Working Group 2 Report: Rare B Decays

- Radiative penguin B decays ($b \rightarrow s,d\ \gamma$)
- Electroweak penguin B decays ($b \rightarrow s\ l^+ l^-$)
- Rare B decays with taus or neutrinos ($B \rightarrow \tau\nu$, $b \rightarrow s\nu\nu$)
- Very rare leptonic B decays ($B_s \rightarrow \mu\mu$)

Flavor in the Era of the LHC
Final Meeting
March 26, 2007

Jeffrey Berryhill (FNAL)
on behalf of other WG2 editors and contributors

Outline

Contemporary Standard Model predictions
Prospects for LHCb, Super B, CMS/ATLAS
Implications for new physics

editors

- **Radiative penguin B decays (P. Gambino, A. Goloutvin)**
  Inclusive and exclusive $b \to s\gamma$, $d\gamma$; BF and CPV

- **Electroweak penguin B decays (T. Feldmann, J. Berryhill)**
  Inclusive $b \to sll$ and angular analysis of $B \to K^*ll$

- **Rare B decays with taus or neutrinos (Y. Grossman, T. Iijima, P. Paradisi)**
  $B \to l\nu$, $D(^*)\tau\nu$, $K\nu\nu$ BF

- **Very rare leptonic B decays (U. Nierste, M. Smizanska)**
  B_s, $B_d \to \mu\mu$ BF

Outline

- Radiative penguin B decays (P. Gambino, A. Goloutvin)

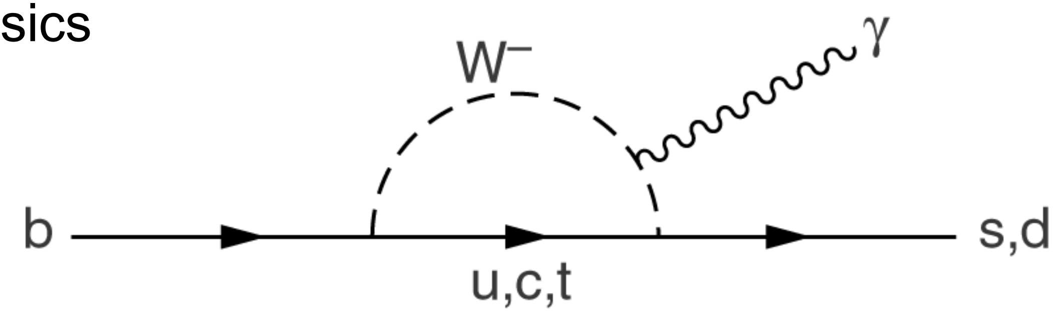
Inclusive b →s,d γ BF and CPV (SuperB)

Exclusive B → Xs,d γ BF, direct CPV, TDCPV
(SuperB, LHCb,ATLAS)

Inclusive b →s γ

A “Standard Candle” of flavor physics

Sensitive to top quark couplings
V_{td}, V_{ts}



Photon is DIS probe of B (shape function, m_B)

Broad sensitivity to new physics (2HDM, SUSY, LR, LED, little Higgs)

Misiak et al.

$$\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma>1.6\,\mathrm{GeV}} = \mathcal{B}(\bar{B} \to X_c e\bar{\nu})_{\mathrm{exp}} \left[\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to ce\bar{\nu})}\right]_{\mathrm{LO\ EW}} f\left(\frac{\alpha_s(M_W)}{\alpha_s(m_b)}\right) \times$$

$$\times \left\{ 1 + \underbrace{\underset{\sim 30\%}{\underset{\mathrm{NLO}}{\mathcal{O}(\alpha_s)}} + \boxed{\underset{\sim 10\%}{\underset{\mathrm{NNLO}}{\mathcal{O}(\alpha_s^2)}}} + \underset{\sim 4\%}{\mathcal{O}(\alpha_{\mathrm{em}})}}_{\text{perturbative corrections}} + \underbrace{\underset{\sim 1\%}{\mathcal{O}\left(\frac{\Lambda^2}{m_b^2}\right)} + \underset{\sim 3\%}{\mathcal{O}\left(\frac{\Lambda^2}{m_c^2}\right)} + \underset{\sim 5\%}{\mathcal{O}\left(\frac{\Lambda}{m_b}\alpha_s\right)}}_{\text{non-perturbative corrections}} \right\}$$

(methods: Optical Theorem,
Operator Product Expansion,
Heavy Quark Effective Theory)

Need NNLO precision to compare with experiment

Inclusive b →s γ

Recent estimate of NNLO decay rate!

Misiak et al.

In collaboration with: H.M. Asatrian, K. Bieri, M. Czakon, A. Czarnecki, T. Ewerth, A. Ferroglia, P. Gambino, M. Gorbahn, C. Greub, U. Haisch, A. Hovhannisyan, T. Hurth, A. Mitov, V. Poghosyan, M. Ślusarczyk and M. Steinhauser.

hep-ph/0609232

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

7.3% precision at NNLO

5% non-perturbative $\mathcal{O}\left(\alpha_s \frac{\Lambda}{m_b}\right)$ ← See e.g. hep-ph/0609224

3% parametric $\left(\underset{2.0\%}{\alpha_s(M_Z)},\ \underset{1.6\%}{\mathcal{B}^{\rm exp}_{\rm semileptonic}},\ \underset{1.1\%}{m_c},\ \ldots\right)$

3% m_c-interpolation ambiguity

3% higher order $\mathcal{O}(\alpha_s^3)$

P.S. :Becher & Neubert, hep-ph/0610067: -5% shift from 2-loop corrections at intermediate and soft scales

$$\mathrm{Br}(\bar{B} \to X_s\gamma) = (2.98 \pm 0.26) \cdot 10^{-4}$$

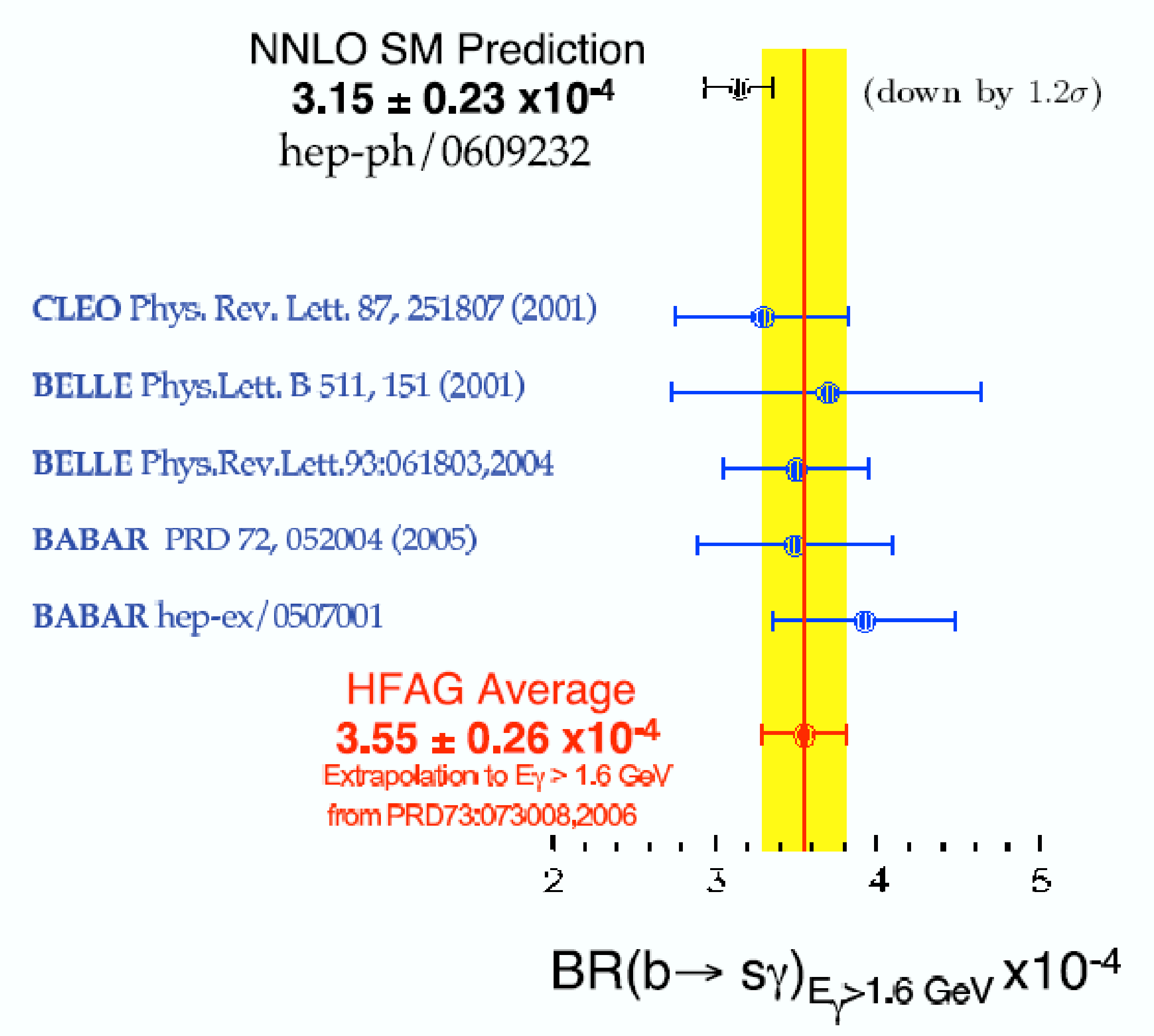
Inclusive b →s γ

Experiment – NNLO Theory = +1.2σ

B factories
are likely to improve
precision to 5%

Super B could push
down Eγ cutoff from current
1.8 GeV to 1.5 GeV

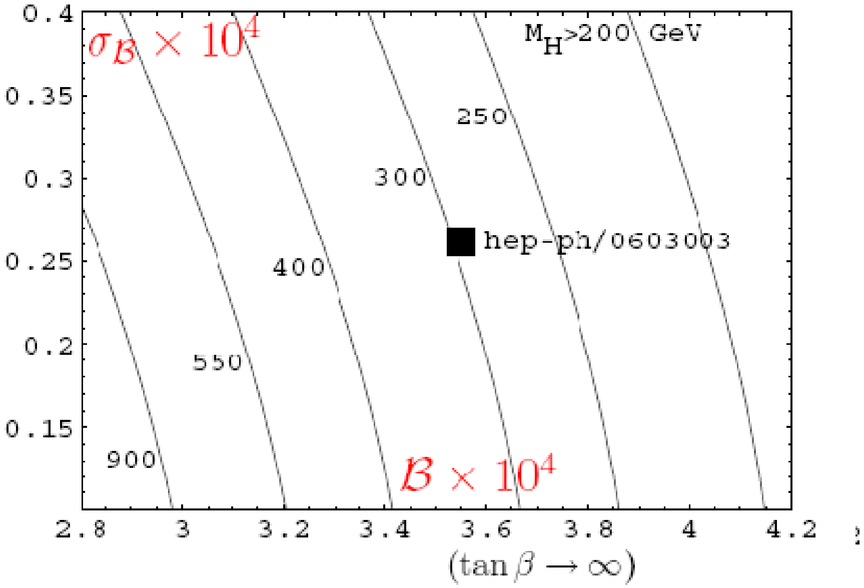
Super B incl. ACP precision:
0.9 % @ 5 ab^{-1}
0.3% @ 50ab^{-1}



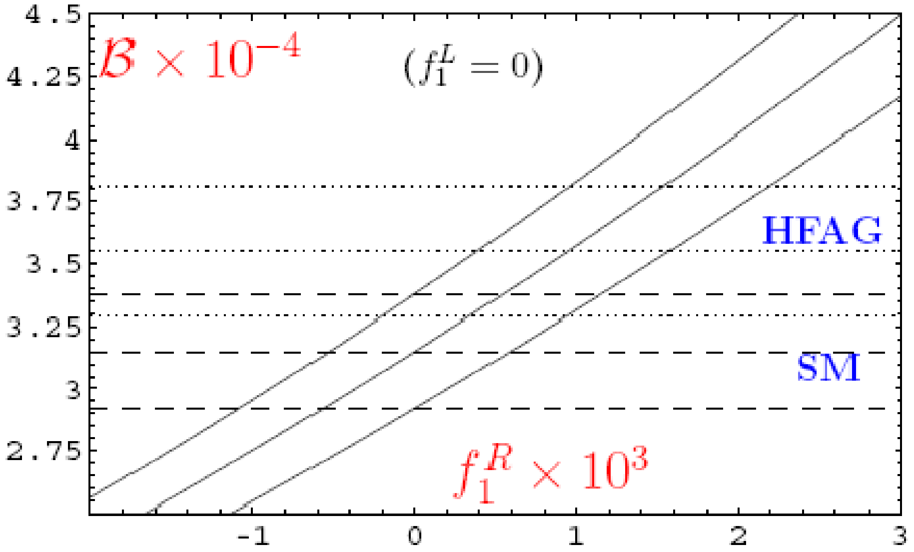
Super B can measure incl. b →dγ rate to 25% with 5 ab^{-1}

Inclusive b →s γ

2HDM II Limit



Right handed Wtb coupling



$f^R \sim 10^{-3}$

$M_{H+} > 295$ **GeV @95% C.L.**

MSSM limits to be (re)evaluated: ideally NLO w/ minimal and general flavor violation

Exclusive b →s,d γ

High-precision measurements will be possible, but predictions complicated by form factors and other non-perturbative effects

Interesting observables are direct/time-dependent CPV and rate ratios:

$$R \equiv \frac{\overline{\mathcal{B}}(B \to (\rho,\omega)\gamma)}{\overline{\mathcal{B}}(B \to K^*\gamma)} = \frac{|V_{td}|^2}{|V_{ts}|^2}(0.75 \pm 0.11(\xi) \pm 0.02(\text{UT param., O}(1/m_b)))$$

$\Delta B = 1$ version of B_s mixing constraint, needs form factor ratio ξ

$$A_I(K^*) = \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)} = (5.4 \pm 1.4)\%$$

Sensitive to sign and size of C7 and C8, A_I ($\rho\gamma$) sensitive to UT angle gamma

$$A_{CP}(t) = \frac{\Gamma(\bar{B}^0(t) \to \bar{K}^{*0}\gamma) - \Gamma(B^0(t) \to K^{*0}\gamma)}{\Gamma(\bar{B}^0(t) \to \bar{K}^{*0}\gamma) + \Gamma(B^0(t) \to K^{*0}\gamma)} = C\cos(\Delta m_B t) + S\sin(\Delta m_B t)$$

C (direct CPV): SM b →s is unobservably small (null test), b→d is large (~10%)
S (TDCPV): at most a few percent (null test)

$S_{V\gamma}$	$B \to \rho$	$B \to \omega$	$B \to K^*$	$B_s \to \bar{K}^*$	$B_s \to \phi$
In %	0.2 ± 1.6	0.1 ± 1.7	$-(2.3 \pm 1.6)$	0.3 ± 1.3	$-(0.1 \pm 0.1)$

Exclusive b →s,d γ: R

$$R \equiv \frac{\overline{\mathcal{B}}(B \to (\rho,\omega)\gamma)}{\overline{\mathcal{B}}(B \to K^*\gamma)} = \frac{|V_{td}|^2}{|V_{ts}|^2}(0.75 \pm 0.11(\xi) \pm 0.02(\text{UT param., O}(1/m_b)))$$

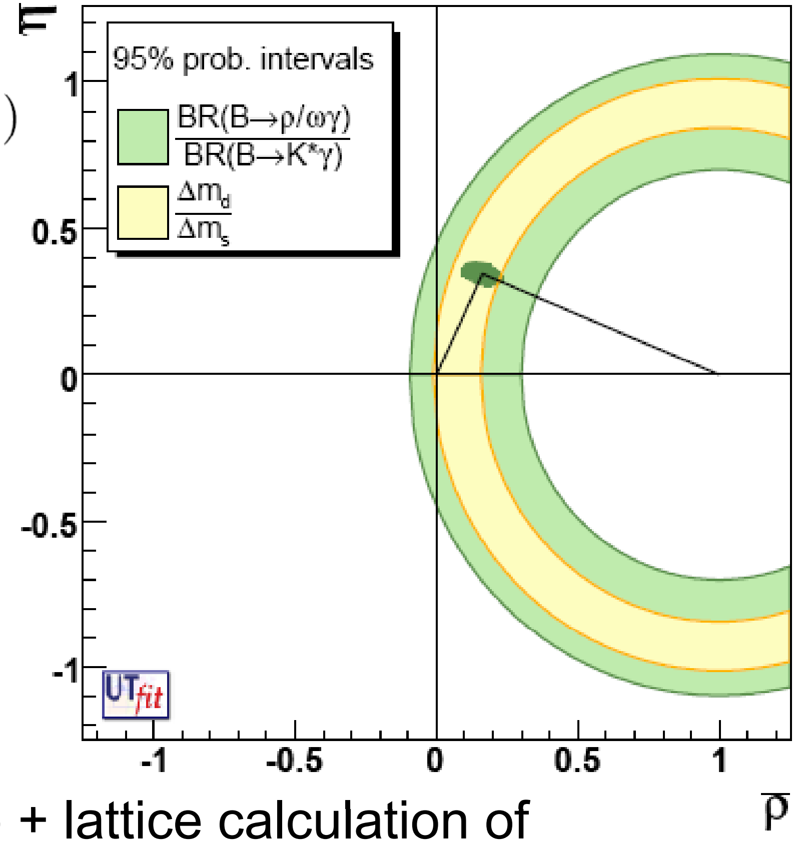
Current B factory average, over ρ+ ρ^0, ω

$$|V_{td}/V_{ts}|^{\text{HFAG}}_{B\to V\gamma} = 0.192 \pm 0.014(\text{th}) \pm 0.016(\text{exp})$$

Agrees well with Tevatron Bs mixing

$$\left|\frac{V_{td}}{V_{ts}}\right|_{\Delta m_d/\Delta m_s} = 0.2060 \pm 0.0007^{+0.0081}_{-0.0060}$$

CDF Phys.Rev.Lett.97:242003 (2006)



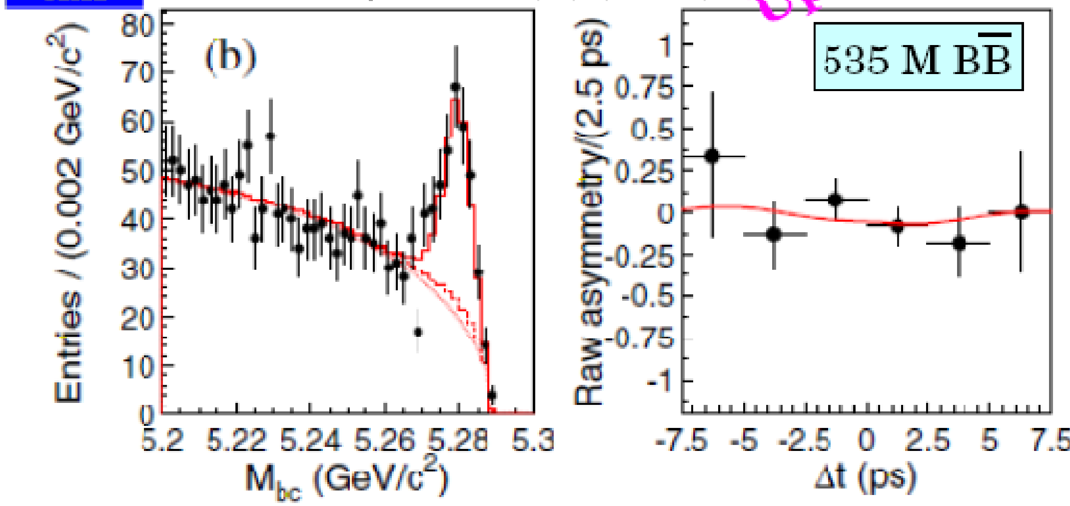
High-precision $\rho^0\gamma$ sample in SuperB/LHCb + lattice calculation of FF ratio could improve error to 3-4% (i.e. comparable to Tevatron)

Exclusive b →s,d γ: Super B

B factories have unique TDCPV capability for $K_s\ \pi^0\ \gamma$

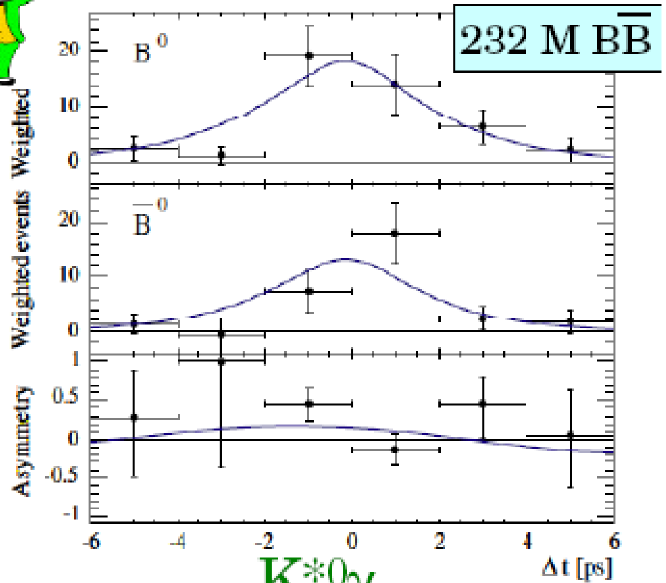
[PRD 74, 111104(R) (2006)]

Updated



$B \rightarrow K_s\pi^0\gamma$ (with $M(K\pi)<1.8\,\mathrm{GeV}$)

[PRD 72, 051103(R) (2005)]



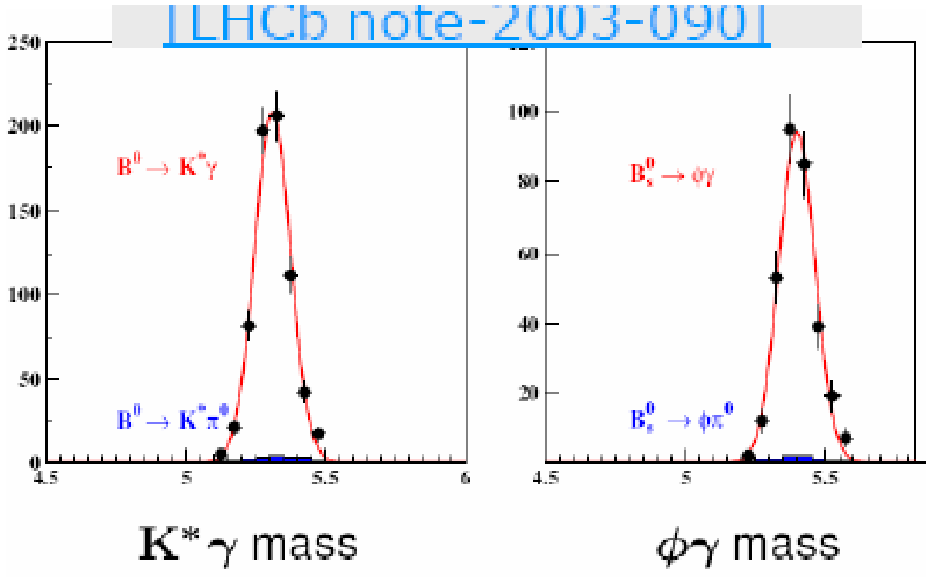
$K^{*0}\gamma$

Current S is – 28 ± 26 %, 10% @ 5 ab^{-1}, 3% @50 ab^{-1}

Could be improved with photon conversion sample, $K_S\ \phi\ \gamma$ sample

Also $S(\rho^0\ \gamma)$ measurement will be possible (10% @ 50 ab^{-1})

Exclusive b →s,d γ: LHCb



Decay	2 fb^{-1} yield	B/S
$B_d \to K^*\gamma$	35000	< 0.7
$B_s \to \phi\gamma$	9000	< 2.4
$\Lambda_b \to \Lambda\gamma$	750	<42
$B_d \to \omega\gamma$	40	< 3.5

Collect radiative decays with photon trigger

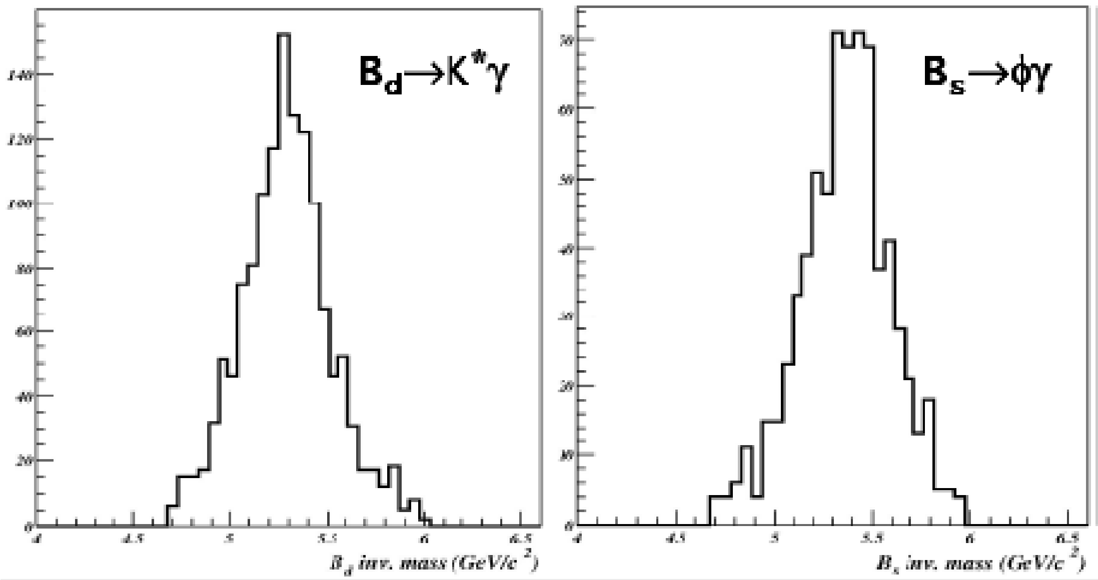
High precision ACP studies possible
Stat error < 1% in 1 year

$B_s \to \phi\gamma$ gives vertex-able TDCPV mode

Photon polarization measured in $\Lambda\gamma$ decay mode 20% @ 2 fb^{-1}

Exclusive b →s,d γ: ATLAS

[ATLAS, phys-pub-2005-006]



Trigger on muon with pT > 6 GeV, Select photons with ET > 5 GeV

Decay	20 fb^{-1} yield	B/S
$B_d \to K^*\gamma$	9400	< 100
$B_s \to \phi\gamma$	3200	< 400

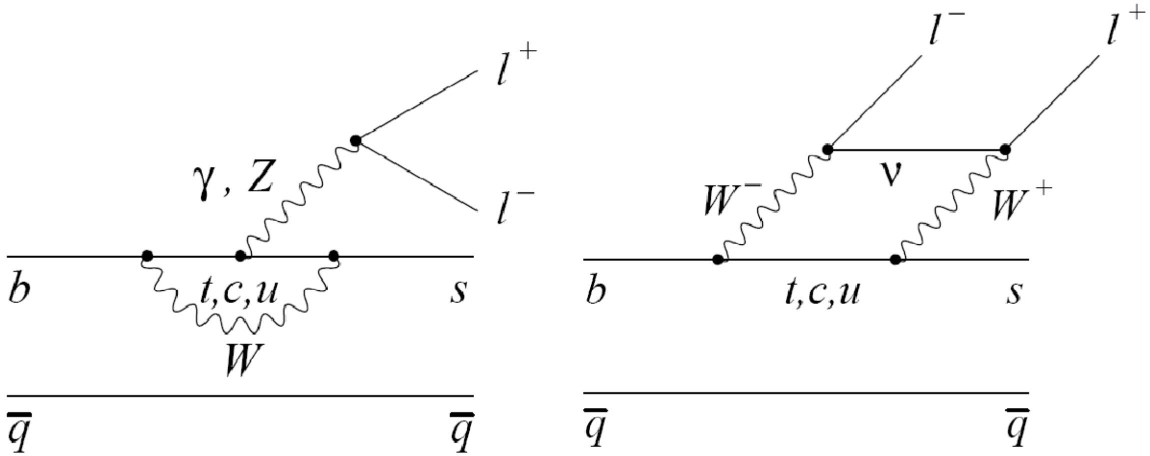
Outline

Electroweak penguin B decays (T. Feldmann, J. Berryhill)

Inclusive b→ sll and angular analysis of B →K*ll

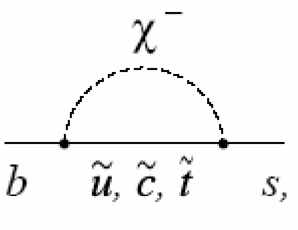
(LHCb, Super B, ATLAS)

B →K *ll*, B →K* *ll*, *b* → *sll*



Photon penguin (C7)
Vector EW (C9)
Axial-vector EW (C10)

Exclusive decays from three b→ s*ll* penguin diagrams



New physics possible for each diagram, and also new operators (scalar penguins, right-handed currents)

Three-body kinematic distributions and decay rates to measure all three (complex) penguin amplitudes

Rare process with BF ~ 10^{-6}

Exclusive decay rates now well-measured; Next step: distributions and asymmetries

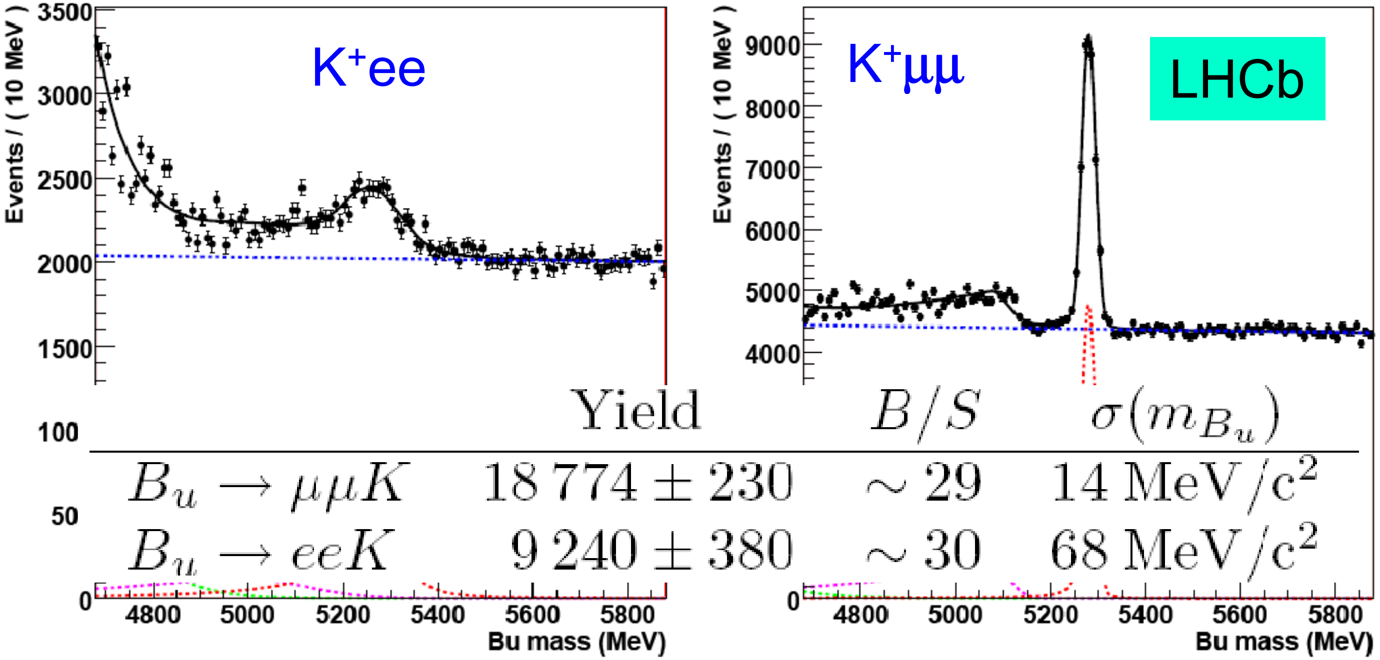
$B^+ \to K^+ l\, l$: LHCb

Higgs-like scalar/pseudoscalar operators can enhance $K^+\mu\mu$ over K^+ee
Interesting cross-check on an anomalous $B_S \to \mu\mu$ signal

Super B precision in RK = BF(B →K μμ)/BF(B →Kee) is 4% @ 50 ab^{-1}
(electrons and muons have roughly equal sensitivity)

LHCb has unequal sensitivity but still a significant K^+ee signal:

LHCb RK
precision is
4.3% @ 10 fb^{-1}

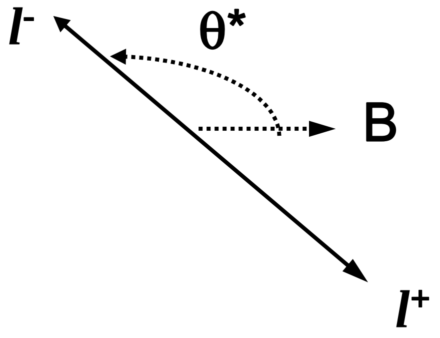


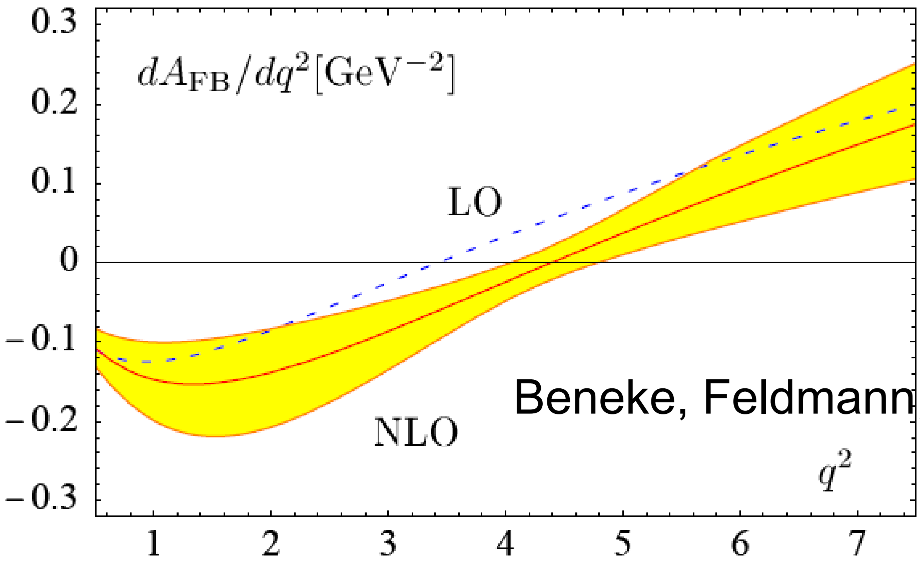
	Yield	B/S	$\sigma(m_{B_u})$
$B_u \to \mu\mu K$	$18\,774 \pm 230$	~ 29	$14\ \mathrm{MeV}/c^2$
$B_u \to eeK$	$9\,240 \pm 380$	~ 30	$68\ \mathrm{MeV}/c^2$

P. Koppenburg, LHCb Note 2007-034

B→K* *ll AFB*

B→ K*ll decay kinematics uniquely described by 3 angles + dilepton mass (q^2)





Beneke, Feldmann, Seidel

Cos θ* lepton- angle

in dilepton rest frame.

Forward-backward asymmetric!

AFB vs. Q^2 : for 1 $\mathrm{GeV}^2 < Q^2 < 4m_c^2$ describe with 2 form factors + Wilson

coefficients from QCDF (Beneke Feldmann Seidel Ali Kramer Zhu)

$$\frac{d^2\Gamma}{dq^2 d\cos\theta} = \frac{G_F^2|V_{ts}^*V_{tb}|^2}{128\pi^3}\left(\frac{\alpha_{em}}{4\pi}\right)^2 m_B^3\lambda_{K^*}\left(1 - \frac{q^2}{m_B^2}\right)^2\left\{2\zeta_\perp^2(1+\cos^2\theta)\frac{q^2}{m_B^2}\times\right.$$
$$\left.(|C_9^\perp|^2+(C_{10}^\perp)^2) - 8\zeta_\perp^2\cos\theta\frac{q^2}{m_B^2}\mathrm{Re}(C_9^\perp)C_{10}^\perp + \zeta_\|^2(1-\cos^2\theta)(|C_9^\||^2+(C_{10}^\|)^2)\right\}$$

B→K* *ll AFB*

Zero of dAFB/dQ^2 is a precise estimator of C9/C7, predicted to 5-8%

$$q_0^2 = (4.07^{+0.16}_{-0.13})\ \mathrm{GeV}^2$$

Ali Kramer Zhu

$$q_0^2[K^{*0}] = 4.36^{+0.33}_{-0.31}\ \mathrm{GeV}^2$$

Beneke Feldmann Seidel

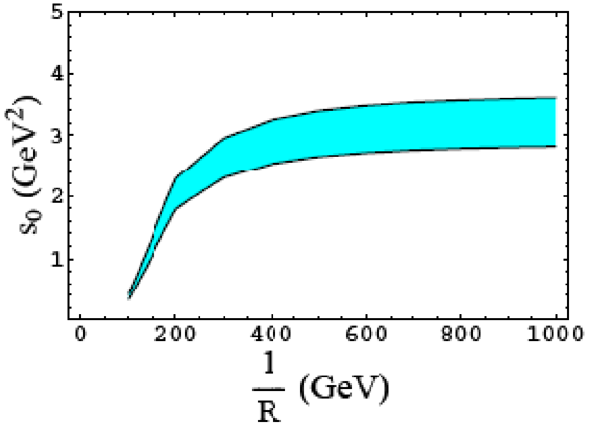
Need to know better: form factors, power corrections, and isospin breaking

Long distance contamination from charmonium and light resonances is difficult to estimate, but is believed to be avoidable for

1 GeV^2 < Q^2 < 6 GeV^2 (Khodjamirian)

CP asymmetry in AFB is a precision null test (Hiller Buchalla Isidori) and so is isopin asymmetry (Feldmann Matias)

Zero of AFB can be shifted by universal extra dimensions (Colangelo De Fazio Ferrandes Pham) →



B →K**ll* : LHCb

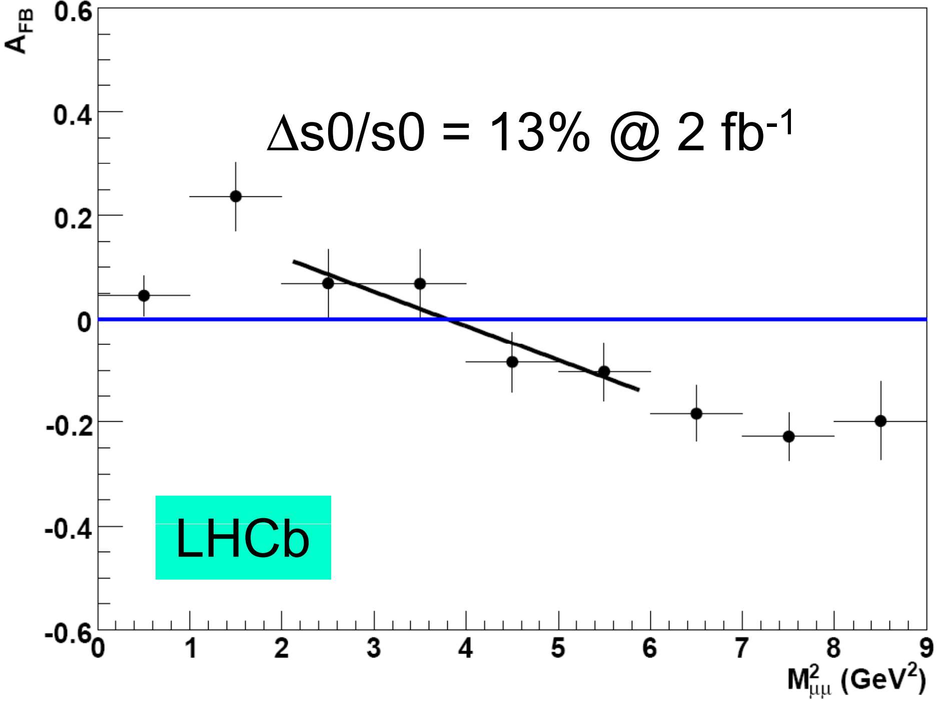
Select events on dimuon trigger, K^{*0} μμ candidates with M = M(B) ± 50 MeV and M(Kπ) = M(K*) ± 100 MeV

In 2 fb^{-1}:
7200 signal, 1770 bb background,
<1730 irreducible Kπ ***ll*** background (not well known, upper bound from BaBar)

With bb background only, signal precision is 1.3% @ 2 fb^{-1}

U. Egede

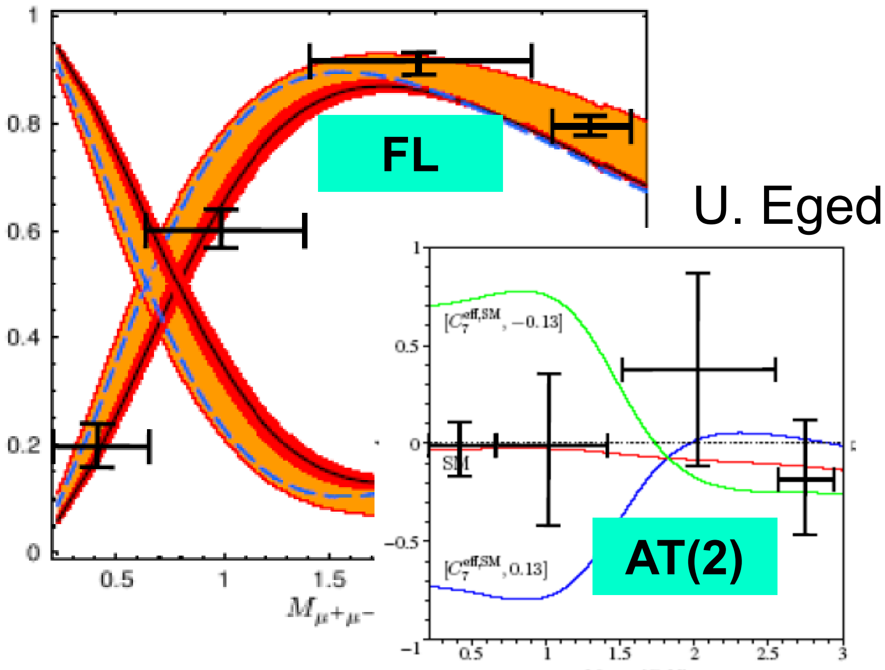
Extract AFB zero from binned linear fit of dA_{FB}/dQ^2 from 2-6 GeV^2



$B \to K^{*}ll$: LHCb transversity angle study

$M_{\mu\mu}^{2}$ range	Resolutions	
	$A_T^{(2)}$	F_L
0.05 → 0.49	0.180	0.037
0.49 → 1.96	0.400	0.033
1.96 → 6.25	0.470	0.018
6.25 → 9.0	0.31	0.020

LHCb projections



U. Egede

$$F_L(q^2) = \frac{|A_0|^2}{|A_\perp|^2 + |A_\parallel|^2 + |A_0|^2} \qquad A_T^{(2)}(q^2) \equiv \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$$

Studying other decay angles (K* polarization, K*/μμ decay planes) will exclude wide range of models with “wrong-handed” penguin operators (like TDCPV in b →s γ)

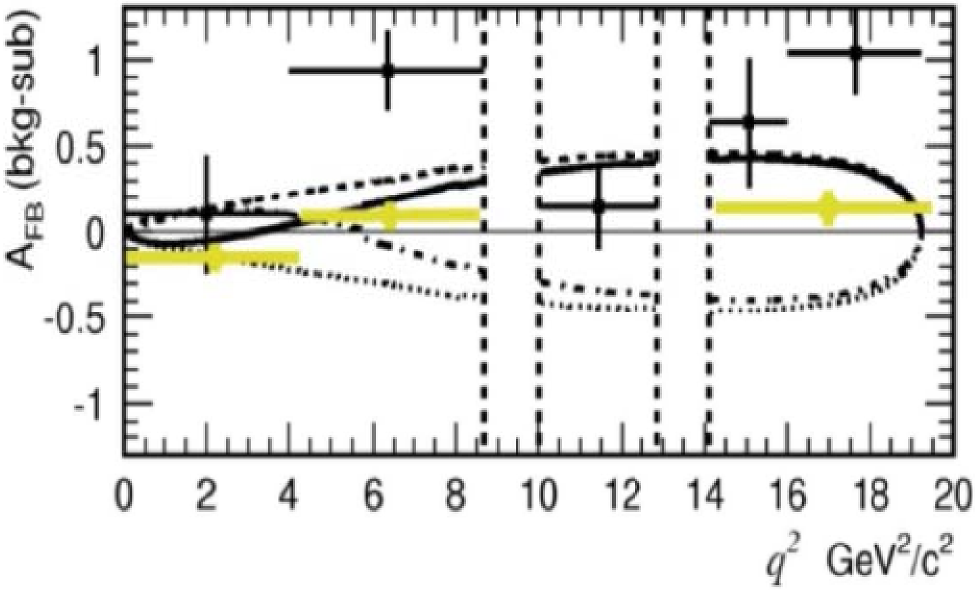
(Kruger and Matias)

B →K*ll : ATLAS

With dimuon trigger, ATLAS should harvest signals for a variety of exclusive channels (BOTH K^{*+} and K^{*0} viable)

Key selection requirements are muon particle ID and dimuon vertexing

Background is dominated by other b decays to muons



S and B @ 30 fb^{-1}

	Decay	Signal	Background
4.8%	$B_d^0 \to K^{0*}\mu^+\mu^-$	2500	12000
	$B_s^0 \to \phi\mu^+\mu^-$	900	10000
5.2%	$B^+ \to K^{*+}\mu^+\mu^-$	2300	12000
3.5%	$B^+ \to K^+\mu^+\mu^-$	4000	12000
	$\Lambda_b \to \Lambda^0\mu^+\mu^-$	800	4000

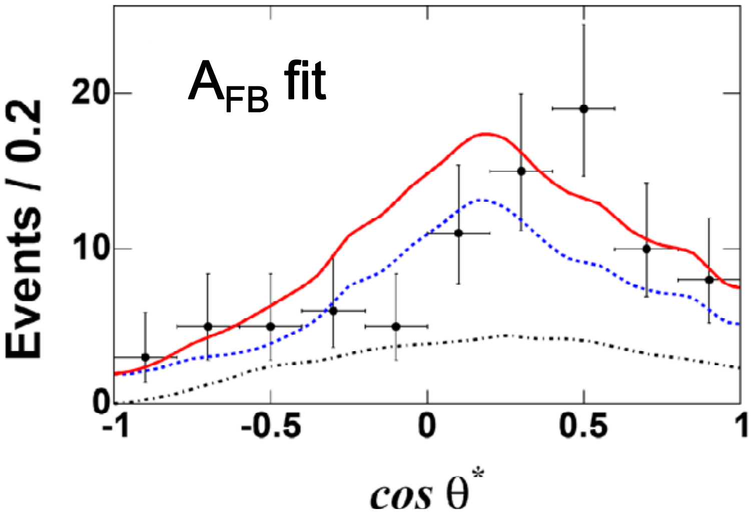
P. Reznicek et al.

B →K**ll* : Super B

K*ll Signals (no Kπll background, all Q^2)
SuperB @ 1 ab^{-1}: 229 ±16 events
LHCb @ 2 fb^{-1}: 7200 ± 95 events
ATLAS @30 fb^{-1}: 4800 ±170 events

2 fb^{-1} LHCb = 30 ab^{-1} Super B = 200 fb^{-1} ATLAS+CMS

BaBar: K* polarization FL and AFB with binned fits to helicity angle distributions



2-3% AFB, FL precision for low Q^2 @ 50 ab^{-1}

precision (%)

$\int \mathcal{L}\,(\mathrm{ab}^{-1})$	1	5	10	50
$K^*\ell\ell\ A_{FB}$				
1-6 GeV^2/c^4	18	8.2	5.8	2.6
$> 10\ \mathrm{GeV}^2/c^4$	11	4.7	3.3	1.5
All	7.9	3.5	2.5	1.1
$K^*\ell\ell\ F_L$				
1-6 GeV^2/c^4	12	5.3	3.7	1.7
$> 10\ \mathrm{GeV}^2/c^4$	9.4	4.2	3.0	1.3
All	7.2	3.2	2.3	1.0
$K^+\ell\ell\ A_{FB}$				
All	8.4	3.7	2.6	1.2

J. Berryhill

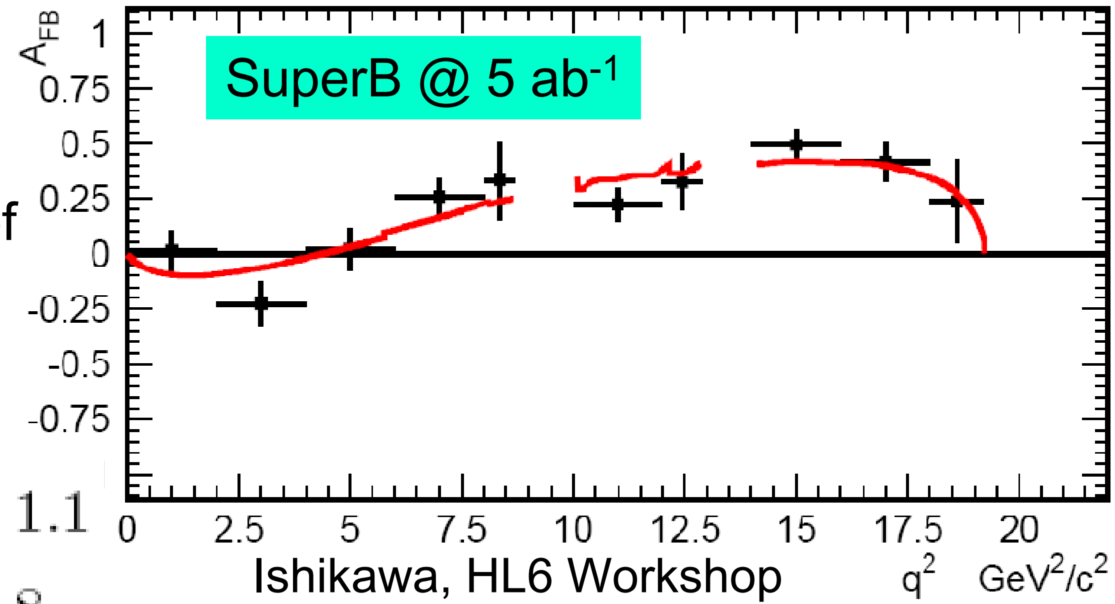
B →K*ll : Super B

Belle has extracted
Wilson coefficients C9 and C10 directly from the data
by fitting global distribution of

$$d^2\Gamma/d\cos\theta_\ell dq^2$$

$$\downarrow$$

$$\begin{aligned} A_9/A_7 &= -15.3^{+3.4}_{-4.8} \pm 1.1 \\ A_{10}/A_7 &= 10.3^{+5.2}_{-3.5} \pm 1.8, \end{aligned}$$



Ishikawa, HL6 Workshop

Extrapolating to SuperB,
A9/A7 (equivalent to AFB zero)
and A10/A7 can be measured
with stat. error of 4%

$\int \mathcal{L}\,(\mathrm{ab}^{-1})$	1	5	10	50
A_9	25	11	7.8	3.5
A_{10}	29	13	9.2	4.1

precision (%)

How global can the fit be to get a comparable theory error?
Restricting to 1-6 GeV^2 roughly doubles the stat errors

Inclusive b →s *l*+ *l*-

In golden range 1-6 GeV^2, inclusive BF is precision observable (7%) rivaling b →s γ   Huber Lunghi Misiak Wyler

$$\mathcal{B}_{\mu\mu} = \Big[1.59 \pm 0.08_{\rm scale} \pm 0.06_{m_t} \pm 0.024_{C,m_c} \pm 0.015_{m_b} \pm 0.02_{\alpha_s(M_Z)} \pm 0.015_{\rm CKM} \pm 0.026_{{\rm BR}_{sl}}\Big] \times 10^{-6} = (1.59 \pm 0.11) \times 10^{-6}$$

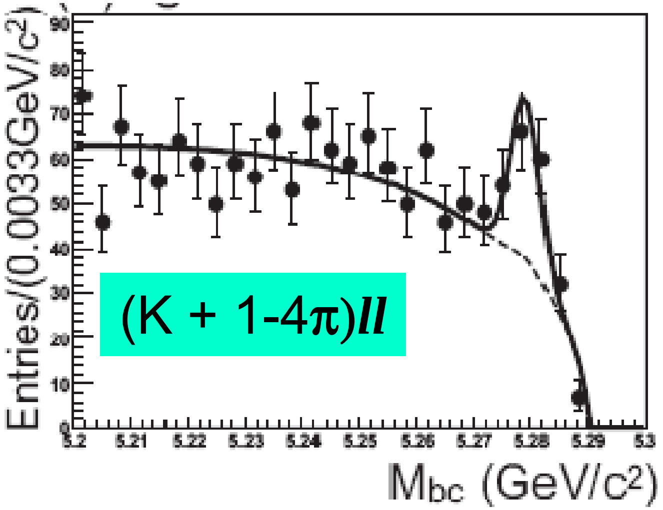
AFB should also be a (more) precise observable

Extrapolating from most recent Belle result (153 fb^{-1}), precision BF is achievable with as little as 3 ab^{-1}

Phys.Rev.D72:092005,2005.

Looser MX cut (and hence more data) may be required to avoid shape function effects (Ligeti, Lee, Stewart, Tackmann)

Xs fragmentation and its impact on AFB must be better understood. SCET may help. (Grinstein and Pirjol)



Outline

•Rare B decays with taus or neutrinos
(Y. Grossman, P. Paradisi, T. Iijima)

$B \to K \nu\nu$

$B \to \tau\nu$

Unique sensitivity at B factories

$B \to \mu\nu$

$B \to D\tau\nu$

Tag Side Reconstruction

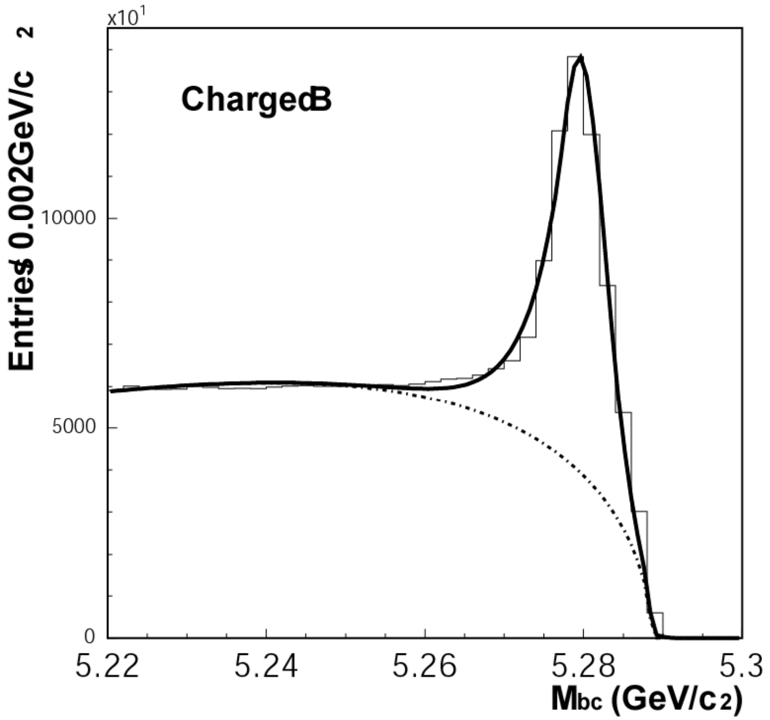
In Y(4S) → BB, reconstruct common, high-purity decay for one B (“tag-side”).

qq background largely eliminated

All other detectable particles must correspond to signal B of interest, with low combinatorial B background

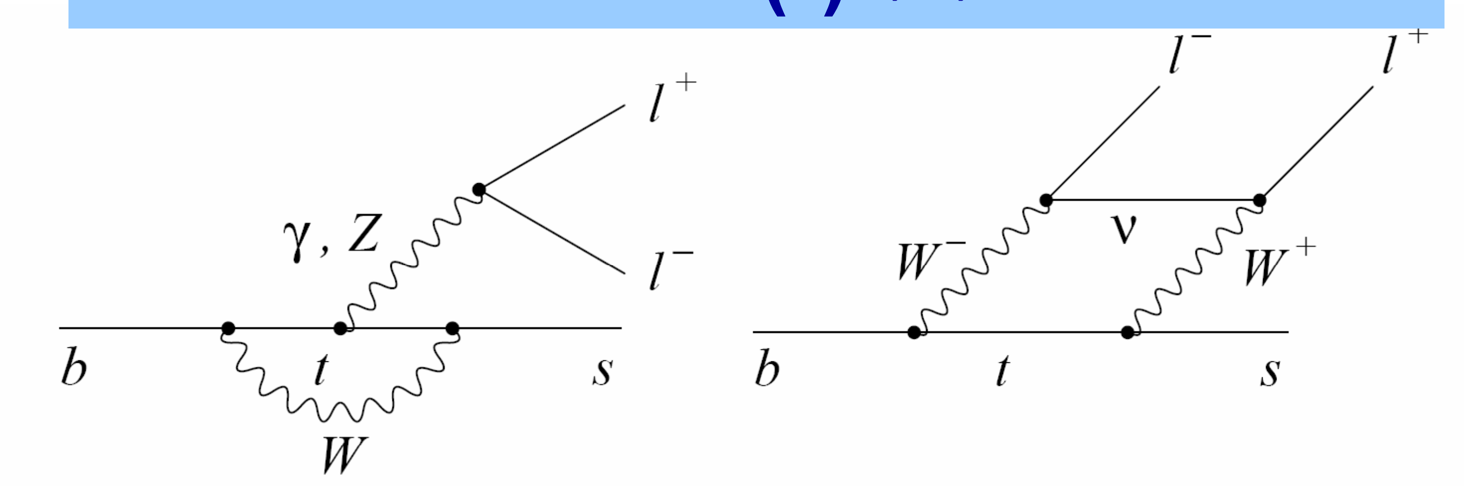
Allows study of B → “anything”
with reasonable S/B
(BF>10^{-5}-10^{-6} @ 50 ab^{-1})

Two popular methods:
Hadronic B decays
pure, 0.1-0.3% efficient



$D^0 X l \nu$ or $D^* l\nu$ tagged semileptonic
Less pure, 0.5% efficient

B →K(*) $\nu\,\nu$



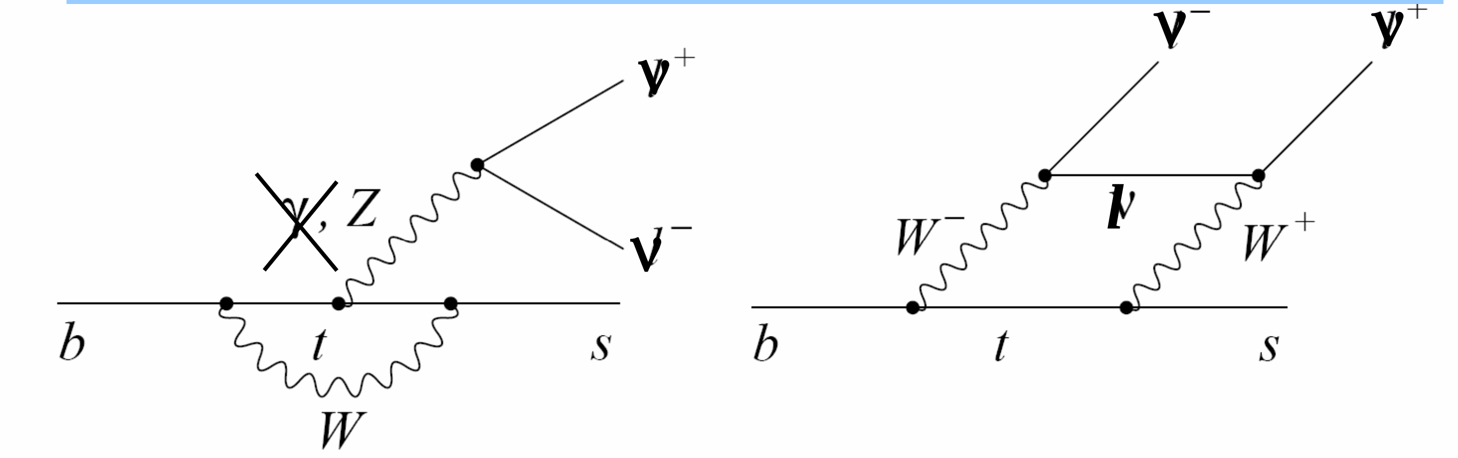
- B physics analog of K →πνν
- Theoretically cleaner mode than K* ***ll*** for probing C9, C10
- Complementary to K* ***ll*** through 3rd generation sensitivity (**tau –neutrinos)**
- No long distance contamination
- K and K* BFs, mass spectrum simply related to left- and right- Wilson coeff.

$$\mathcal{B}(B \to K\nu\bar{\nu}) = (3.8^{+1.2}_{-0.6}) \times 10^{-6} \left| \frac{C_L^\nu + C_R^\nu}{C_L|^\nu_{SM}} \right|^2$$

SM $C_R = 0$

$$\mathcal{B}(B \to K^*\nu\bar{\nu}) = (2.4^{+1.0}_{-0.5}) \times 10^{-6} \left| \frac{C_L^\nu + C_R^\nu}{C_L|^\nu_{SM}} \right|^2 + (1.1^{+0.3}_{-0.2}) \times 10^{-5} \left| \frac{C_L^\nu - C_R^\nu}{C_L|^\nu_{SM}} \right|^2$$

B →K(*) $\nu\,\nu$



- B physics analog of K $\to \pi\nu\nu$
- Theoretically cleaner mode than K* ***ll*** for probing C9, C10
- Complementary to K* ***ll*** through 3rd generation sensitivity (**tau –neutrinos**)
- No long distance contamination
- K and K* BFs, mass spectrum simply related to left- and right- Wilson coeff.

$$\mathcal{B}(B \to K\nu\bar{\nu}) = (3.8^{+1.2}_{-0.6}) \times 10^{-6} \left| \frac{C_L^\nu + C_R^\nu}{C_L|^\nu_{SM}} \right|^2$$

SM $C_R = 0$

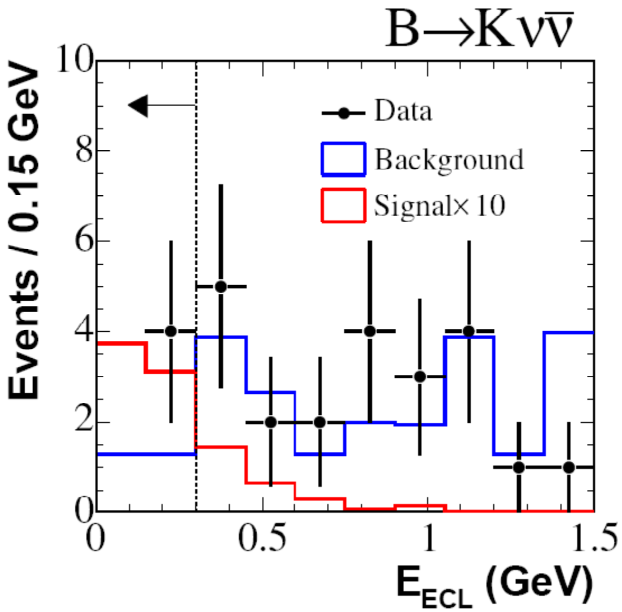
$$\mathcal{B}(B \to K^*\nu\bar{\nu}) = (2.4^{+1.0}_{-0.5}) \times 10^{-6} \left| \frac{C_L^\nu + C_R^\nu}{C_L|^\nu_{SM}} \right|^2 + (1.1^{+0.3}_{-0.2}) \times 10^{-5} \left| \frac{C_L^\nu - C_R^\nu}{C_L|^\nu_{SM}} \right|^2$$

B →K(*) $\nu\,\nu$

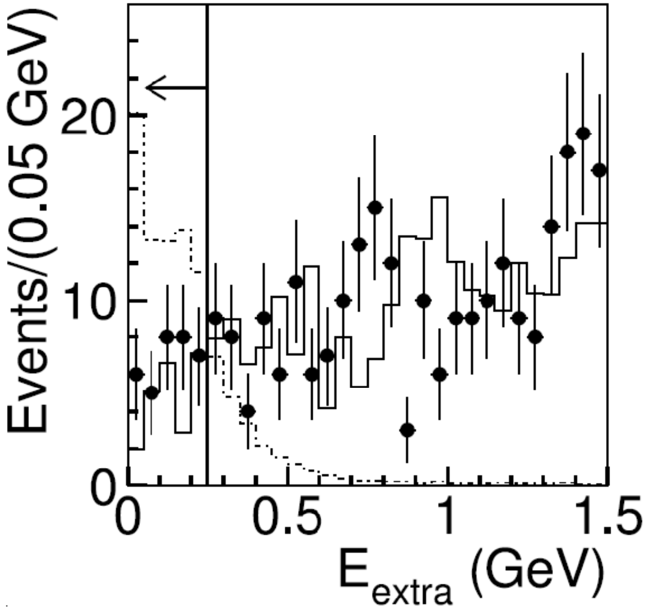
<u>Tag side reco of:</u>
hadronic B decay
(Belle, ε = 0.15%)
or D* *l* ν decay
(BaBar, ε = 0.5%)

& signal side K^+
& no other tracks
& small extra ECAL energy
(ε = 40%)

Belle 253 fb^{-1}



BaBar 82 fb^{-1}



$\mathcal{B}(B^- \to K^-\nu\bar{\nu}) < 3.6\times 10^{-5}$ (10 X SM)

Belle preliminary hep-ex/0507034

$\mathcal{B}(B^0 \to K^{*0}\nu\,\bar{\nu}) < 3.4\times 10^{-4}$ (20 X SM)

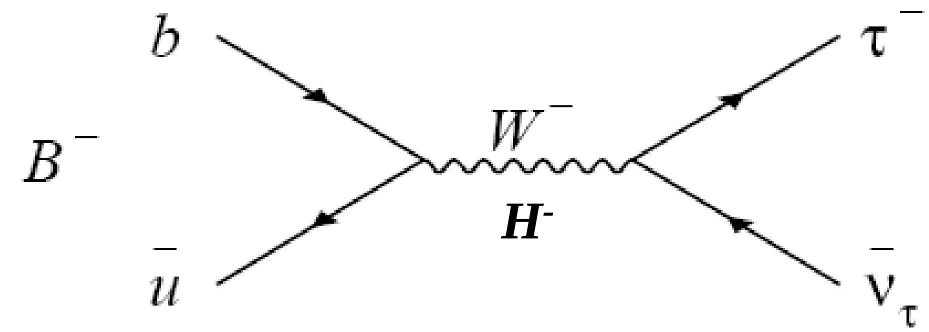
Belle preliminary hep-ex/0608047

For Super B factory, 3σ Kνν SM signal @ 12 ab^{-1}, 5σ @ 33ab^{-1}, 18 % measurement @ 50 ab^{-1}, with hadronic tag alone

B+ → $\tau^+\nu$

Simple decay through weak annihilation

Sensitive to B decay constant f_B or to charged Higgs boson



$$\mathcal{B}(B_u \to \tau\nu)^{\rm SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1-\frac{m_\tau^2}{m_B^2}\right)^2 f_B^2|V_{ub}|^2\tau_B \;= (1.59\pm 0.40)\times 10^{-4}$$

$\tan^4\beta$ modifications in 2HDM II model:

$$R_{B\tau\nu} = \frac{\mathcal{B}(B_u\to\tau\nu)}{\mathcal{B}(B_u\to\tau\nu)^{\rm SM}} = r_H = \left[1-\tan^2\beta\,\frac{m_B^2}{m_{H^\pm}^2}\right]^2$$

f_B dependence can be removed via ratio with Δm_d, error shrinks 25% → <13% (Isidori & Paradisi)

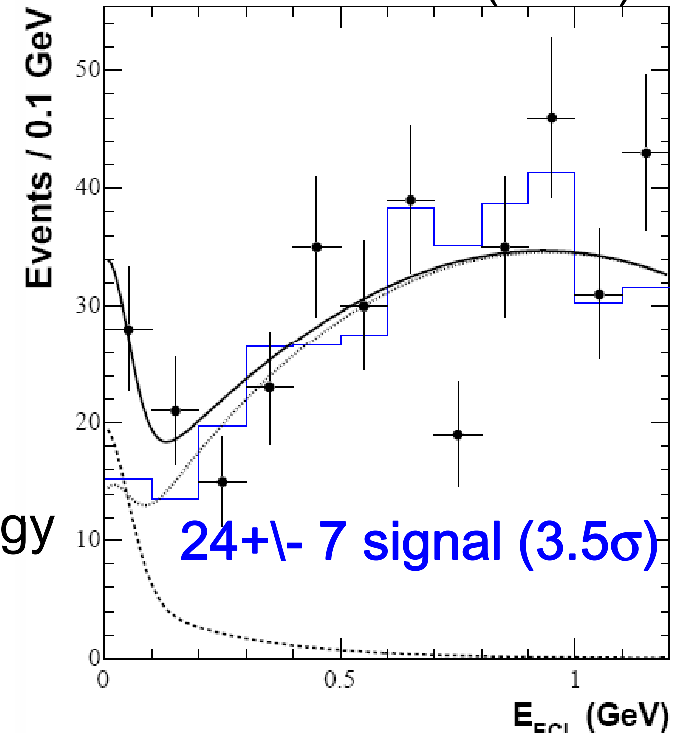
$$\left.\frac{\mathcal{B}(B_u\to\tau\nu)}{\tau_B \Delta M_{B_d}}\right|^{\rm SM} \quad = 1.77\times 10^{-4}\left(\frac{|V_{ub}/V_{td}|}{0.464}\right)^2\left(\frac{0.836}{\hat{B}_{B_d}}\right)$$

B+ → $\tau^+\nu$

Tag side reco of:
hadronic B decay (Belle, $\varepsilon = 0.15\%$)
or D^0 ***l*** X ν decay (BaBar, $\varepsilon = 0.6\%$)

& signal side τ
(Belle: leptonic or 1- or 3-prong, $\varepsilon = 16\%$)
(BaBar: leptonic or 1-prong, $\varepsilon = 13\%$)
& no other tracks & small extra ECAL energy

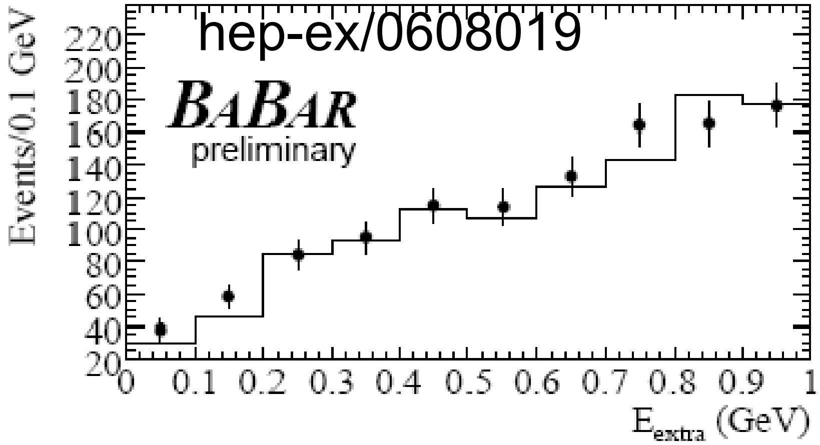
Belle PRL 97 (2006) 251802



24+\- 7 signal (3.5σ)

HFAG BF(B → τν) = 1.34 ± 0.48 10^{-4}

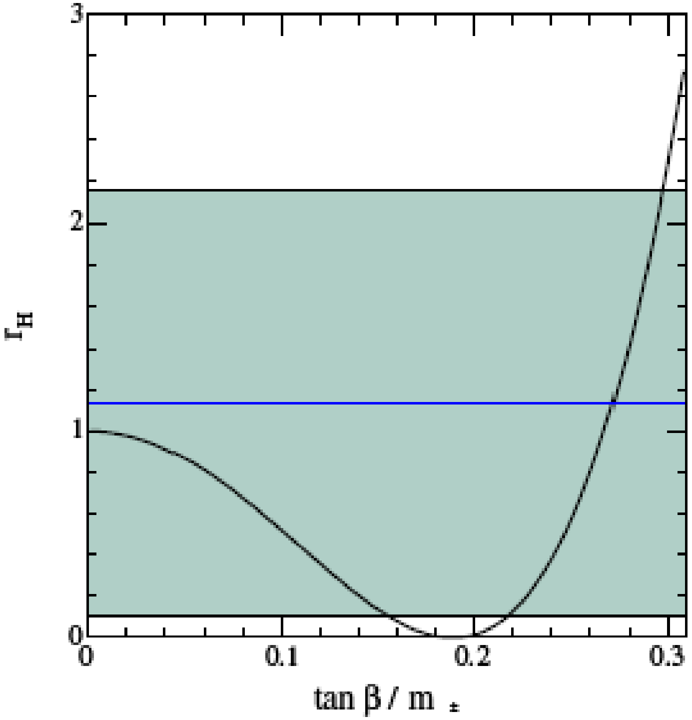
Consistent with SM.

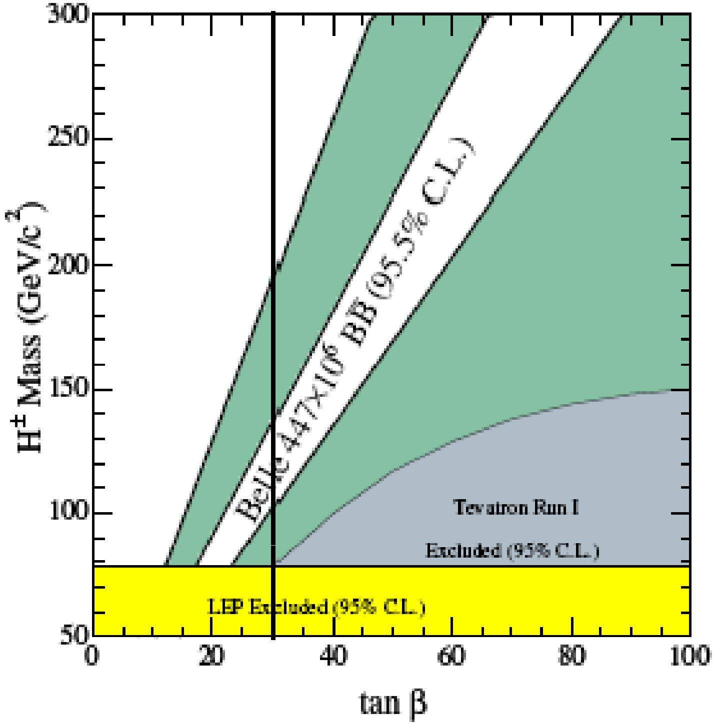


hep-ex/0608019

B+ → $\tau^+\nu$

Belle result excludes (at tan β = 30) M(H+) < 100, 130 < M(H+) < 190 GeV

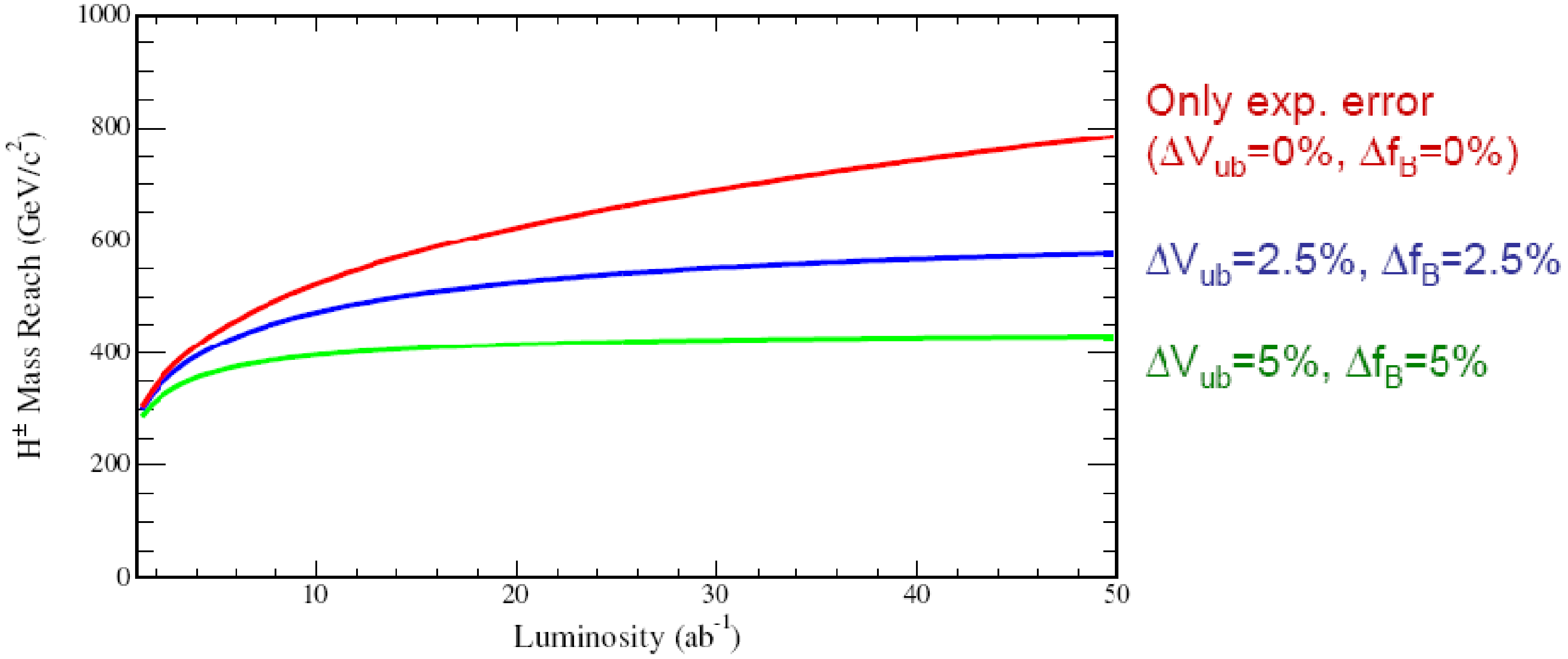




Alternatively, assuming SM, f_B is measured:

$$f_B = 0.229^{+0.036}_{-0.031}(\text{sta})^{+0.034}_{-0.037}(\text{sta})\ \text{GeV}$$

B+ → $\tau^+\nu$: Super B Prospects

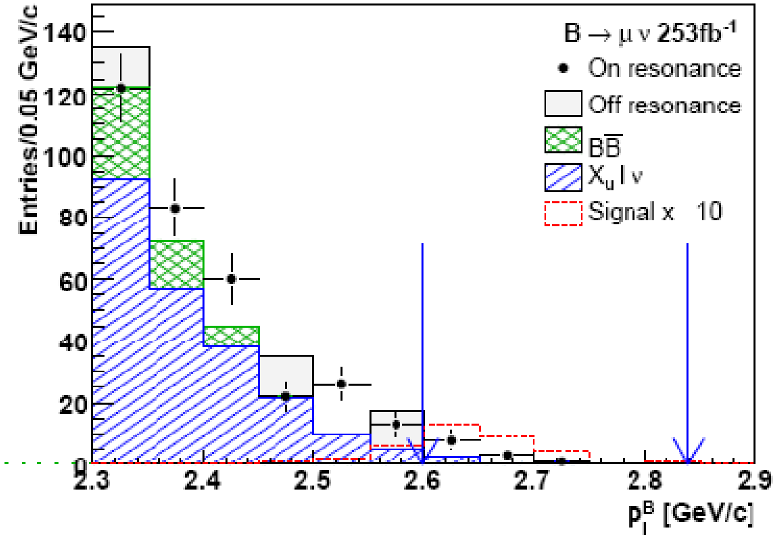


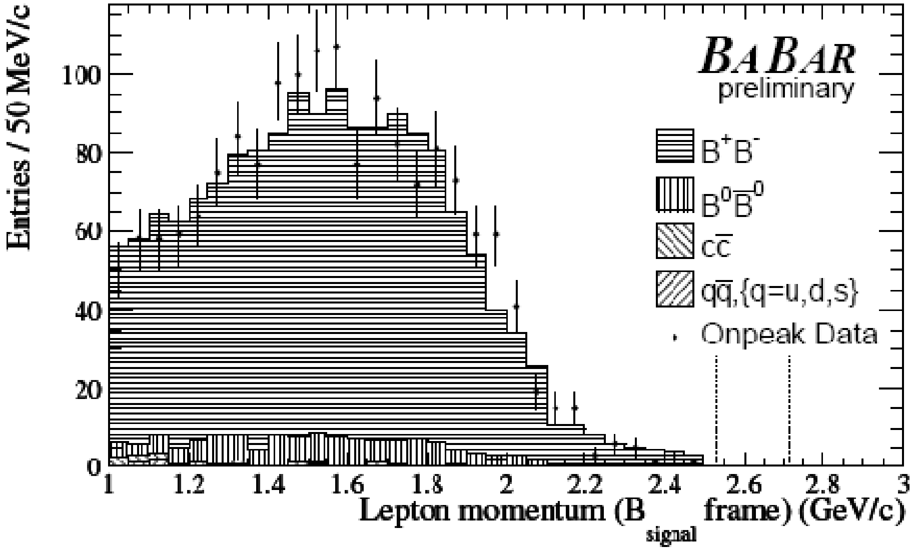
To scale like luminosity, BF measurement requires more precise modelling of extra energy distribution (use bigger control samples)

With also improved parametric uncertainties, can exclude charged higgs M(H+) < 575 GeV (tan β = 30) @ 50 ab^{-1}

B+ → $e^+\nu$, $\mu^+\nu$

SM rates highly helicity suppressed relative to B →$\tau\nu$, but
ratio with B→ $\tau\nu$ can be enhanced by 2x (10x) for LFV SUSY
(Masiero, Paradisi, Petronzio)





Monochromatic lepton with P* = $m_B/2$, with tag-side mass cut or hadronic reco

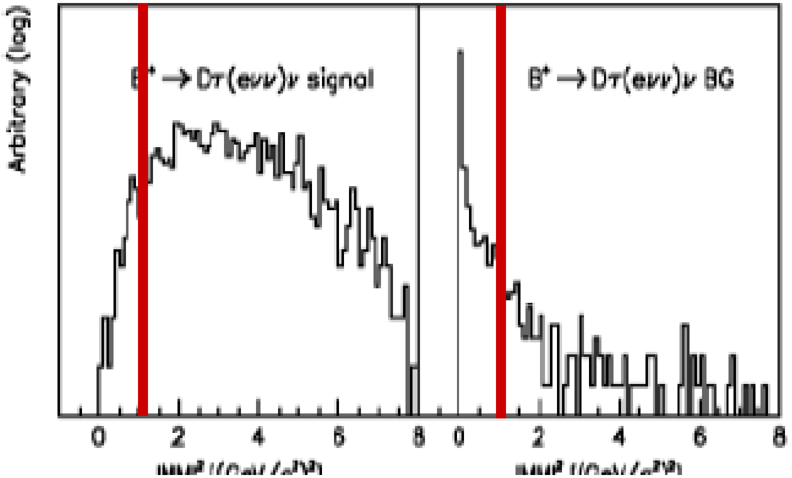
Current limits @ 253 fb^{-1} : B→ eν < 9.8 10^{-7} B →$\mu\nu$ < 1.7 10^{-6}

SM B →$\mu\nu$ will be measured at SuperB :
3σ @ 1.6 ab^{-1}, 5σ @ 4.3 ab^{-1}, 6% stat. precision @ 50 ab^{-1}

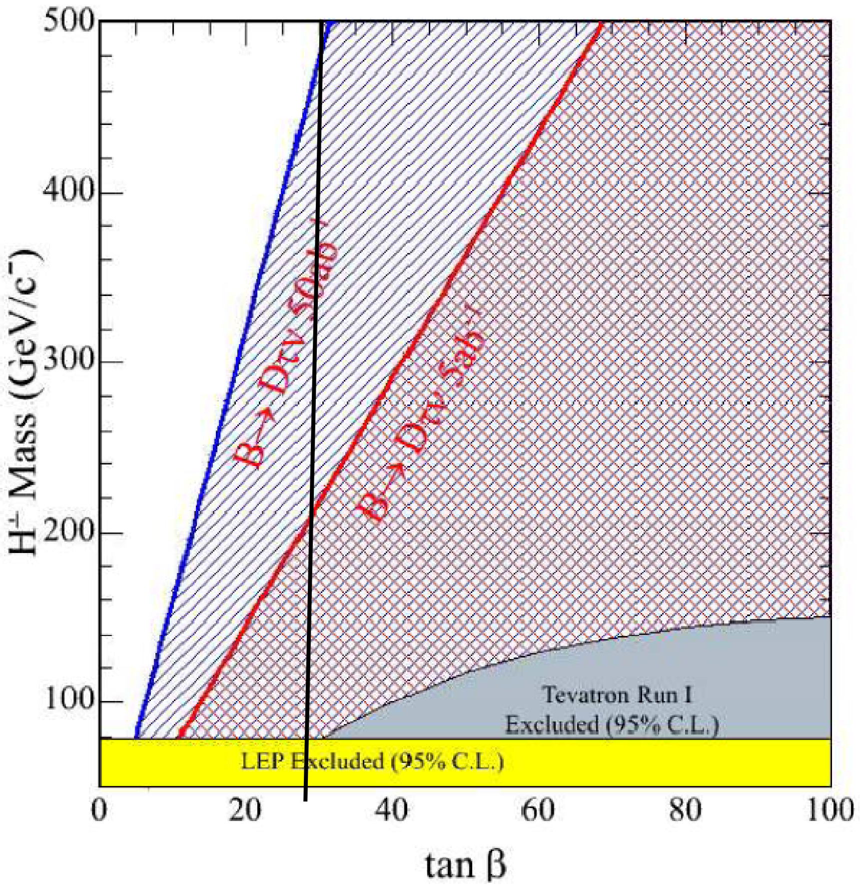
B → D(*) $\tau\nu$

Ratio of BF(B →D $\tau\nu$)/BF(B→ D $\mu\nu$) a precise estimator of charged Higgs amplitude.

Large BF with large B →D$\mu\nu$ bkg (remove with missing mass cut)



Mode @5 ab^{-1}	Nsig	Nbkg	dB/B
$D^0\tau^+(1^+\overline{\nu}_\tau\nu_1)\nu_\tau$	280	550	7.9%
$D^0\tau^+(h^+\overline{\nu}_\tau)\nu_\tau$	620	3600	



For tan β = 30, exclude
M(H+) < 200 GeV @ 5 ab^{-1}
< 500 GeV @ 50 ab^{-1}

Outline

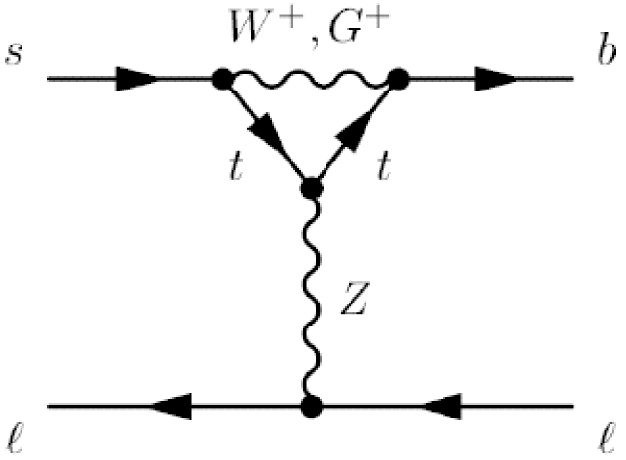
•Very rare leptonic B decays (U. Nierste, M. Smizanska)

B_s, $B_d \rightarrow \mu\mu$ BF

(LHCb, ATLAS, CMS, Super B)

$B_s \rightarrow \mu\mu$

In SM, dominated by (helicity suppressed) axial vector Z penguin



$$\mathcal{B}\left(B_s \to \mu^+\mu^-\right) = (3.86 \pm 0.15)\cdot 10^{-9} \times \frac{\tau_{B_s}}{1.527\,\mathrm{ps}}\left[\frac{|V_{ts}|}{0.0408}\right]^2\left[\frac{f_{B_s}}{240\ \mathrm{MeV}}\right]^2$$

In general, scalar and pseudoscalar (but not vector) operators also contribute (not helicity suppressed)

$$\frac{G_F^2\,\alpha_{\mathrm{QED}}^2}{64\,\pi^3\sin^4\theta_W}\,|V_{tb}^*V_{tq}|^2\,\frac{\tau_{B_q}}{\hbar}\,M_{B_q}^3 f_{B_q}^2\sqrt{1-\frac{4m_\ell^2}{M_{B_q}^2}} \times\left[\left(1-\frac{4m_\ell^2}{M_{B_q}^2}\right)M_{B_q}^2 C_S^2 + \left(M_{B_q}C_P - \frac{2m_\ell}{M_{B_q}}C_A\right)^2\right]$$

G. Buchalla and A. J. Buras, Nucl. Phys. B **400** (1993) 225. M. Misiak and J. Urban, Phys. Lett. B **451** (1999) 161 [arXiv:hep-ph/9901278].

G. Buchalla and A. J. Buras, Nucl. Phys. B **548** (1999) 309 [arXiv:hep-ph/9901288].

$B_s \rightarrow \mu\mu$

Wide variety of models enhance BF, esp. with multiple Higgs doublets and large tan β

Type II 2HDM, $\tan^4 \beta$

$$C_S = C_P = \frac{m_\ell}{2M_W^2} \tan^2\beta \, \frac{\ln r}{r-1} \qquad r = \frac{M_{H^+}^2}{m_t^2}$$

In MSSM, squark loops
Increase enhancement to $\tan^6 \beta$,
In general or minimal flavor violation

$$Br^{\rm SUSY}(B_q \rightarrow \ell^+\ell^-) \quad \propto \quad \frac{m_b^2 m_\ell^2 \tan^6\beta}{M_{A^0}^4}$$

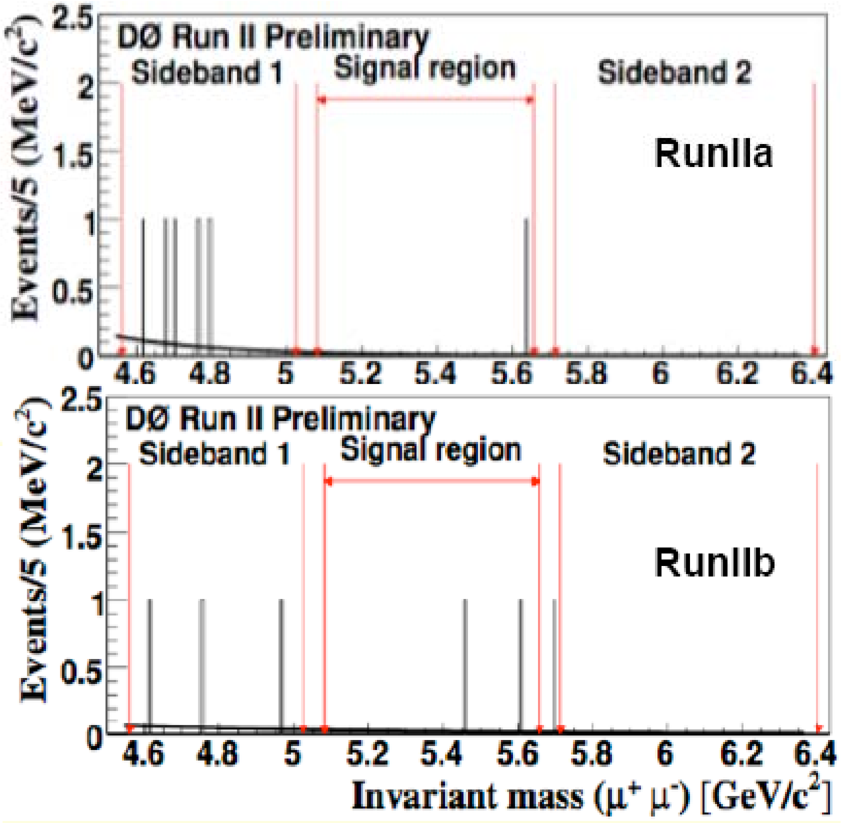
For constrained SUSY models (mSUGRA, CMSSM), correlations between Bs → μμ, b → sγ , Δms, gμ -2, and SUSY Higgs sector

For SO(10) SUSY GUTS, BF and Δm of Bs, B→ τν disentangle top-bottom Yukawa unification

$B_s \to \mu\mu$ Today

New D0 90CL limit bounds BF to 20X SM with 2 fb^{-1} (Alberto Sanchez, Moriond EW)

Backgrounds still reasonable, ultimate combined Tevatron limit could improve by another 2-4X



90%CL 7.5 x 10^{-8} (DØ combined)

Summary

Exp	Mode	Lumi [fb^{-1}]	Evts	Bgrd Pred	BR Limit (95% CL)
DØ	$B_s \to \mu^+\mu^-$	2	3	2.3 ± 0.5	$< 0.93 \times 10^{-7}$
CDF	$B_s \to \mu^+\mu^-$	0.78	1	1.27 ± 0.37	$< 1.0 \times 10^{-7}$
	$B_d \to \mu^+\mu^-$	0.78	2	2.45 ± 0.40	$< 0.3 \times 10^{-7}$

$$\frac{Br(B_s)\,\text{limit}}{Br(B_s)\,\text{SM}} \approx 20$$

$$\frac{Br(B_d)\,\text{limit}}{Br(B_d)\,\text{SM}} \approx 300$$

$B_s \rightarrow \mu\mu$ @ LHC

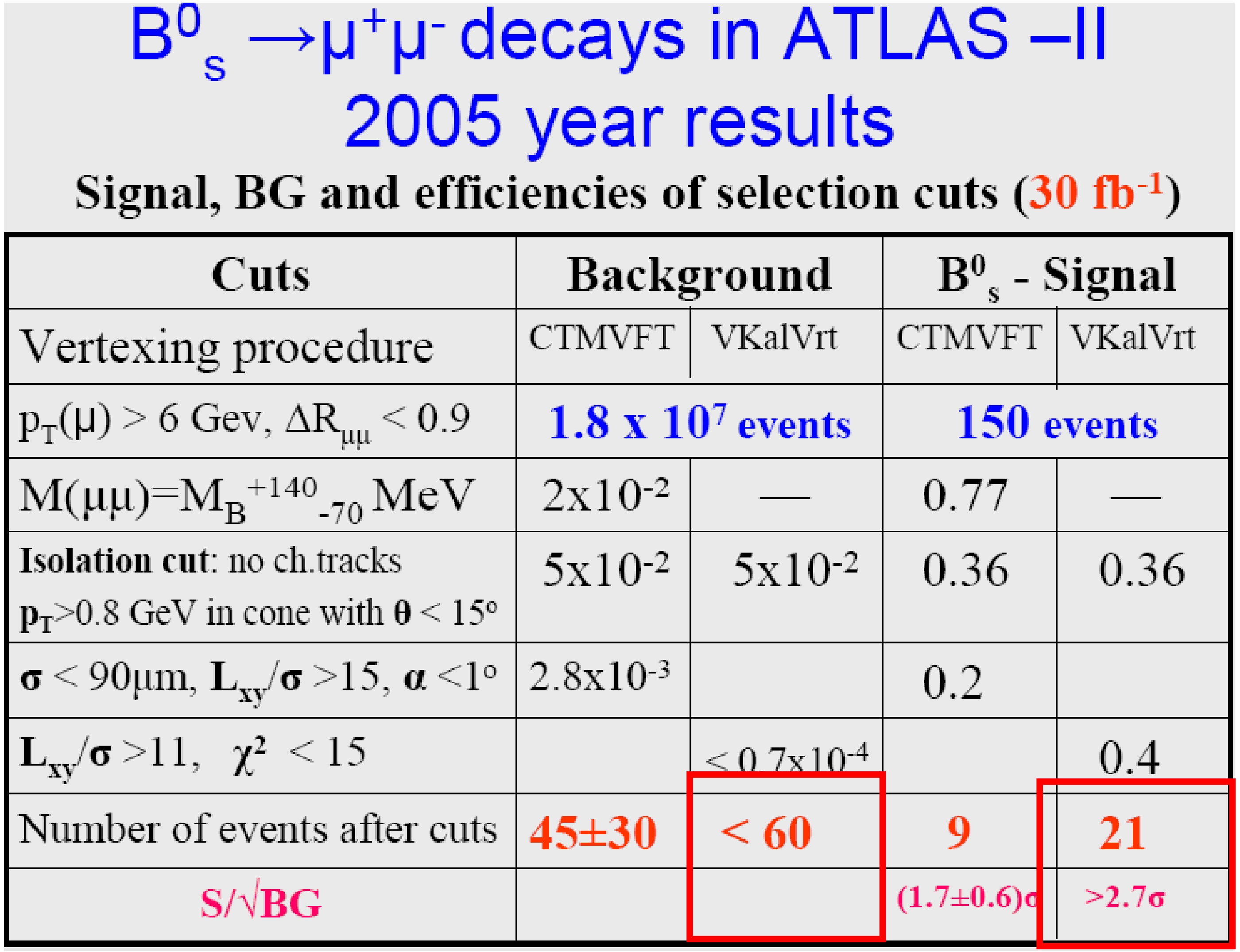
Key to LHC detection is good trigger acc. X eff. for low pT dimuons

Experiment	**L1(0) momentum cut**	**L1(0) Rate**	HLT
ATLAS	$p_T(\mu) \geq 6.0 GeV/c$	1kHz	
CMS	$p_T(\mu) \geq 3.0 GeV/c$	0.9kHz	~Hz
LHCb 1μ	$p_T(\mu) \geq 1.1 GeV/c$	110kHz	
LHCb 2μ	$\Sigma p_T(\mu\mu) \geq 1.3 GeV/c$	145kHz	660 Hz

Three key offline selection criteria:
Tracking (lifetime, impact parameter, vertex chi2, track isolation)
PID (low fake rates to suppress hadronic B background)
Mass (better resolution → better significance per signal event, better avoidance of peaking backgrounds)

Experiment	$2 fb^{-1}$	$10 fb^{-1}$	$30 fb^{-1}$	$100 fb^{-1}$
ATLAS	1.4	7.0	21.0	92
CMS	1.2	6.1	18.3	26
LHCb new	20	100	-	-

$B_s \rightarrow \mu\mu$: ATLAS



$B^0_s \rightarrow \mu^+\mu^-$ decays in ATLAS –II 2005 year results

Signal, BG and efficiencies of selection cuts (30 fb^{-1})

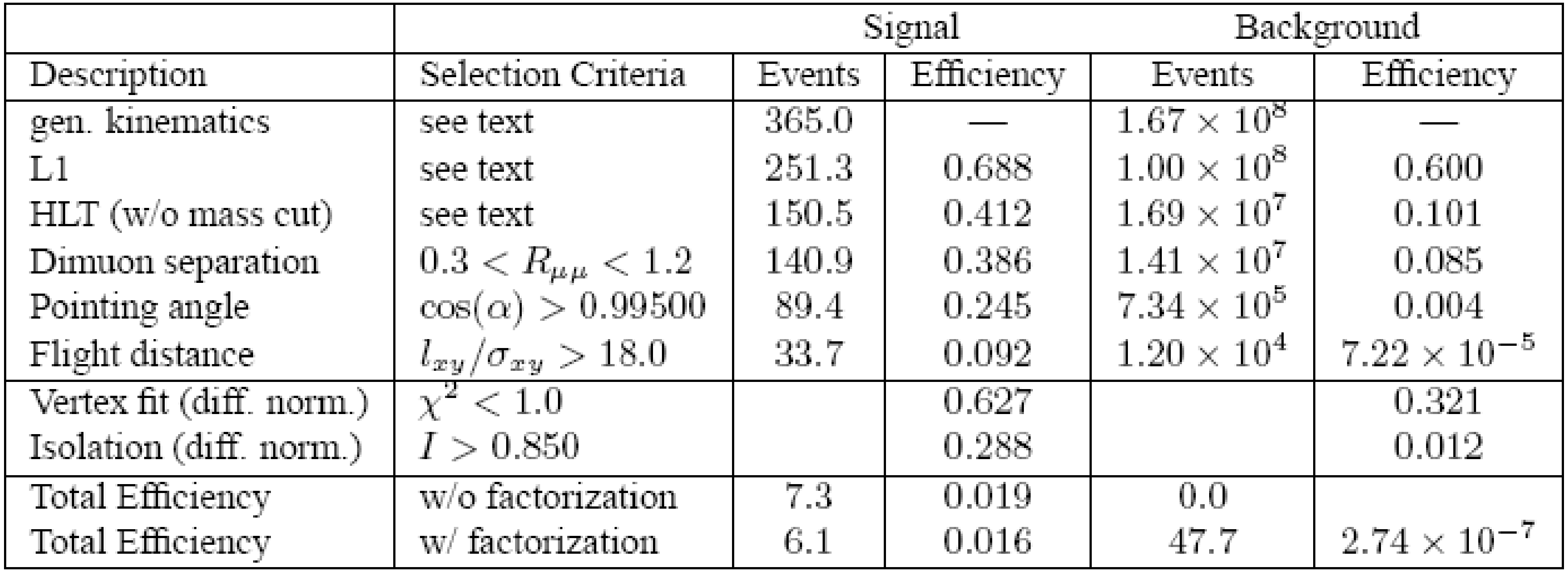
Cuts	Background		B^0_s - Signal	
Vertexing procedure	CTMVFT	VKalVrt	CTMVFT	VKalVrt
$p_T(\mu) > 6$ Gev, $\Delta R_{\mu\mu} < 0.9$	**1.8×10^7 events**		**150 events**	
$M(\mu\mu)=M_B{}^{+140}_{-70}$ MeV	2×10^{-2}	—	0.77	—
Isolation cut: no ch.tracks p_T>0.8 GeV in cone with $\theta < 15°$	5×10^{-2}	5×10^{-2}	0.36	0.36
$\sigma < 90\mu m$, $L_{xy}/\sigma > 15$, $\alpha < 1°$	2.8×10^{-3}		0.2	
$L_{xy}/\sigma > 11$, $\chi^2 < 15$		$< 0.7 \times 10^{-4}$		0.4
Number of events after cuts	**45±30**	**< 60**	**9**	**21**
S/√BG			**$(1.7 \pm 0.6)\sigma$**	**$>2.7\sigma$**

Expect
3σ evidence
with 30 fb^{-1}

N. Nikitin *et al.*, "Rare B-decays at ATLAS," J. *Nuclear Physics B* **156** (2006) 119-123

$B_s \to \mu\mu$: CMS

CMS AN 2006/097



		Signal		Background	
Description	Selection Criteria	Events	Efficiency	Events	Efficiency
gen. kinematics	see text	365.0	—	1.67×10^8	—
L1	see text	251.3	0.688	1.00×10^8	0.600
HLT (w/o mass cut)	see text	150.5	0.412	1.69×10^7	0.101
Dimuon separation	$0.3 < R_{\mu\mu} < 1.2$	140.9	0.386	1.41×10^7	0.085
Pointing angle	$\cos(\alpha) > 0.99500$	89.4	0.245	7.34×10^5	0.004
Flight distance	$l_{xy}/\sigma_{xy} > 18.0$	33.7	0.092	1.20×10^4	7.22×10^{-5}
Vertex fit (diff. norm.)	$\chi^2 < 1.0$		0.627		0.321
Isolation (diff. norm.)	$I > 0.850$		0.288		0.012
Total Efficiency	w/o factorization	7.3	0.019	0.0	
Total Efficiency	w/ factorization	6.1	0.016	47.7	2.74×10^{-7}

In 10 fb^{-1}, 6 signal + 14 bkg (after ±100 MeV dimuon mass cut)

S/B essentially identical to ATLAS study

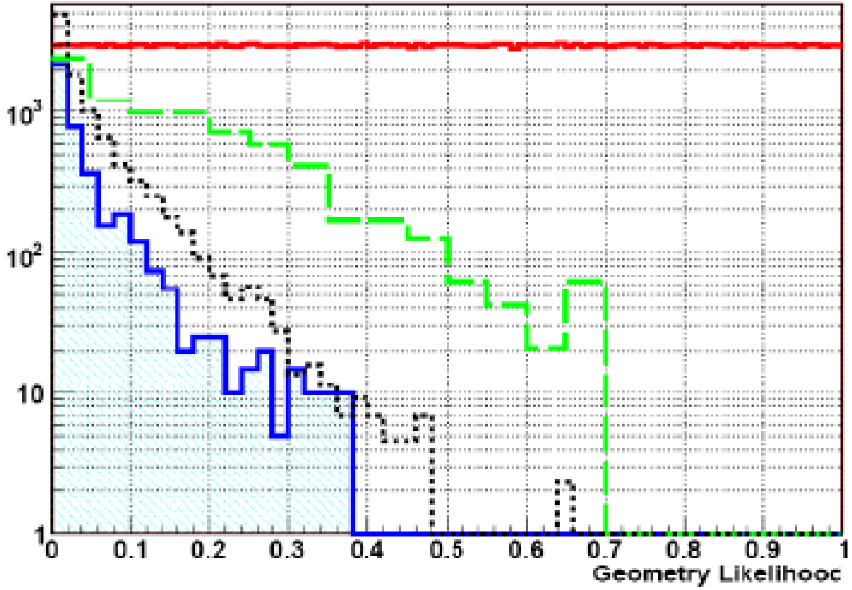
Results in 1.4 10^{-8} 90% CL limit (3X SM)

$B_s \rightarrow \mu\mu$: LHCb

Background rejected
with a likelihood function
combining:

Lifetime
Muon IP
B IP
Mu-mu DOCA
Isolation

Signal
bb
b→ μ b → μ
$B_c \rightarrow J/\psi\, \mu\nu$



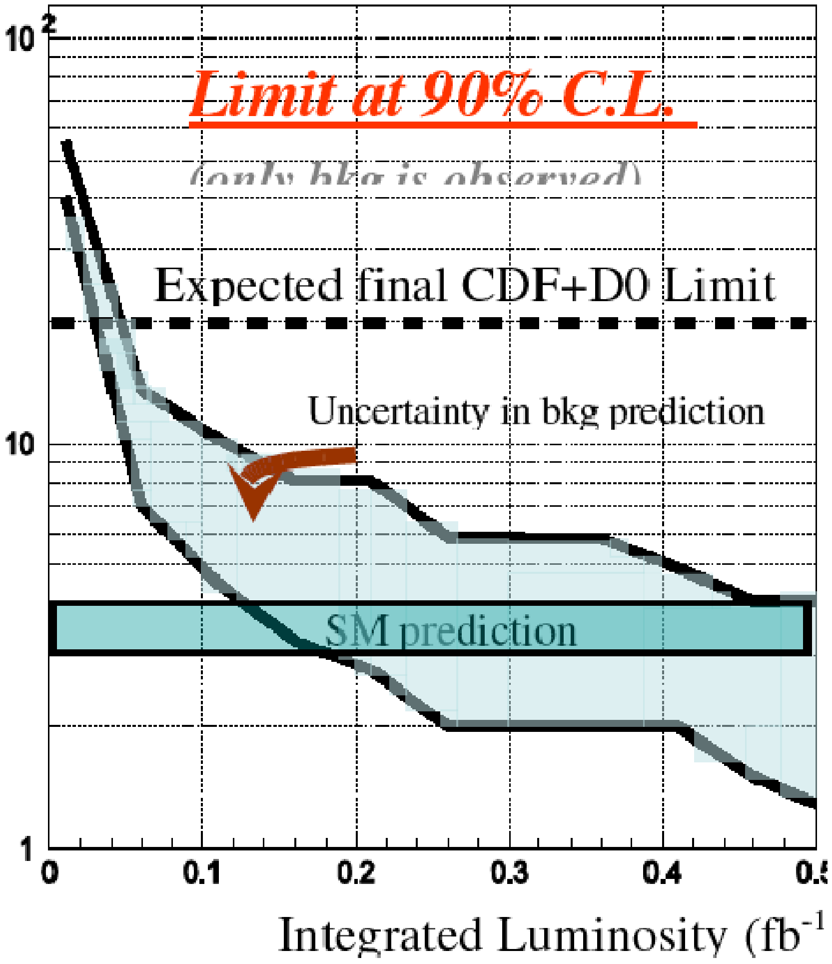
Before LH cuts, for 1 fb^{-1} S = 36 and B = 600k
in ±60 MeV window around M(Bs)

Peaking backgrounds are much less of a concern due to
very good mass resolution (18 MeV)

Signal is extracted with a CLs likelihood ratio method.

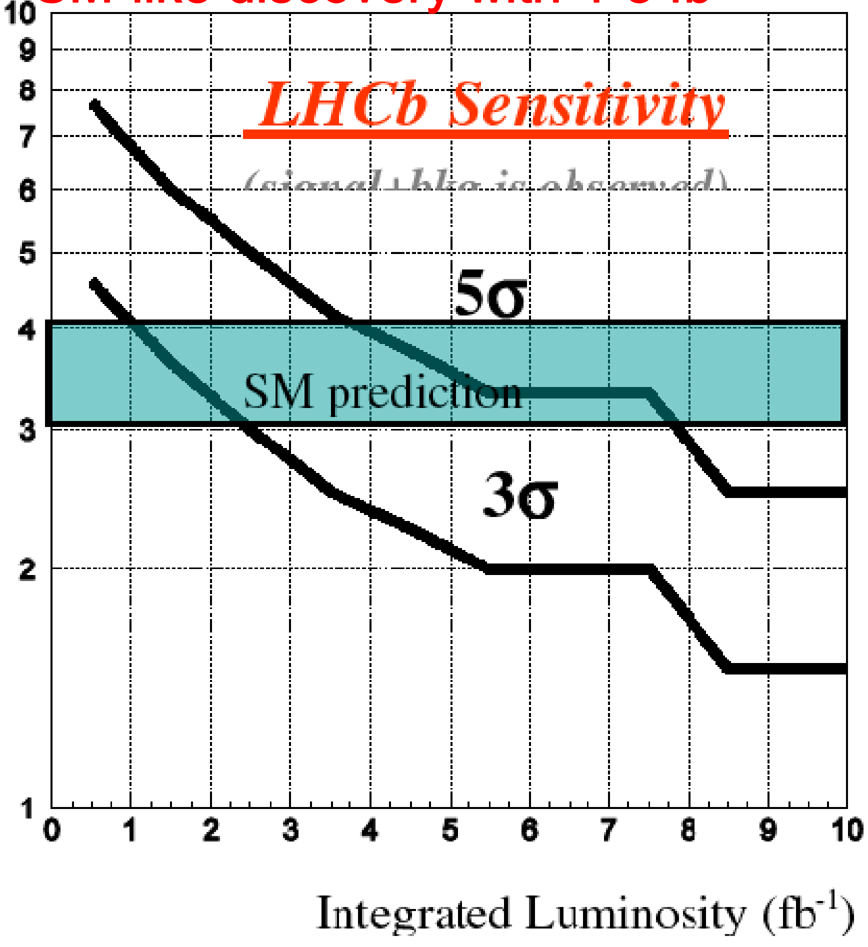
$B_s \to \mu\mu$: LHCb

SM-like limit with few 100 pb^{-1}



SM-like evidence with 1-2 fb^{-1}

SM-like discovery with 4-8 fb^{-1}



Summary: Three Principles of Complementarity

1.Rare B decays present a host of observables with complementary sensitivity to new physics at the TeV scale.

2.Experimental coverage of them is complementary

$B_s \to \mu\mu$	LHC
$B \to K^* \mu\mu$ AFB	LHC & SuperB
$b \to sll$ BF and AFB	SuperB
$b \to s\gamma$ BF and CPV	SuperB
$B \to$ Xs,d γ CPV	LHC & SuperB
$B \to \tau\nu$ and K $\nu\nu$ BF	SuperB

3. Low PT complementary to High PT

Once the form of EWSB is revealed or constrained by high PT physics at ATLAS+CMS, its flavor structure, or the structure of a non-trivial Higgs sector, will be revealed or constrained further at low PT

Probability Density Functions

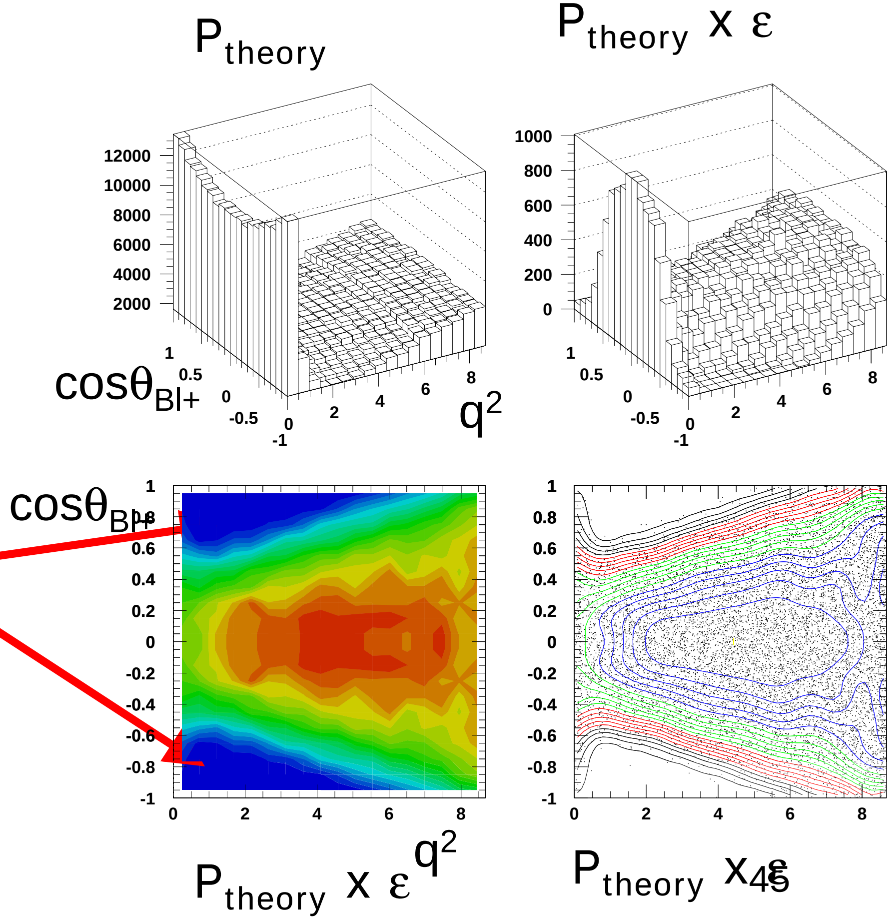
$$
\begin{aligned}
\mathrm{PDF} = \; & f_{sig} \times P_{theory}(A_7,A_9,A_{10};q^2,\cos\theta)/N(A_7,A_9,A_{10}) \times \varepsilon(q^2,\cos\theta) \\
& + (1 - f_{sig} - f_{psi} - f_{K^*hh}) \times P_{dilepton}(q^2,\cos\theta) \\
& + f_{psi} \times P_{psi}(q^2,\cos\theta) \\
& + f_{K^*hh} \times P_{K^*hh}(q^2,\cos\theta)
\end{aligned}
$$

K*μμ Signal PDF for q^2 below J/psi veto window

We can not measure low q^2 and high $\cos\theta_{Bl+}$ event since one of muon is low momentum.

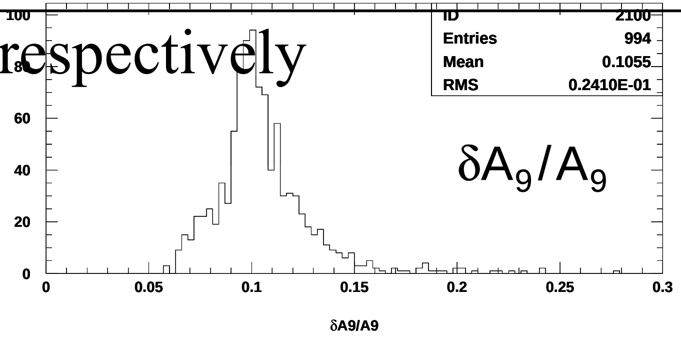
So we need muon detector for low momentum region.

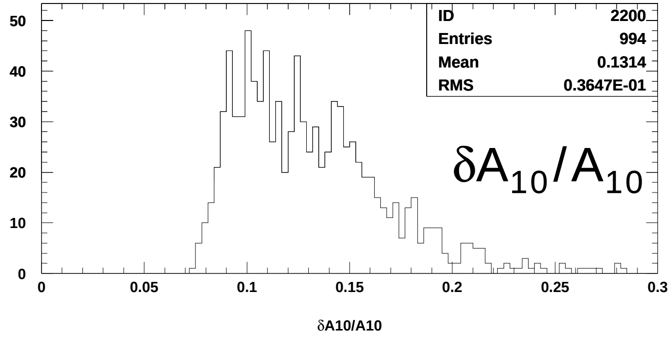
(Acceptance for electron modes are a bit better.)

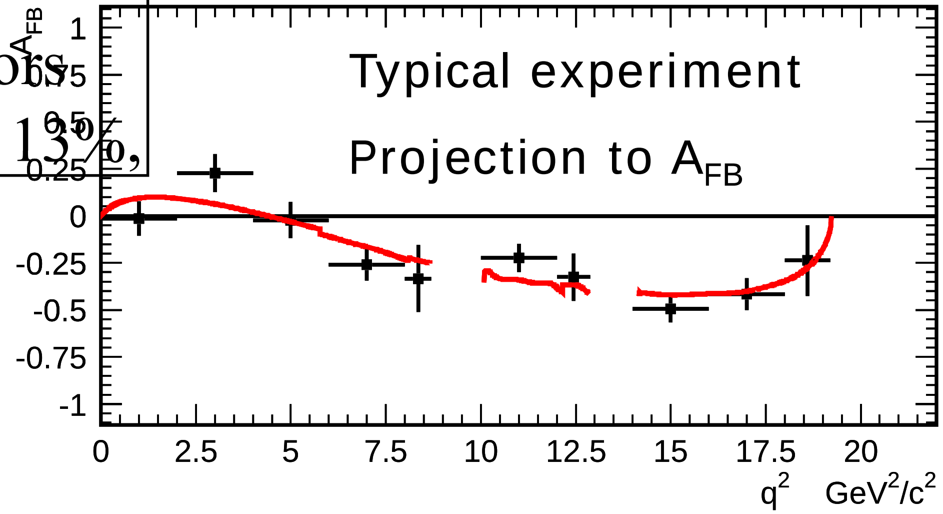


Fit Results

- We perform 1000 pseudo experiments with SM input values
- With 5/ab data, Means of errors for A9 and A10 are 11% and 13%, respectively



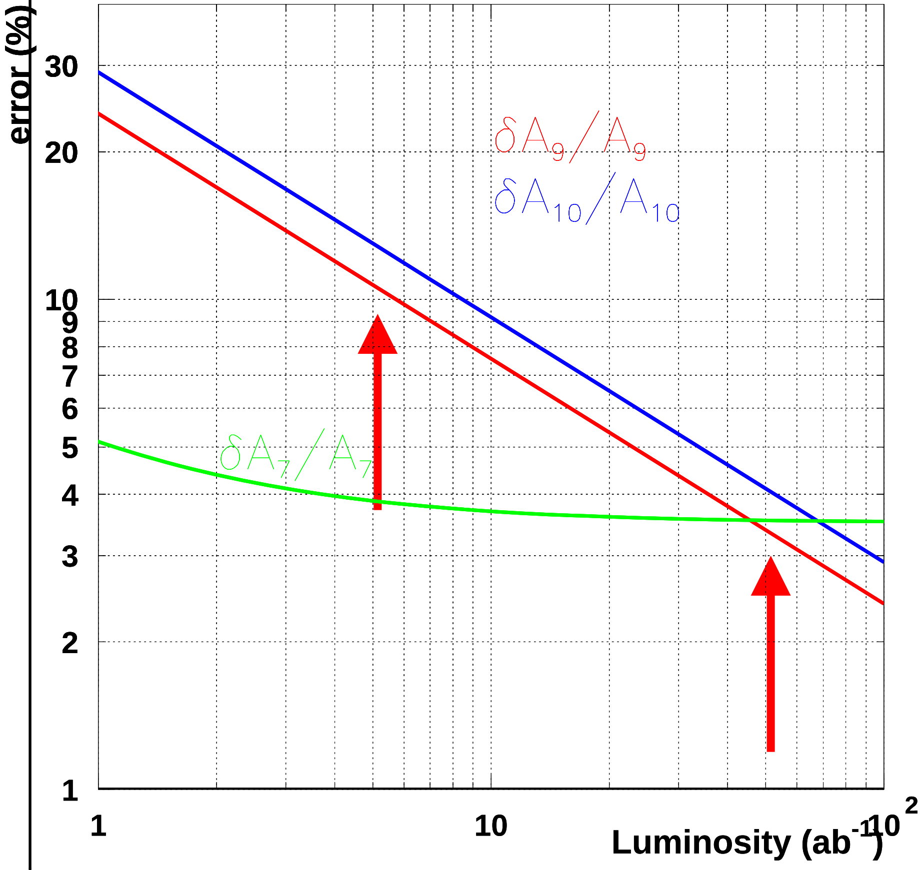




Extrapolation to 50/ab

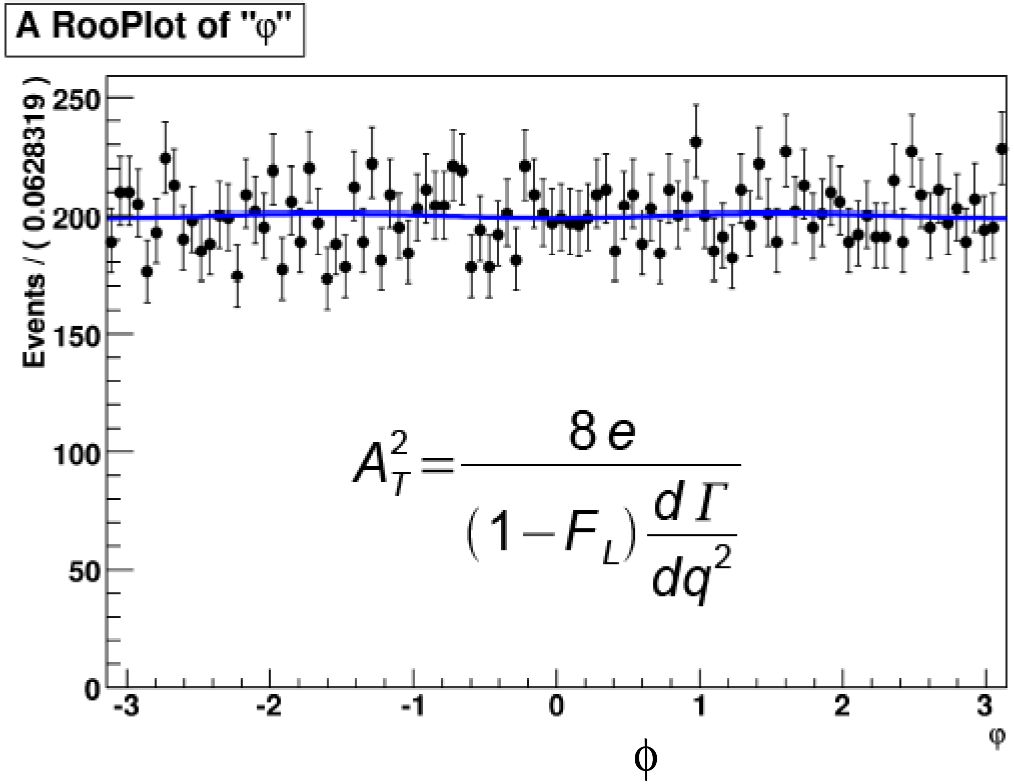
- Systematic error has not been estimated, so we just extrapolate statistical error.
- With 50/ab, we can achieve 4% statistical errors for A_9 and A_{10}, which is comparable to total error for A_7 from b→sγ (~2.5(exp)+2.5(theo)=3.5%?).
- Systematic error will dominate with 50/ab.
- Error for s_0 is obtained from this formula $\delta s_0/s_0=\delta(C_7/C_9)/(C_7/C_9)$, so we can measure s_0 with 5% accuracy using 50/ab data sample.

$$\hat{s}_0 \sim -2\hat{m}_b \frac{C_7}{\mathrm{Re}(C_9)} \sim 0.16$$



$B_d \rightarrow K^*\mu\mu$: Transversity Angles

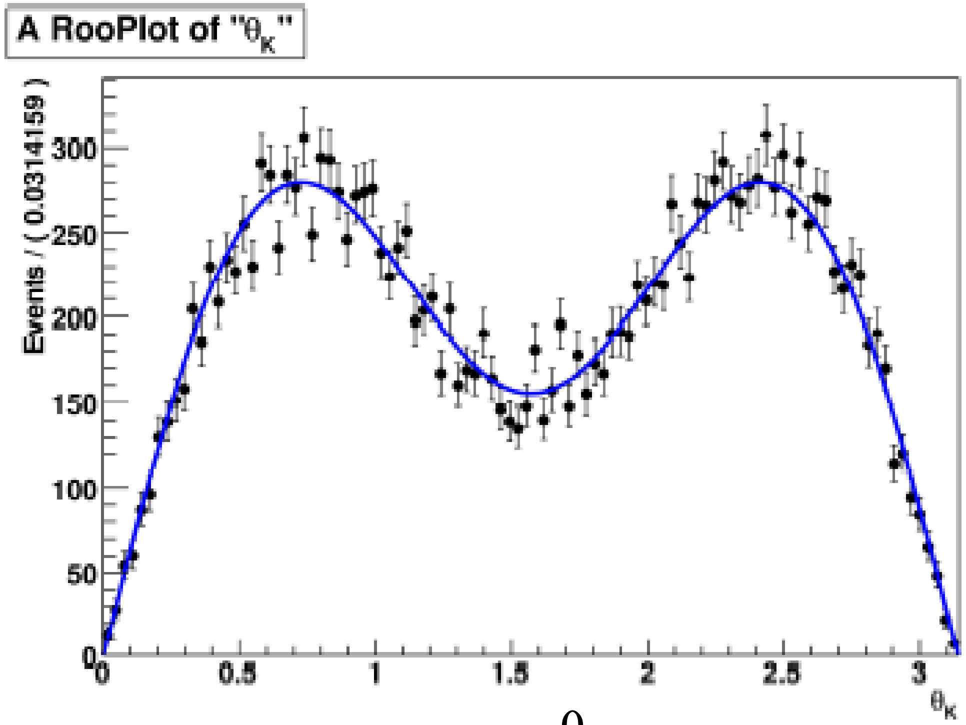
$$\frac{d^2\Gamma}{dq^2\,d\varphi} = \frac{1}{2\pi}\left(e\cos 2\varphi + m\sin 2\varphi\right) + \frac{1}{2\pi}\frac{d\Gamma}{dq^2}$$



$$A_T^2 = \frac{8e}{\left(1-F_L\right)\frac{d\Gamma}{dq^2}}$$

$B_d \to K^*\mu\mu$: Transversity Angles

$$\frac{d^2\Gamma}{dq^2\,d\theta_K}=\frac{3}{4}\sin\theta_K\left(2F_L\cos^2\theta_K+(1-F_L)\sin^2\theta_K\right)\frac{d\Gamma}{dq^2}$$



θ_{K^*}

Projected upper limits : $B_s \rightarrow \mu\mu$

ATLAS/CMS expectation