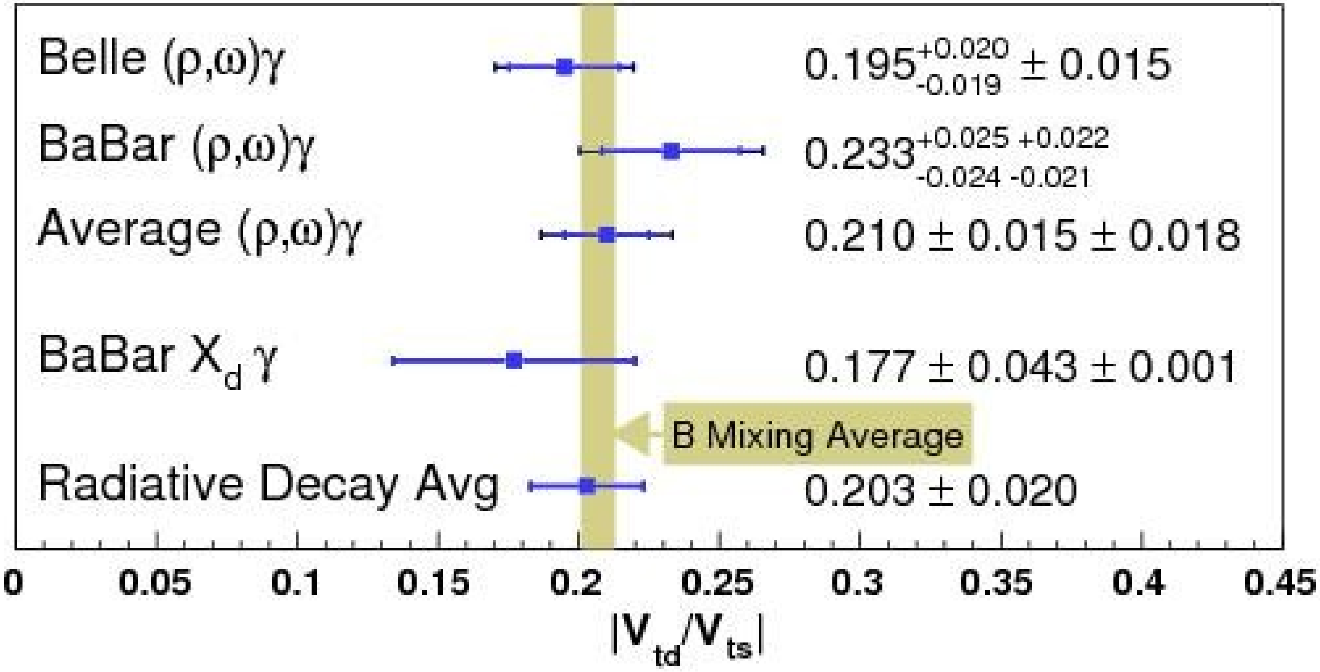
X_d analysis only

Measurement of $|V_{td}/V_{ts}|$

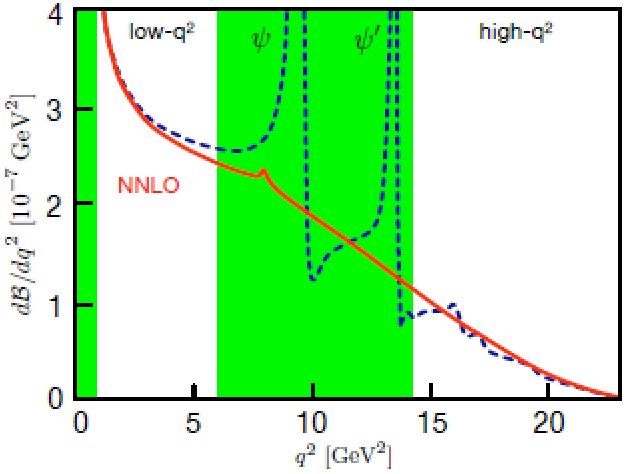
Would like to produce "radiative" average as part of write-up.

Some non-trivial issues related to overlapping selections.

Should mainly be seen as a test for NP rather than a competitive measurement with the mixing result.



$B \to X_s\, l^+l^-$: Solved and open issues



Solved problems:

- NNLO fixed-order for dB/dq^2 and A_{FB}
- Model-independent NLO with M_X cut
- SM predictions with (5−15)% errors

Open issues:

- Fully consistent to cut out ψ and ψ´ and compare to short-distance calculation ?
- Like in $b \to s\gamma$ non-perturbative corrections of order $\alpha_s \Lambda_{QCD}/m_b$ difficult to quantify precise impact of QED collinear logarithms

Learning effectively from $B \to X_s\, l^+l^-$

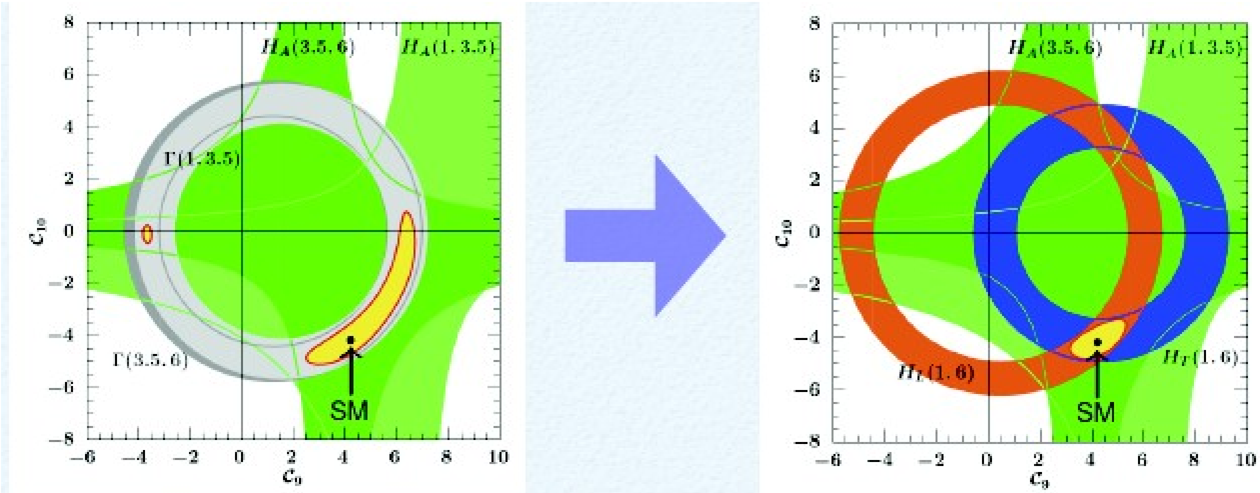
Angular decomposition

$$\frac{d^2\Gamma}{ds\,dz} \sim \Bigg\{ (1+z^2)\left[\left(C_9 + \frac{2}{s}C_7\right)^2 + C_{10}^2\right] + (1-z^2)\left[(C_9+2C_7)^2 + C_{10}^2\right] - 4zsC_{10}\left(C_9 + \frac{2}{s}C_7\right)\Bigg\}$$

$$\equiv \underbrace{H_T + H_L}_{\sim\,\Gamma} + \underbrace{H_A}_{\sim\,A_{\rm FB}}$$

$$(s = q^2/m_b^2, z = \cos\theta, \theta : \sphericalangle b, l^+)$$

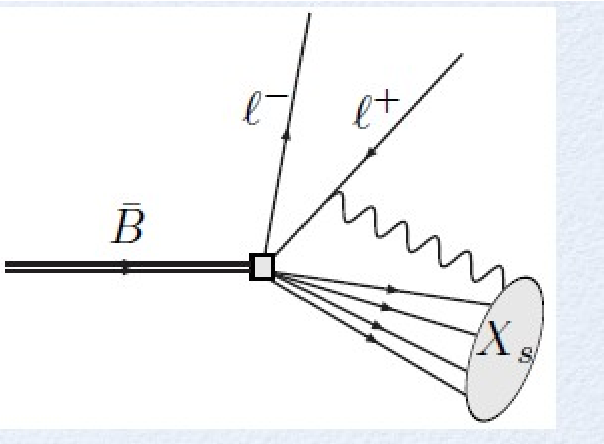
$$H_{T,L,A}(q_1^2, q_2^2) \equiv \int_{q_1^2}^{q_2^2} dq^2 H_{T,L,A}(q^2)$$



[Toy analysis: data extrapolated at 1 ab^{-1}, $C_7 < 0$ taken from b→sγ]

Problem with measurement of inclusive rate

- In semi-inclusive analysis the X_s system is reconstructed from a sum over exclusive states (K + <= 4π).
  - Momentum conservation is used to guarantee the absence of energetic photons
- The collinear log present in the virtual corrections is not accompanied by the corresponding log in the real emission diagrams and doesn't cancel.
- Exact theory prediction depends on details of the experimental analysis and clearly close collaboration required.

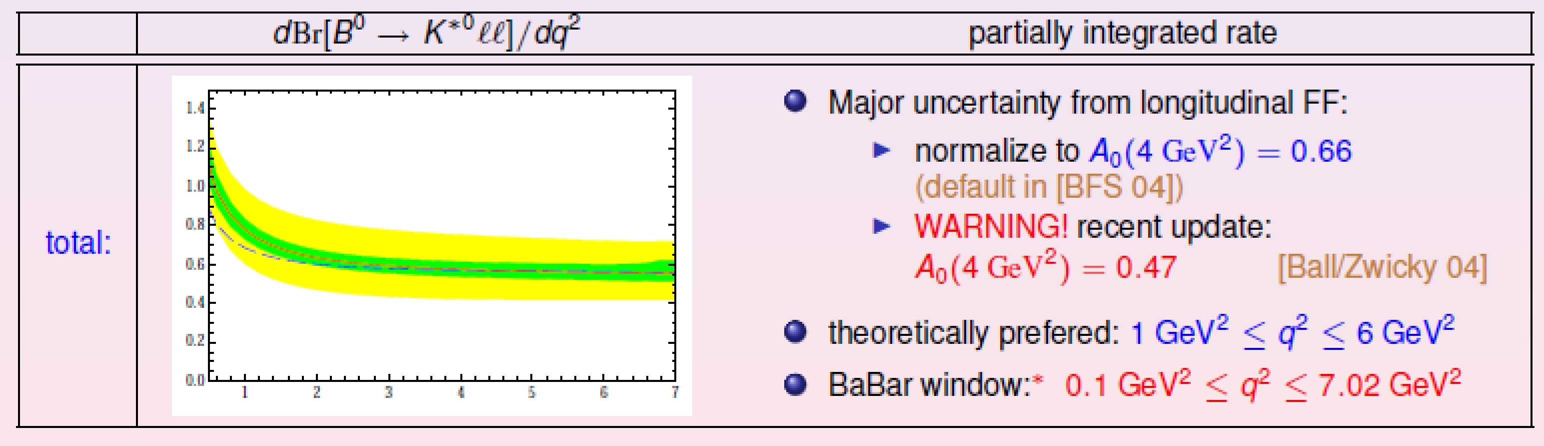


$B_d \to K^{*0}\, l^+l^-$ rates and amplitudes

Theoretically safe region for calculating quantities is

$1 < q^2 < 6$ GeV^2.

Strong encouragement to experiments to quote results like that.



	$d\mathrm{Br}[B^0 \to K^{*0}\ell\ell]/dq^2$	partially integrated rate
total:		- Major uncertainty from longitudinal FF: ► normalize to $A_0(4\,\mathrm{GeV}^2) = 0.66$ (default in [BFS 04]) ► WARNING! recent update: $A_0(4\,\mathrm{GeV}^2) = 0.47$ [Ball/Zwicky 04] - theoretically prefered: $1\,\mathrm{GeV}^2 \leq q^2 \leq 6\,\mathrm{GeV}^2$ - BaBar window:* $0.1\,\mathrm{GeV}^2 \leq q^2 \leq 7.02\,\mathrm{GeV}^2$

Results in figure does not include (unknown) Λ/m_b corrections.

Warnings/questions for $B_d \rightarrow K^{*0}\, l^+l^-$

Systematic uncertainties from (partly) neglected $1/m_b$ corrections.

Extract form factor estimates from sum rules/lattice or from experimental data on $B \rightarrow K^*\,\gamma$?

How reliable are the phenomenological estimates for light-cone wave functions?

How much do vector meson poles influence the intermediate q^2 region?

New observables

Construct a careful set of observables for $B_d \to K^{*0} \mu^+\mu^-$

- Respect symmetries of angular distribution
- Small theoretical uncertainty through LO cancellation of form factors.
- Good sensitivity to right handed currents (C_7')
- Good experimental resolution

Old

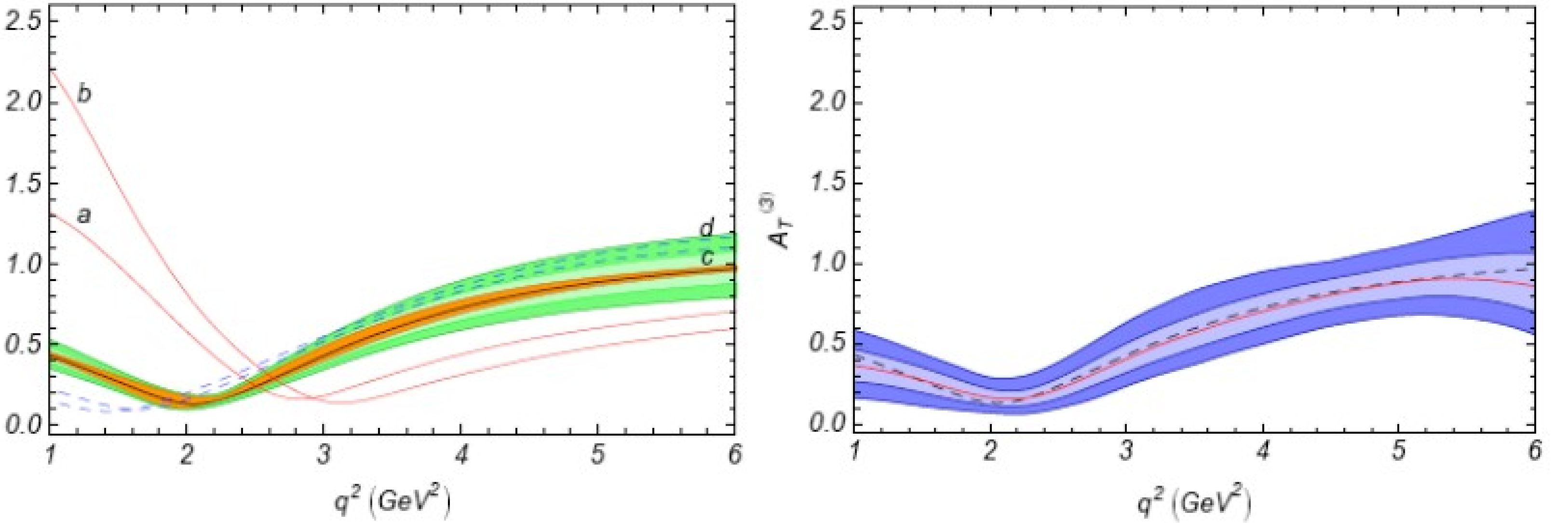
$$\xcancel{A_T^{(1)} = \frac{-2\mathrm{Re}(A_\parallel A_\perp^*)}{|A_\perp|^2+|A_\parallel|^2}} \qquad A_T^{(2)} = \frac{|A_\perp|^2-|A_\parallel|^2}{|A_\perp|^2+|A_\parallel|^2}$$

New

$$A_T^{(3)} = \frac{|A_{0L}A^*_{\parallel L} - A^*_{0R}A_{\parallel R}|}{\sqrt{|A_0|^2|A_\perp|^2}} \qquad A_T^{(4)} = \frac{|A_{0L}A^*_{\perp L} - A^*_{0R}A_{\perp R}|}{|A^*_{0L}A_{\parallel L} + A_{0R}A^*_{\parallel R}|}$$

$A_T^{(3)}$ in different SUSY models

Sensitivity to right handed current will be better than B → V γ in LHCb era



Theoretical uncertainty

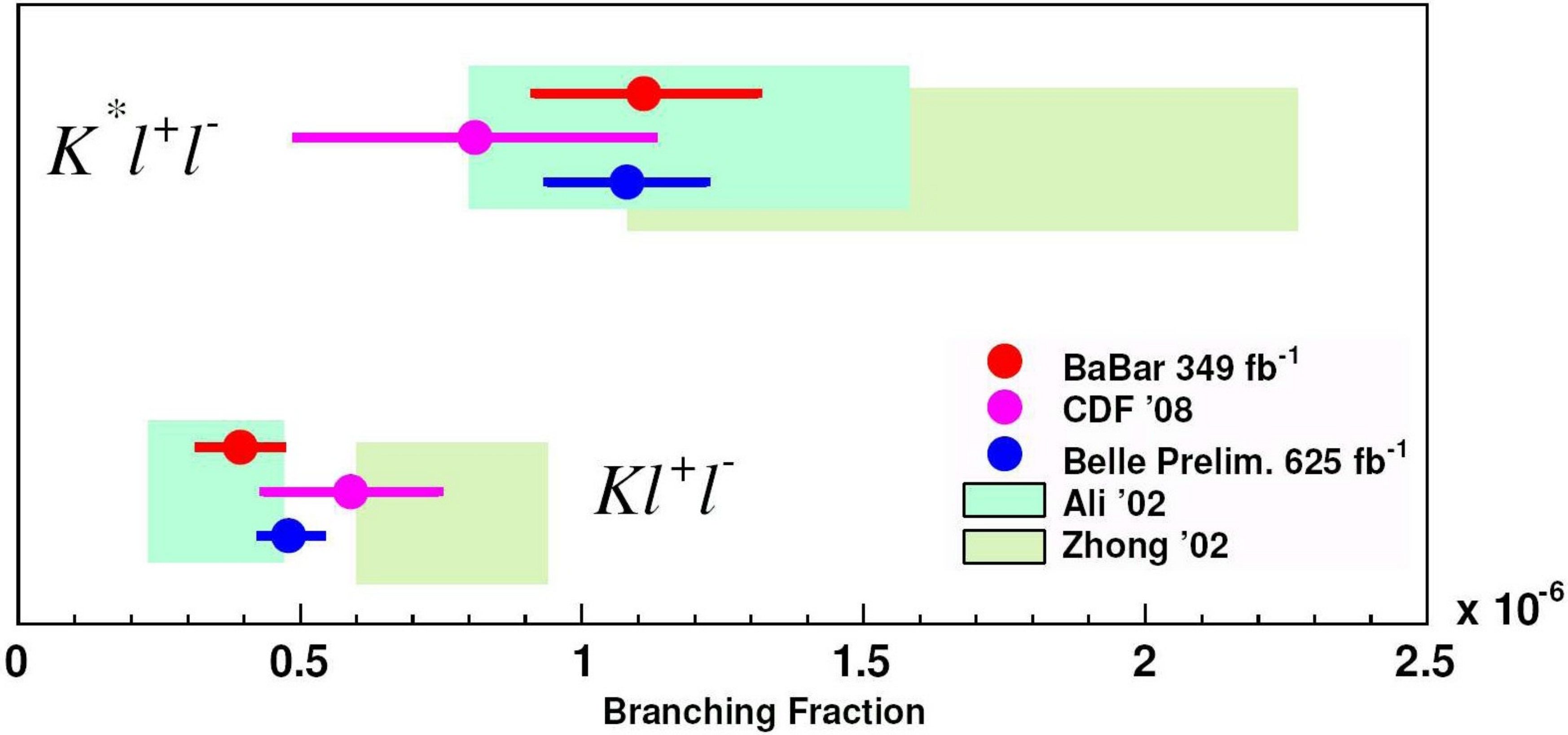
- Light green
  - 5% Λ / m_b corrections
- Dark green
  - 10% Λ / m_b corrections

Exp uncertainty at LHCb

- Light blue
  - 1σ contour at 10 fb-1 @ LHCb
- Dark blue
  - 2σ contour at 10 fb-1 @ LHCb

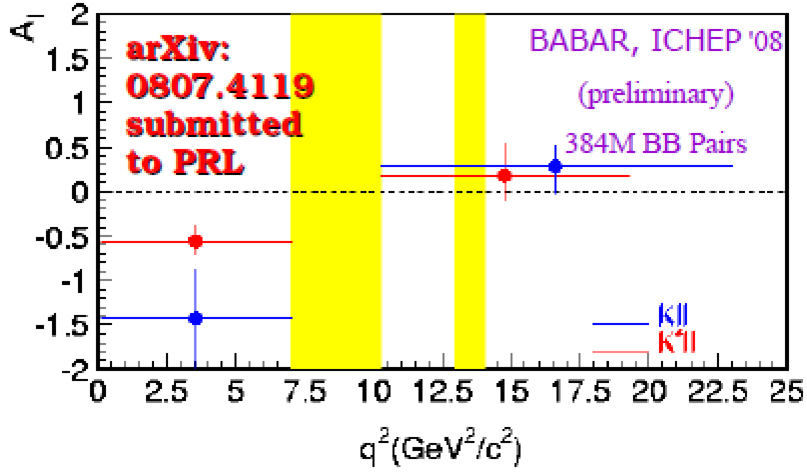
Exclusive experimental results

New results from both BaBar and BELLE this year



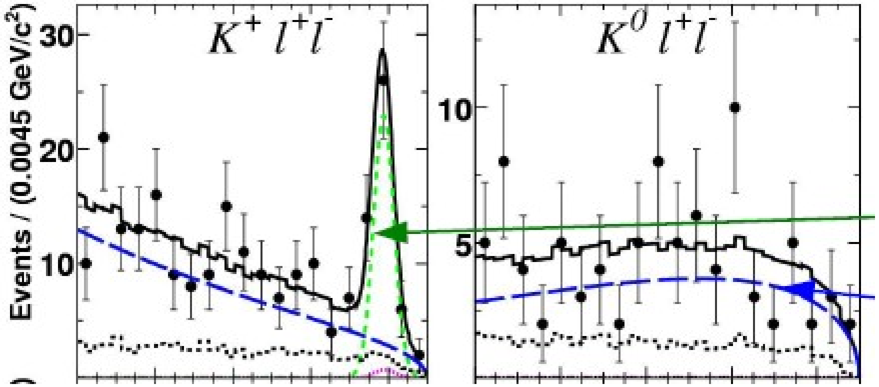
$B \to K^{(*)} l^+l^-$ isospin asymmetry

Look at asymmetry between B^0 and B^+ decays

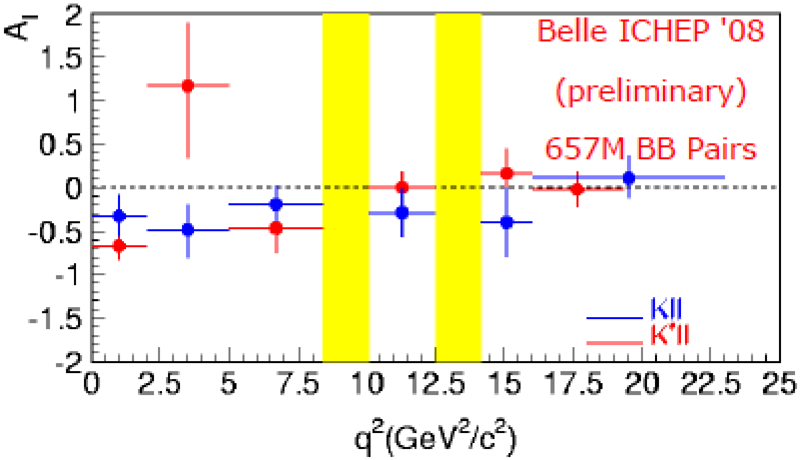

arXiv: 0807.4119 submitted to PRL

BABAR, ICHEP '08 (preliminary)

384M BB Pairs



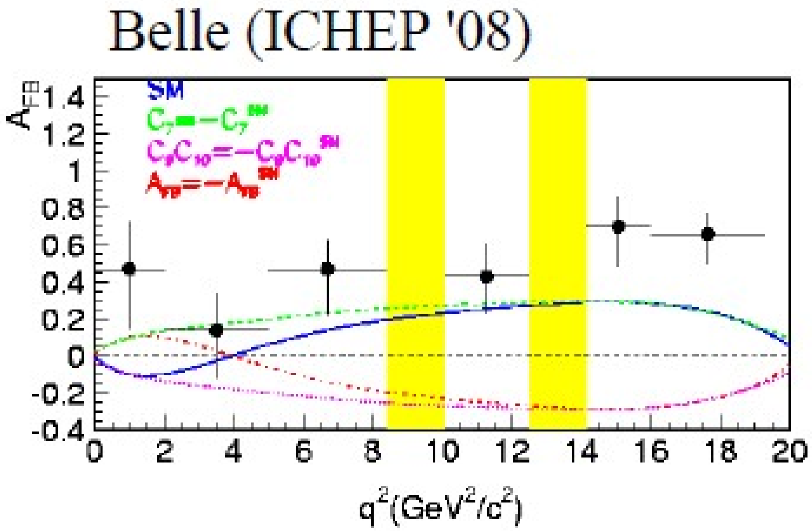
From BaBar analysis

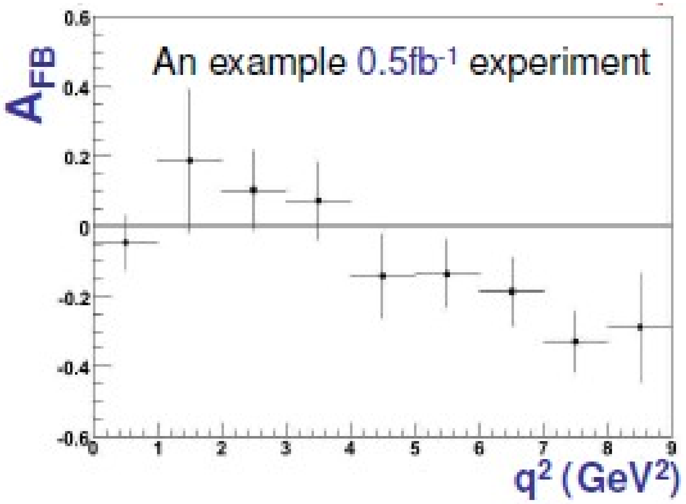

Belle ICHEP '08 (preliminary)

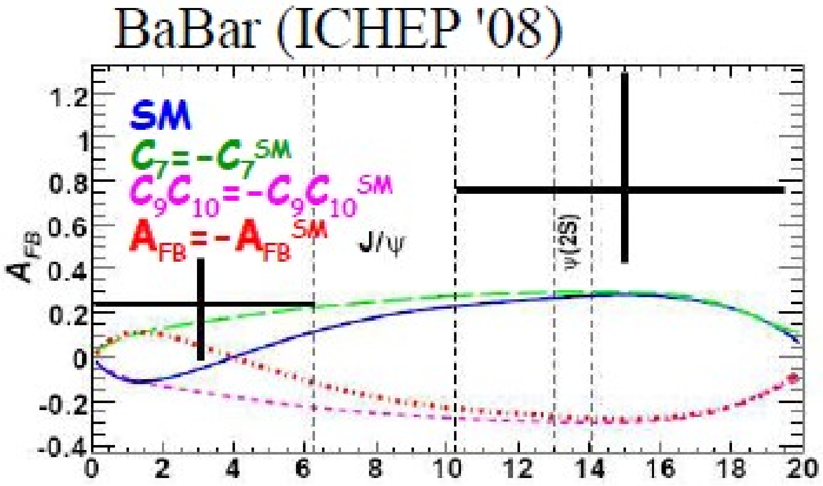
657M BB Pairs

B → $K^* l^+l^-$ forward backward asymmetry

- Results are compatible with SM but are certainly interesting!
- Great prospects for LHCb to resolve this.
  - Expect O(2k) events in 2009



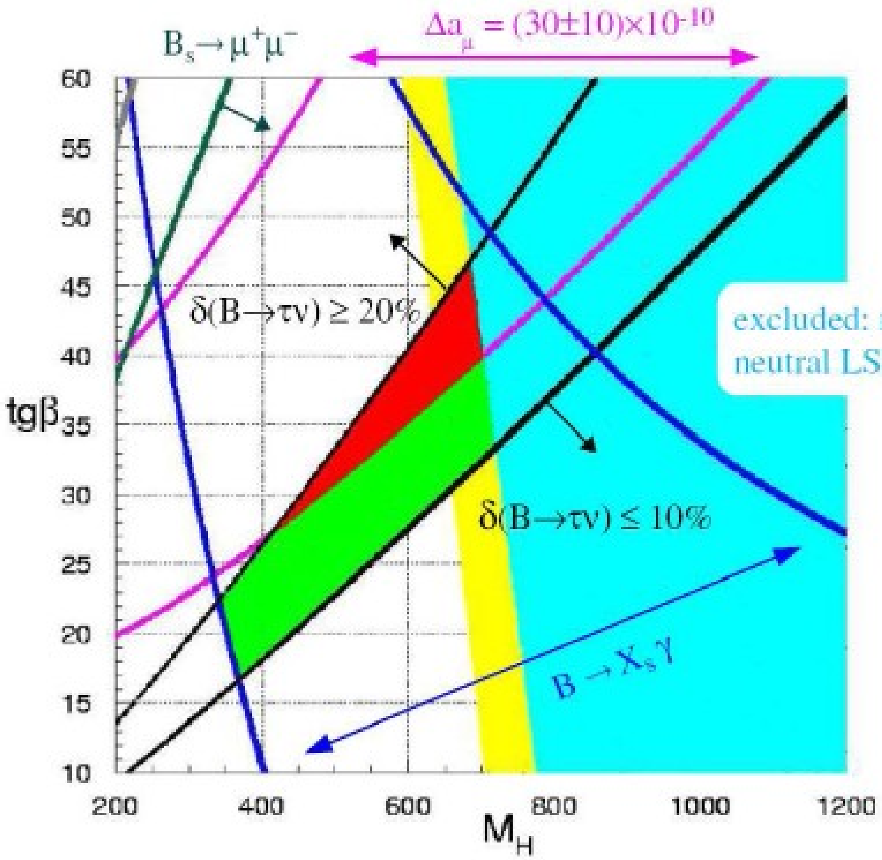




Fully leptonic decays

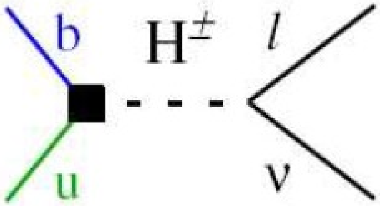
Can set many servere constraints on NP

B-physics, $(g\text{-}2)_\mu$ and WMAP



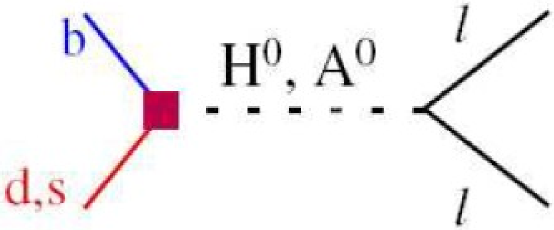
Scenarios in MFV

$\tan\beta \sim (30-50)$, $\mathbf{M_H \sim (300-500)GeV}$, $\mathbf{M_{\tilde{q}} \sim (1-2)TeV}$



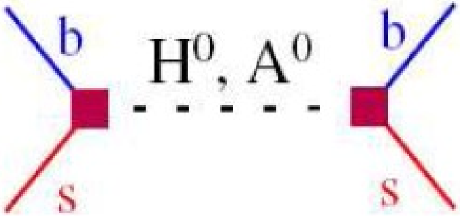
$B^{\pm} \to l^{\pm}\nu$

$\sim (10-30)\%$ suppression



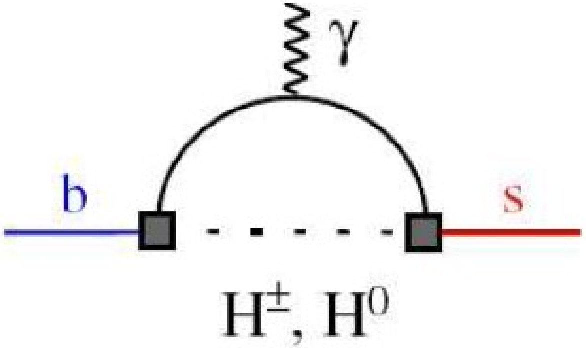
$B_{s,d} \to l^{+}l^{-}$

up to $10\times$ enhancement



ΔM_{B_s}

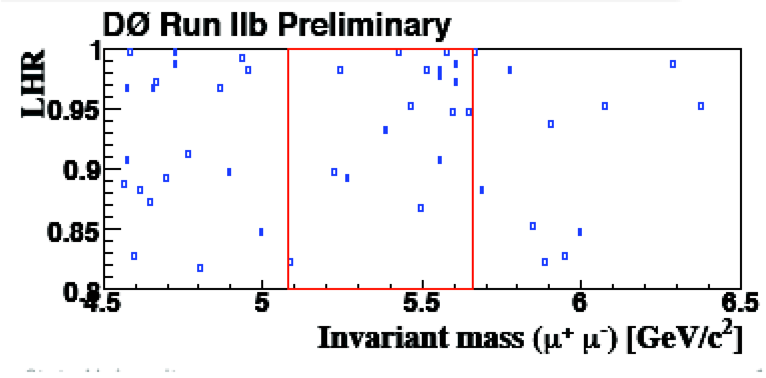
$\sim (0-10)\%$ suppression

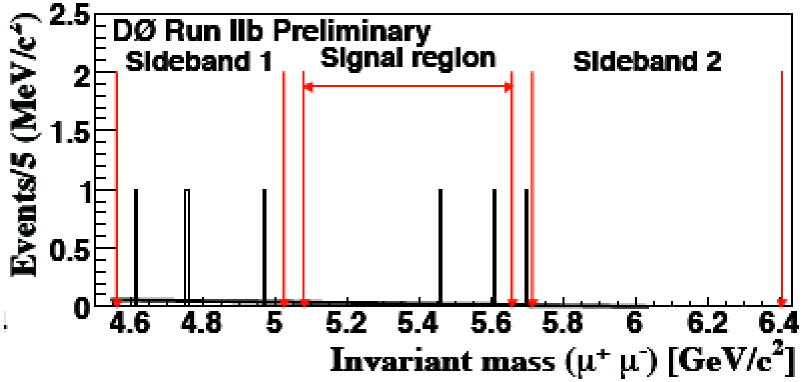


$B \to X_s\gamma$

up $\sim (0-20)\%$ enhancement

Search for $B^0 \rightarrow \mu^+\mu^-$

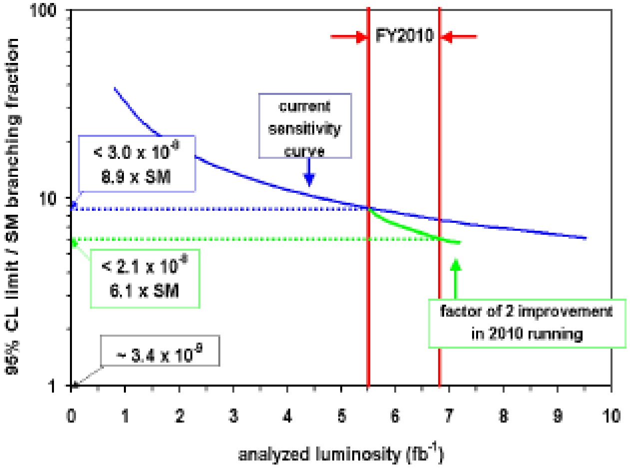




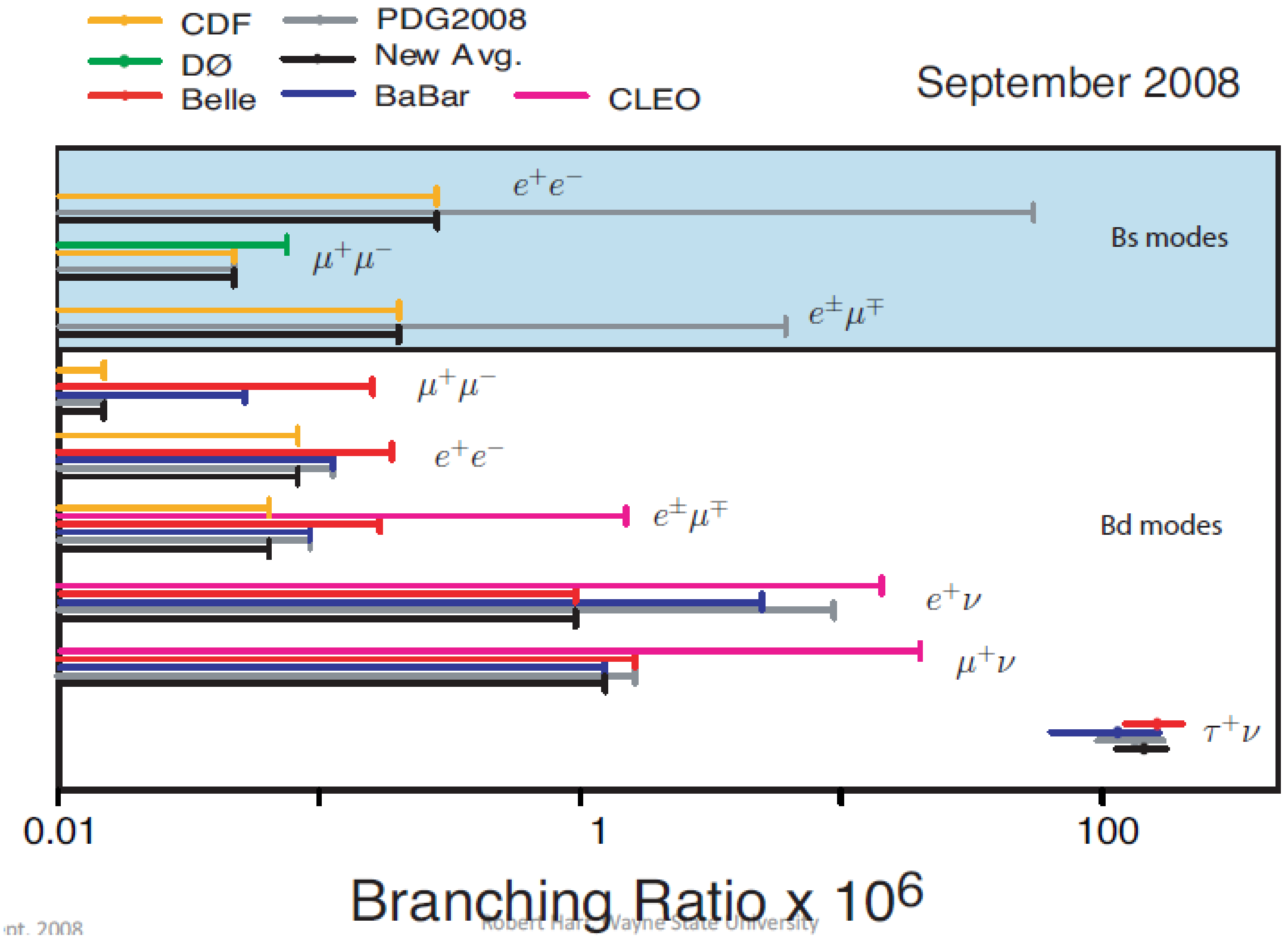
Projections indicate that Tevatron can push combined limit to 4x SM.

At LHC, LHCb will be dominant, at least in initial years

- 1 nominal year (2 fb^{-1}) will provide 3σ evidence at SM level.



Leptonic decays



Write-up

Radiative decays b → s/d γ

Shohei Nishida, **Ben Pecjak**

Semi-leptonic decays

Gerald Eigen, Thorsten Feldmann

Leptonic decays

Bob Harr, Paride Paradisi

Rare K decays

Christopher Smith, David Jaffe

Many thanks to the whole working group!