Semileptonic B_s Decays @ Babar, Belle, & D0

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On Behalf of the Belle collaboration

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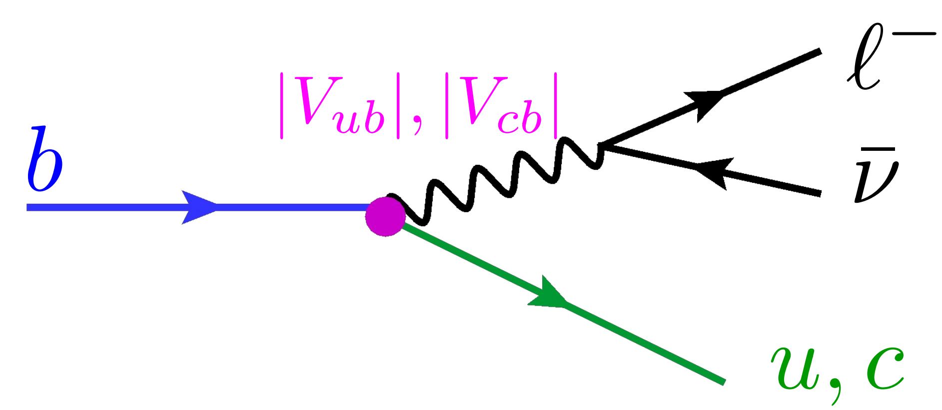
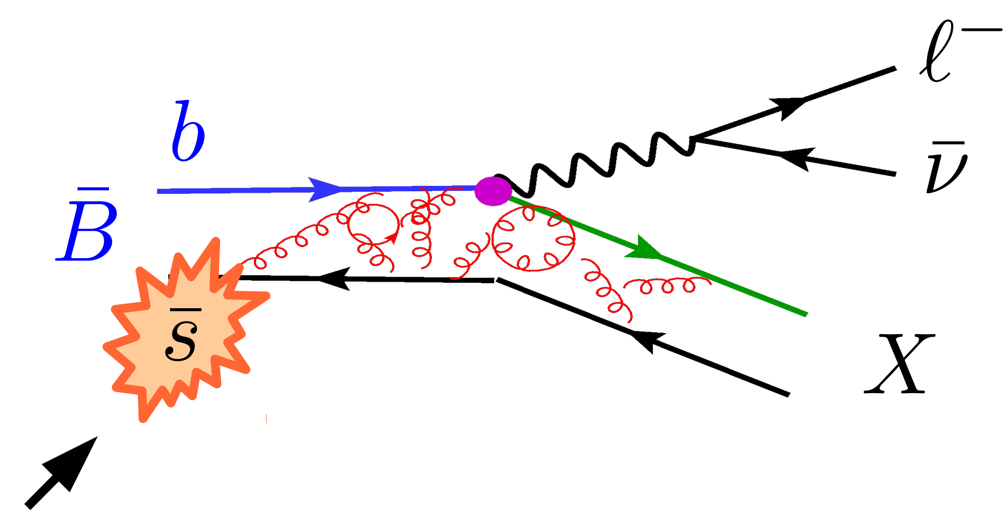
Introduction

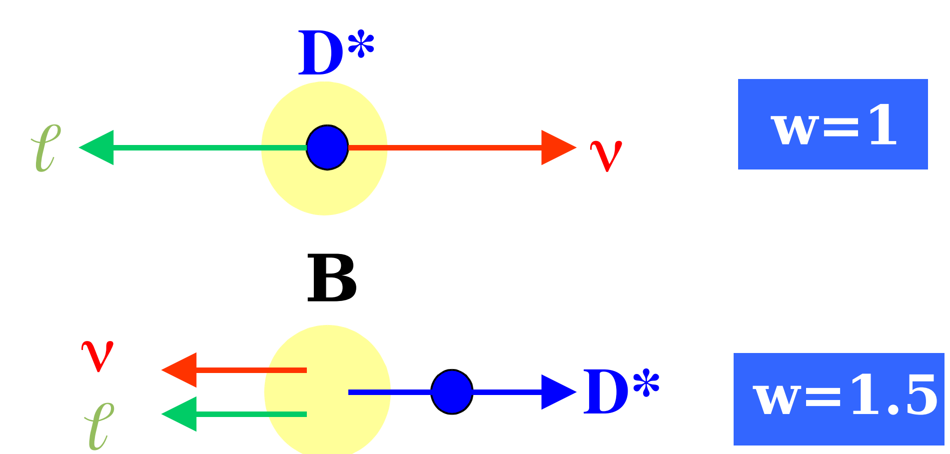
- Fewer measurements of semileptonic $\boldsymbol{B_s}$ than that of **B^+, B^0**
  - *Inclusive*, Exclusive, $|V_{cb}|$, $|V_{ub}|$, HQ parameters... not for B_s, but what can we learn?

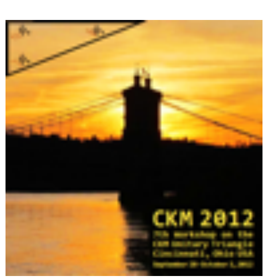


- Semileptonic $\boldsymbol{B_s}$ decays are *(already)* used as **standard candles of $\boldsymbol{B_s}$** measurements, e.g. LHCb & D0 hadronisation fraction, f_s, determinations [PRD.85.032008 (2011)]
  - Normalisation of **B_s** production essential for comparison between SM and data



- $\boldsymbol{B_s}$ modes may be more **precise in determining exclusive $|V_{qb}|$**, due to lattice predictions with heavier quarks, and more phase space at lower recoil...But can experiment keep up?





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Inclusive Semileptonic B_s decay predictions

- The most important prediction for SL B_s decays is **Flavour SU(3) (& U-spin) Symmetry**, which must be tested.
- Non-perturbative QCD contributions are modified, which are most significant at third order e.g. *spin orbit operator. Largest effect in **charmless modes.***
- *High order corrections, e.g. due to weak annihilation, expected to be small.*

$$\frac{\Gamma_{\rm sl}(B_s^0 \to X_c \ell \nu)}{\Gamma_{\rm sl}(B_d^0 \to X_c \ell \nu)} = 0.99 \pm 0.04$$

$$\frac{\Gamma_{\rm sl}(B_s^0 \to X_c \ell \nu)}{\Gamma_{\rm sl}(B_d^0 \to X_c \ell \nu)} \approx 0.99$$

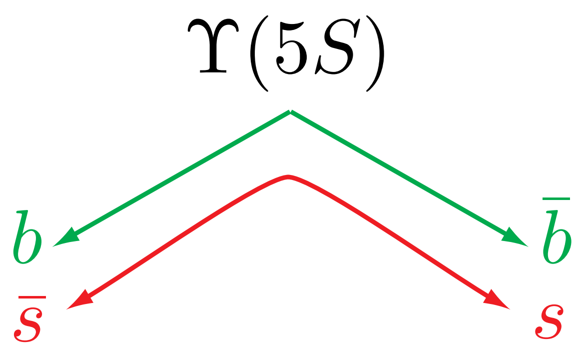
$$\frac{\Gamma_{\rm sl}(B_s^0 \to X_u \ell \nu)}{\Gamma_{\rm sl}(B_d^0 \to X_u \ell \nu)} \approx 0.97$$

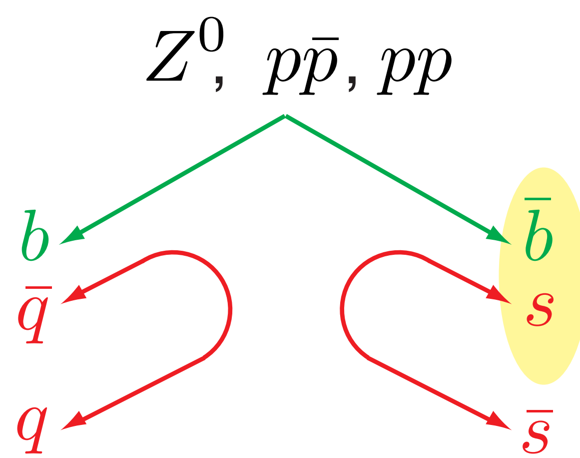
Order	Term	$\delta\Gamma$%	δ*Term* *(d↔s)*	$\delta\Gamma_c$ *(d↔s)%*	$\delta\Gamma_u$ *(d↔s)%*
$1/m_b^2$	μ_π^2	-1	25%	-0.25	-
	μ_G^2	-3.5	10%	-0.4	-
$1/m_b^3$	ρ_D^3	-3	50%	-1.5	2.5
Higher orders		0.5		0.5	2

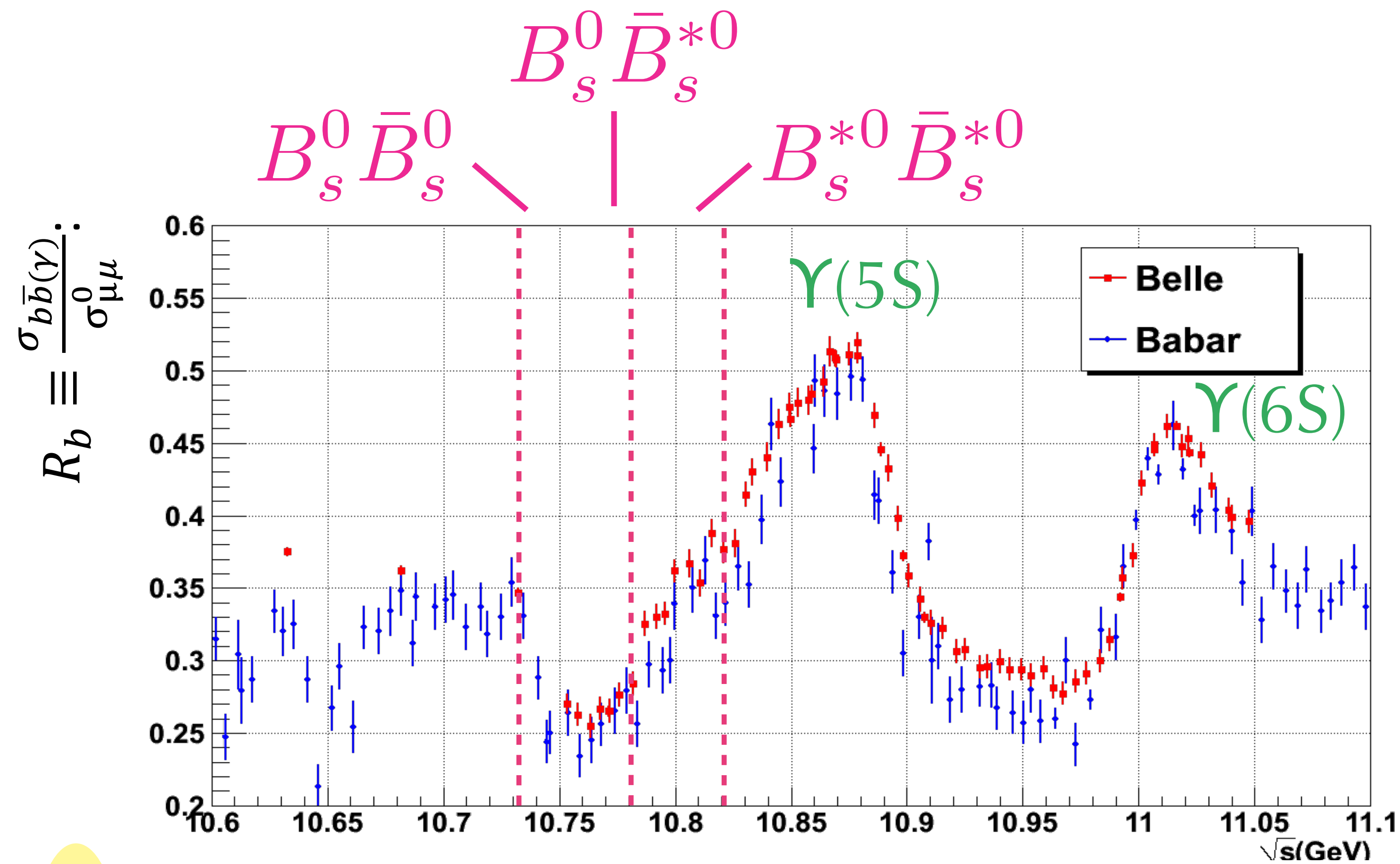
- **Bigi et al., JHEP 1109 (2011) 012,**
- **Gronau, Rosner, PhysRevD.83.034025 (2012)**
- These parameters were measured directly in $|V_{cb}|/m_b$ moment fits

B_s production *near* the $\Upsilon(5S)$

- **Correlated B_s** production
  - B_s tagging can be exploited for **unbiased** absolute measurements, and to **suppress B_{ud} background.**





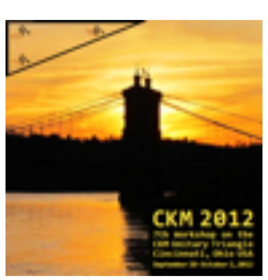


Babar PRL 102 012001 (2009)

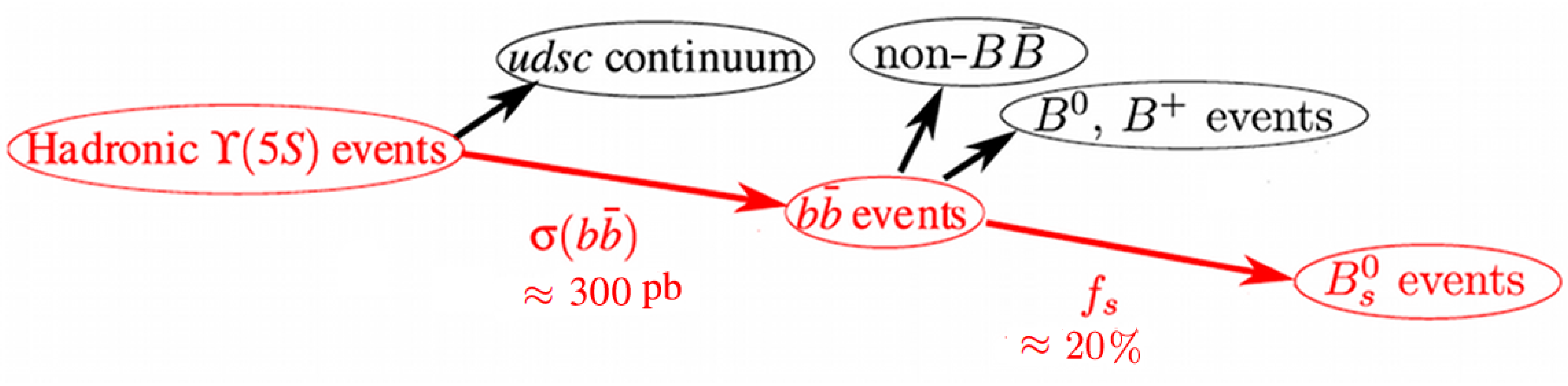
Belle Preliminary 2012

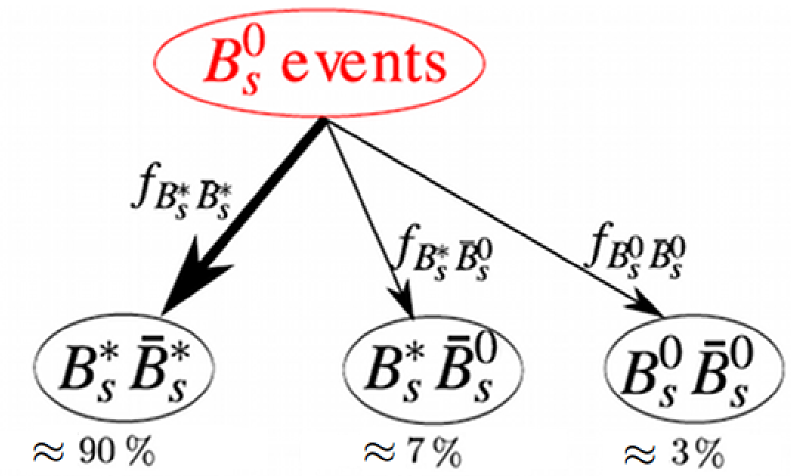
- $\Upsilon(5S) \rightarrow B^{(*)}B^{(*)}(n\pi)$, $B_s^{(*)}B_s^{(*)}$, $\Upsilon(nS)\pi\pi$

Experiment	Luminosity
Babar: $\sqrt{s} > 2m_{Bs}$	~3.2 fb^{-1}
Belle: $\sqrt{s} \sim m_{\Upsilon(5S)}$	121 fb^{-1}
CLEO: $\sqrt{s} \sim m_{\Upsilon(5S)}$	~0.5 fb^{-1}

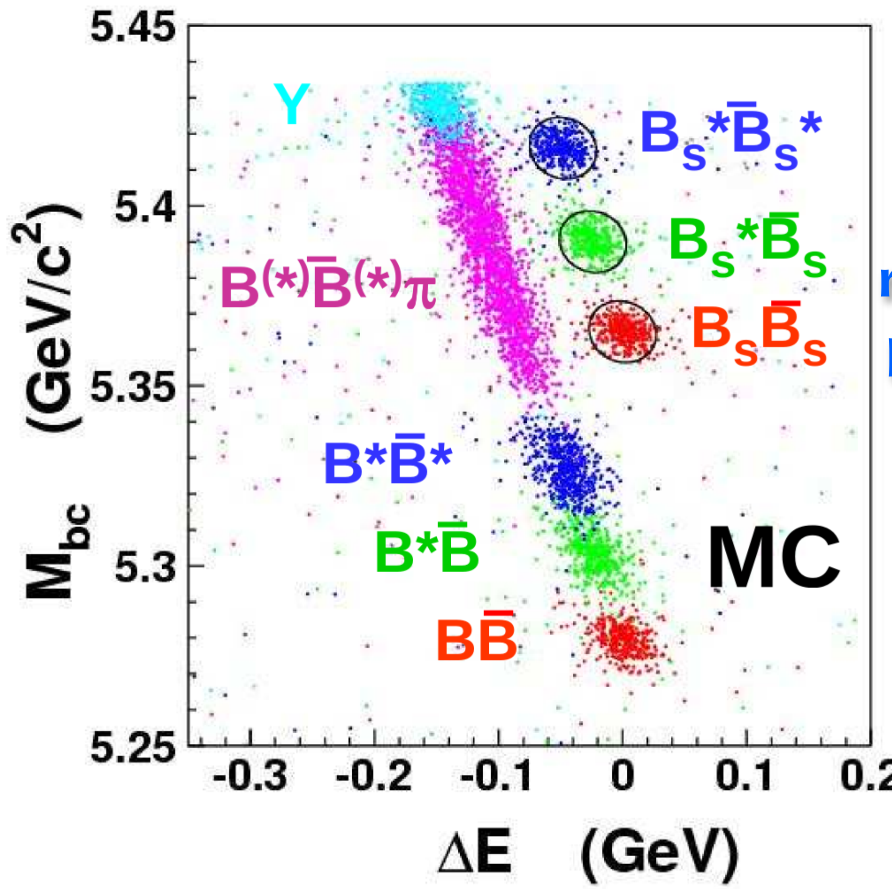


B_s production @ Υ(5S)

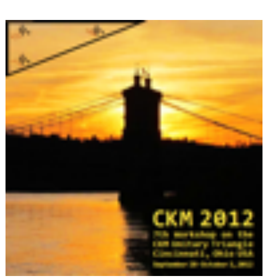




- Challenges (for precise measurements)
  - $\sigma_{bb}^{(\sqrt{s}=10.87\text{GeV})}/\sigma_{bb}^{(\sqrt{s}=10.58\text{GeV})} \sim 0.3$
  - $f_s \sim 0.199 \pm 0.030$ [HFAG 2012], large uncertainty! impacting most absolute BF measurements at Υ(5S).
    - Above $B_s^{(*)}B_s^{(*)}$ threshold **~14M B_s^0** in **121 fb^{-1}** at Belle
  - Excited production: kinematic smearing
    - **BF(Υ(5S)→ $B_s^* B_s^*$)~90%**
    - **$B_s^* \to B_s \gamma$, $m(B_s^*)-m(B_s) \simeq 49$ MeV**

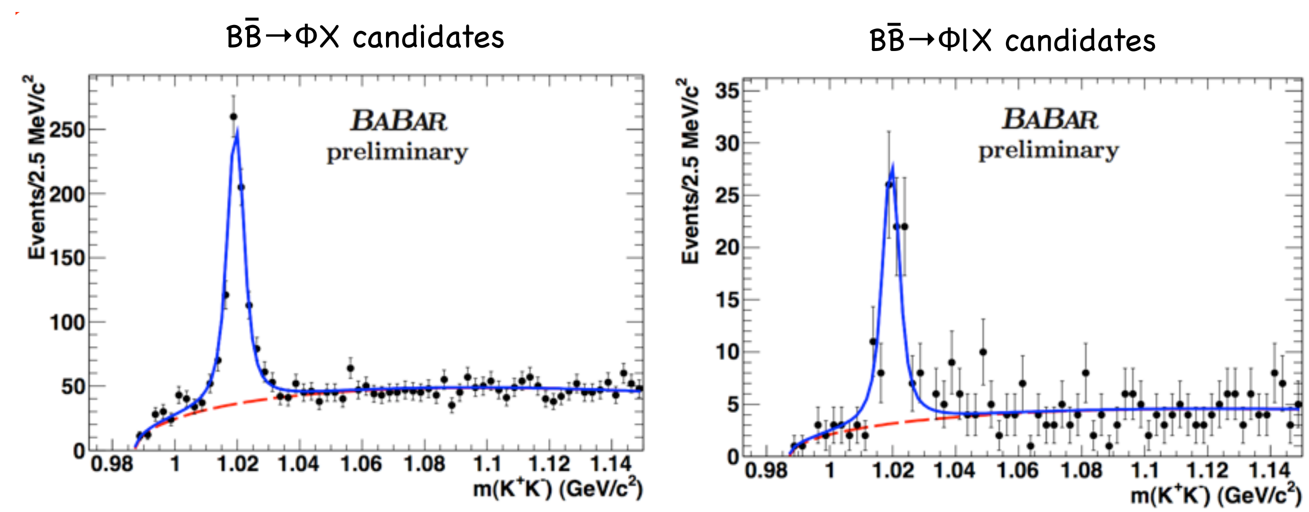


Fully reconstructed B_s candidates

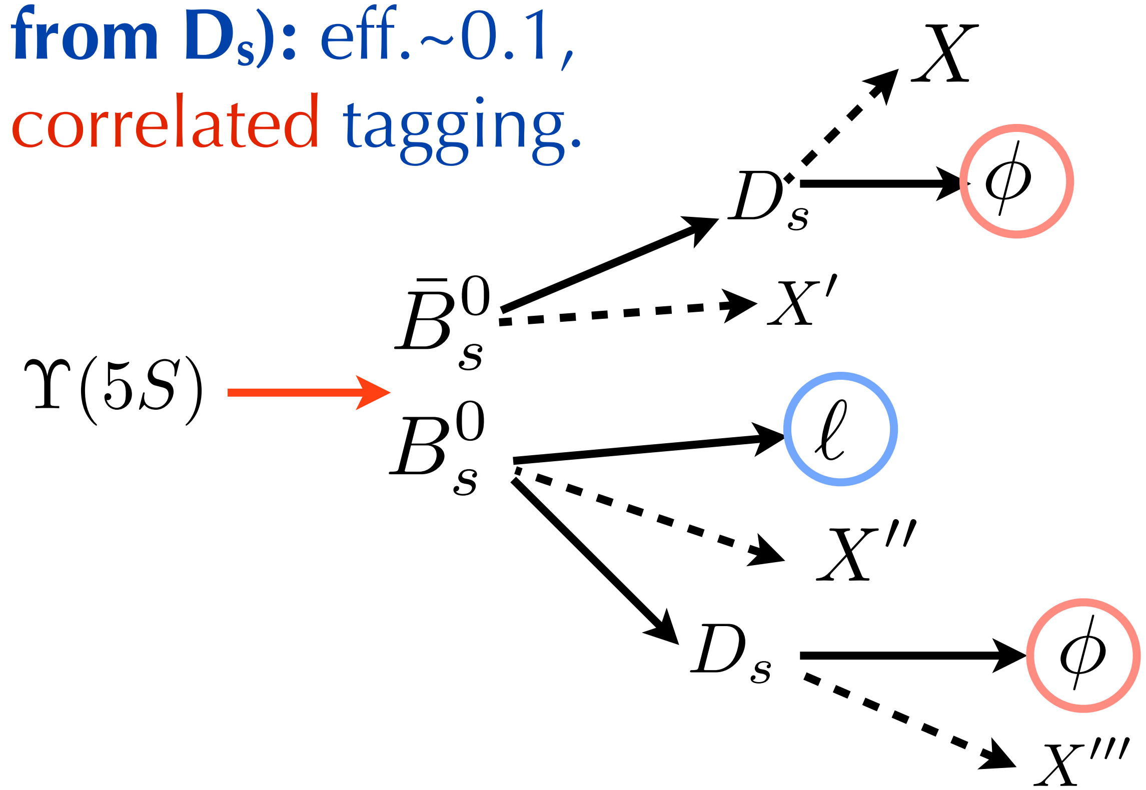


Current B_s Tagging methods

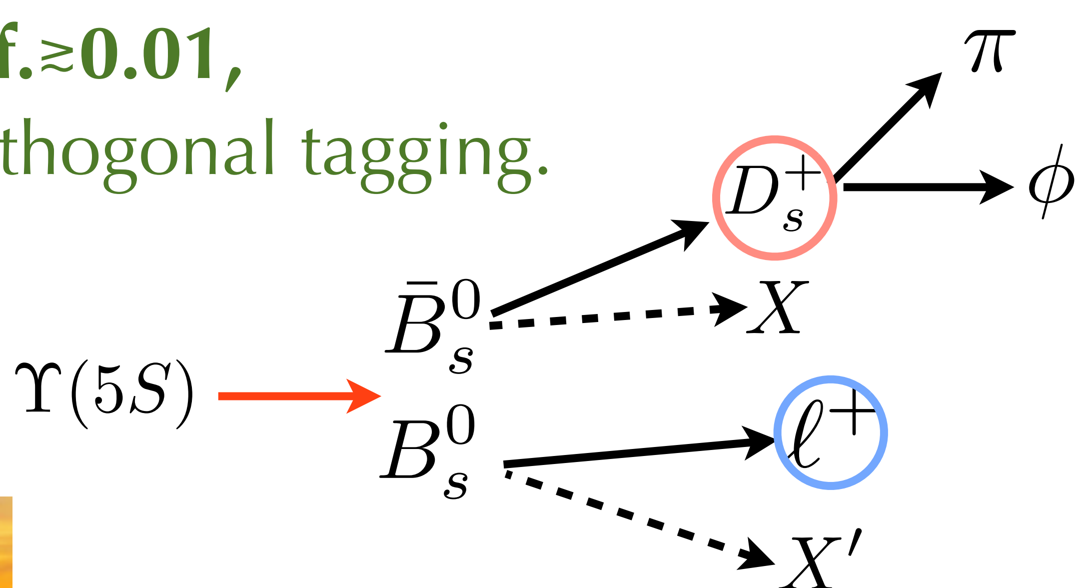
- **Smaller data samples and $B_{u/d}$ contamination**,
  Choose particles that have very different decay rates from **B** and $\mathbf{B_s}$
  e.g. [PDG2012]
  - $\mathbf{B(B_s^0 \to D_s^{\pm} X) = (93 \pm 25)\%}$,
    $\mathbf{B(B \to D_s^{\pm} X) = (8.3 \pm 0.8)\%}$
- *Two methods* $\boldsymbol{\Phi}$, $\boldsymbol{D_s^+}$:

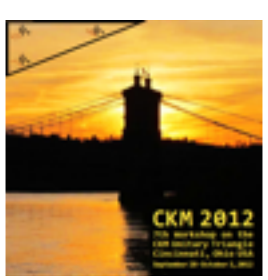


Φ Method (mostly from D_s): eff.~0.1, correlated tagging.



***D_s^+ Method*:**
Eff.≥0.01,
orthogonal tagging.

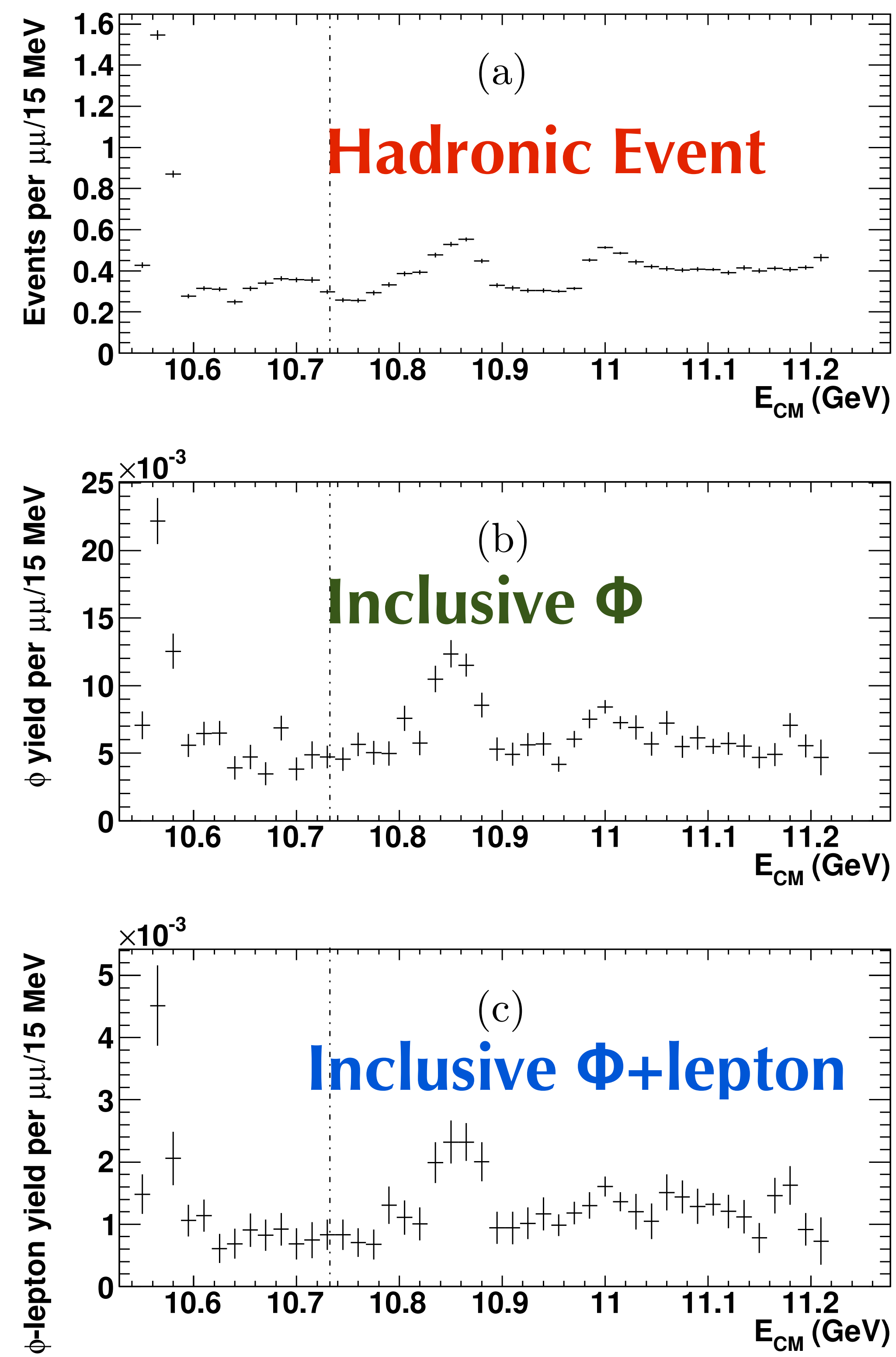




Babar Inclusive

- Measure number of events, Φ yield, and Φ +lepton yield in correlation with a high-momentum lepton as a function of CM energy

Φ→K⁺K⁻ production	Φ	Φ+l (same B)	Φ+l (Opp. B)
$B(B_s \to D_s X)$ x $B(D_s \to \Phi X)$	15%	1.3%	1.4%
$B(B \to \Phi X)$	3.4%	0.1%	0.7%

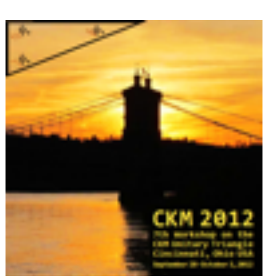


Rates

$$C_h = R_B\left[f_s\epsilon^s_h + (1-f_s)\epsilon_h\right]$$
$$C_\phi = R_B\left[f_s\epsilon^s_\phi P(B_s\overline{B}_s \to \phi X) + (1-f_s)\epsilon_\phi P(B\overline{B} \to \phi X)\right]$$
$$C_{\phi\ell} = R_B\left[f_s\epsilon^s_{\phi\ell} P(B_s\overline{B}_s \to \phi\ell X) + (1-f_s)\epsilon_{\phi\ell} P(B\overline{B} \to \phi\ell X)\right]$$

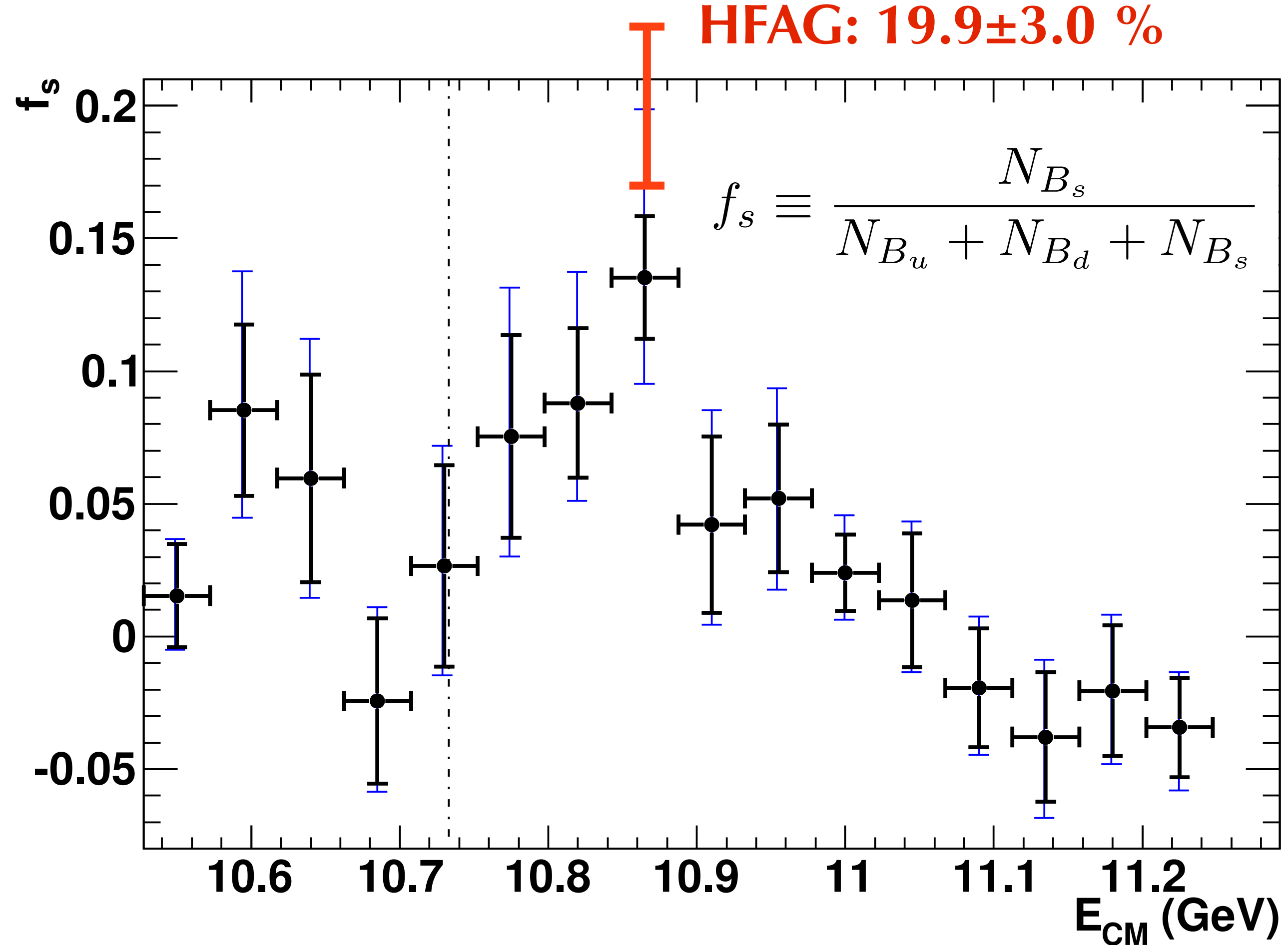
$$R_B = \sum_{q=u,d,s}\sigma(e^+e^- \to B_q\bar{B}_q)/\sigma_{\mu^+\mu^-}$$

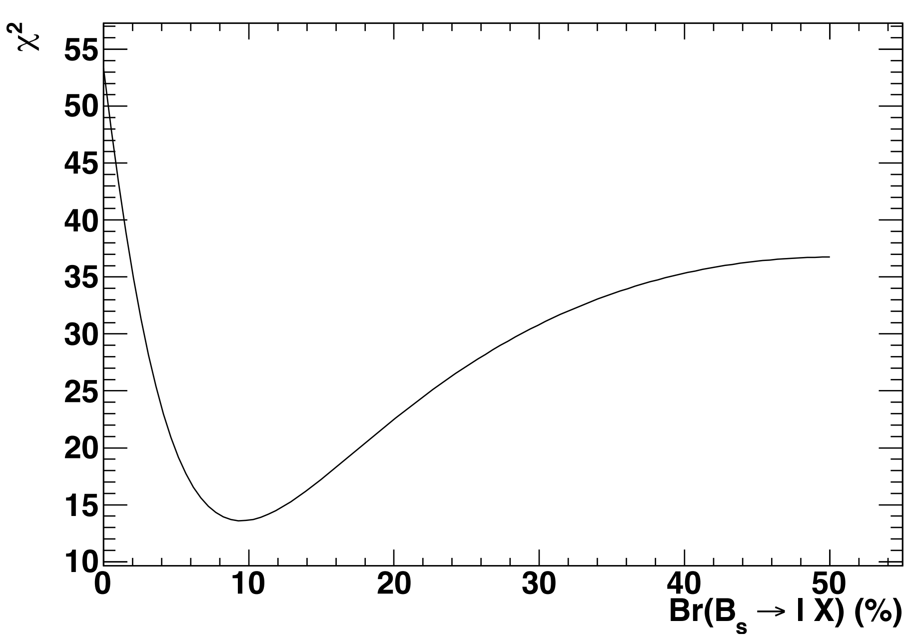
- **p(B→ΦX)** are probabilities that a **Φ** is produced in a **BBbar** event



Babar Inclusive

- **$B_{u/d}$** from **Y(4S),** Continuum from using **off resonance**
- f_s extracted simultaneously at each energy scan point from **N_{events}**, and **Φ** yield
- B_s contributions depend on various inputs *e.g.* BFs:
  $B_s \to D_sX$, $B_s \to l\nu X$,
  $D_s \to l\nu X$, $D_s \to \Phi X$, $D_s \to \Phi l\nu X'$
- **χ^2** constructed from measured and expected value of **P(BBbar→ΦlX)**, minimising for **$BF(B_s \to l\nu X)$**





- $BF(B_s \to l\nu X) = 9.5\ ^{+2.5}_{-2.0}{}^{+1.1}_{-1.9}$ %
- Dominant systematic (~%10) from inclusive D_s yield.

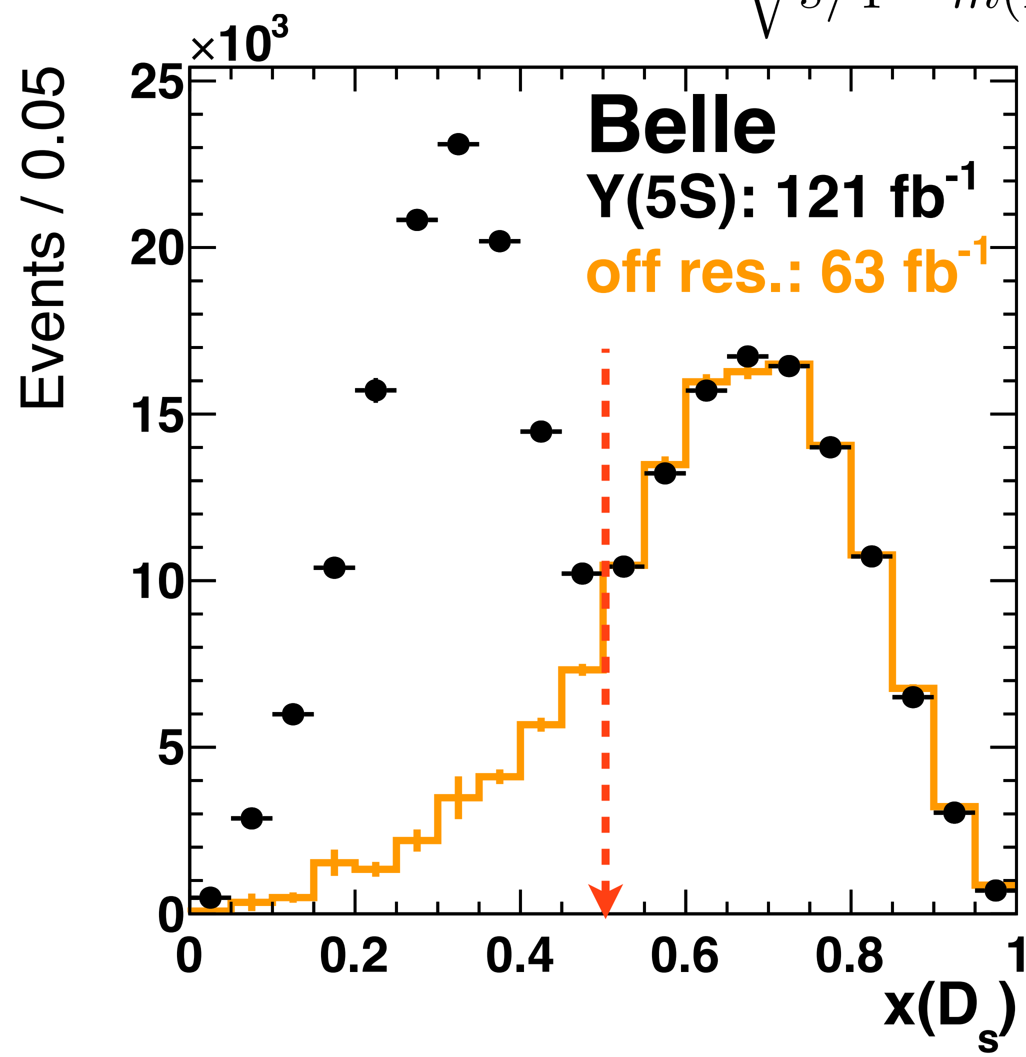
Belle Inclusive

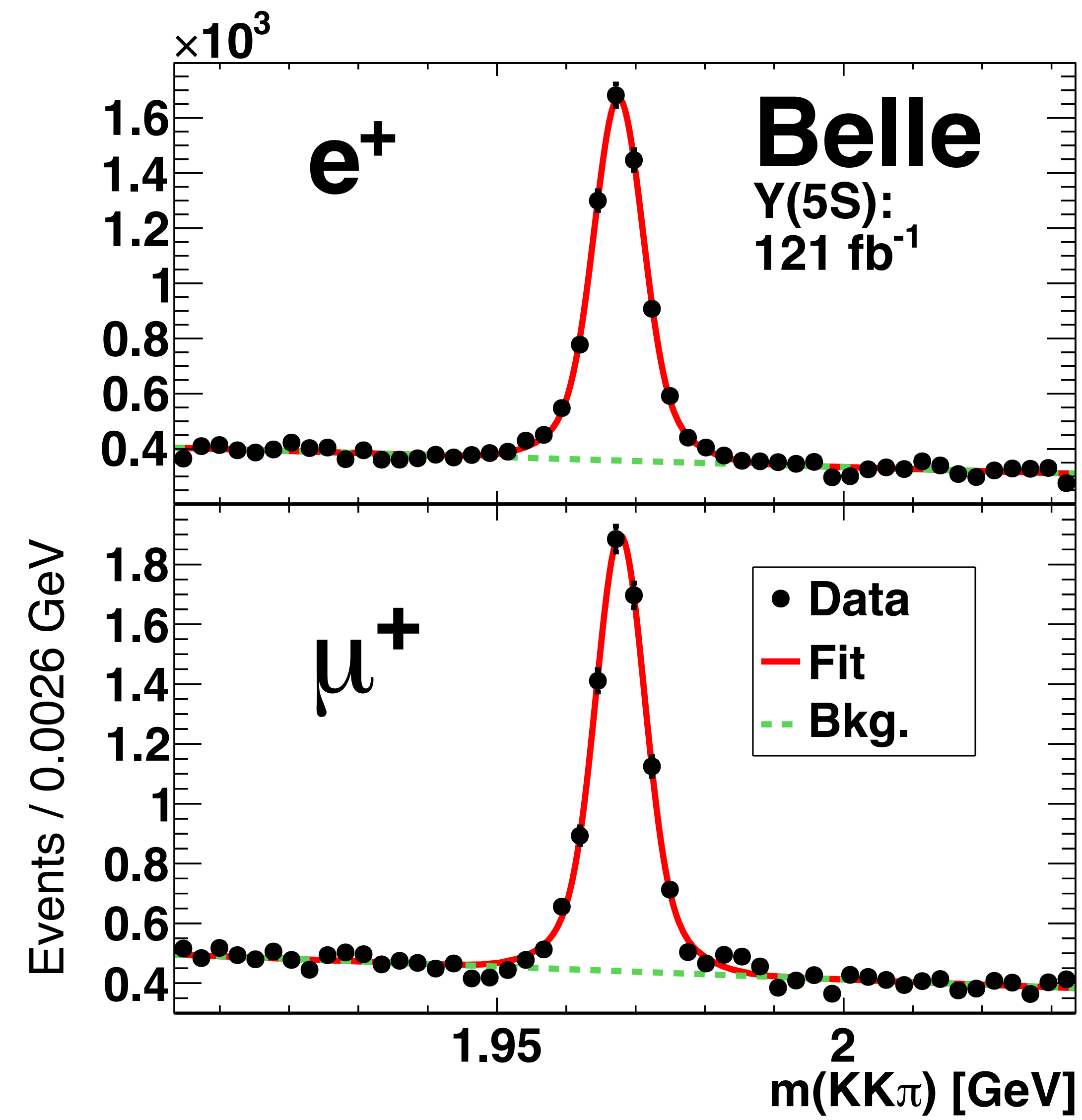
- Same sign tagging $D_s^- l^-$ **: *no tag bias***
- Fit m(**KKπ**) in bins of lepton momentum
- Continuum subtracted with off resonance (**Lumi(off)/Lumi(on)~0.5**)

$$x(D_s^+) = \frac{p^*(D_s^+)}{p^*_{\max}(D_s^+)} = \frac{p^*(D_s^+)}{\sqrt{s/4 - m(D_s^+)^2}}$$

$$N(D_s^- \ell^-) \propto f_s \cdot \mathcal{B}(B_s^0 \to X \ell^+ \nu_\ell)$$

Background from $B_{u,d}$ decays





- **x(D$_s$)** separates continuum

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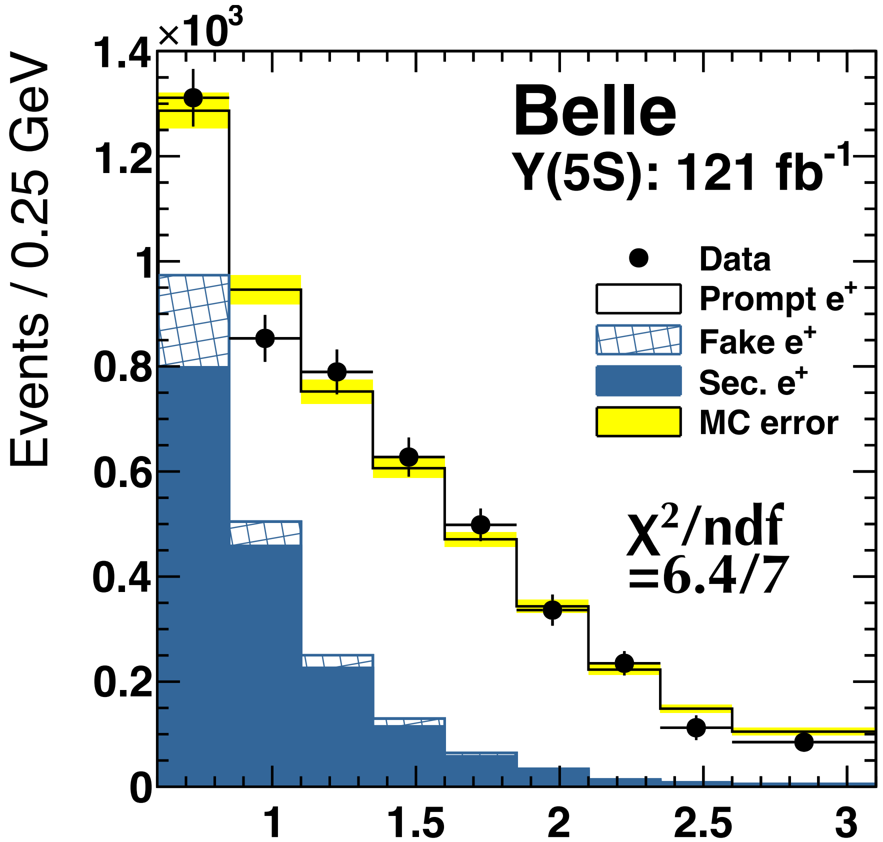
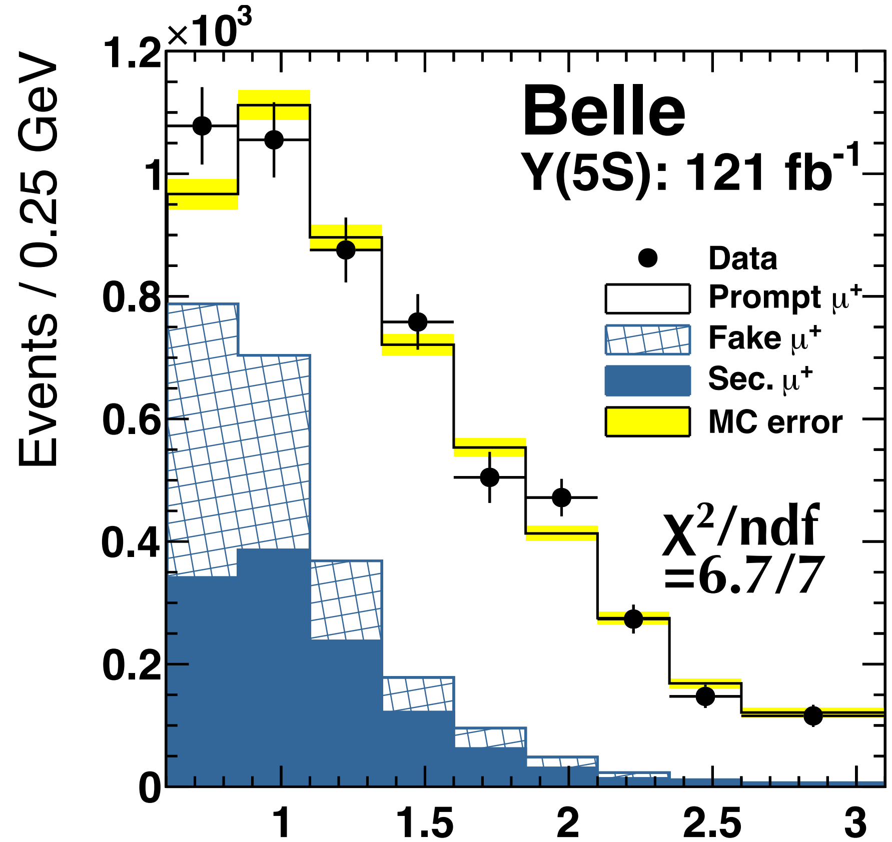
Belle Inclusive



$N(D_s^- e^-)$=4260±190



$N(D_s^- e^-)$=4760±230

Two component fraction fit: **prompt leptons** and **secondary and fake** leptons

$$\frac{N(D_s^- e^-)}{N(D_s^-)} = 0.0426 \pm 0.0020 \pm 0.0013$$

$$\frac{N(D_s^- \mu^-)}{N(D_s^-)} = 0.0471 \pm 0.0024 \pm 0.0016$$

Rel. Systematic Uncertainty	e^-	μ^-
Lepton ID, fake rate	0.7	1.4
D_s efficiency	0.8	0.8
KKπ fit	2.0	2.2
Secondary leptons	1.0	1.5
Continuum	1.1	
Semileptonic Width Composition	1.2	

BF Extraction

Measurement — Expectation from external parameters

$$\frac{N(D_s^-\ell^-)}{N(D_s^-)} = \frac{N_s(D_s^-\ell^-) + N_{u,d}(D_s^-\ell^-)}{N_s(D_s^-) + N_{u,d}(D_s^-)}$$

$$= \frac{\mathcal{F}_{D_s^+\ell^+}(B_s^{(*)}\bar{B}_s^{(*)}) + \mathcal{F}_{D_s^+\ell^+}(B_{u,d}^{(*)}\bar{B}_{ud}^{(*)}(\pi))}{\mathcal{F}_{D_s^+}(B_s^{(*)}\bar{B}_s^{(*)}) + \mathcal{F}_{D_s^+}(B_{u,d}^{(*)}\bar{B}_{ud}^{(*)}(\pi))}$$

D_s^+

$$\mathcal{F}_{D_s^+}(B_s^{(*)}\bar{B}_s^{(*)}) = 2 \cdot f_s \cdot \mathcal{B}(B_s^0 \to D_s^\pm X),$$

$$\mathcal{F}_{D_s^+}(B_{u,d}^{(*)}\bar{B}_{ud}^{(*)}(\pi)) = 2 \cdot f_{ud} \cdot [\, 1/2 \cdot \mathcal{B}(B^0 \to D_s^\pm X) + 1/2 \cdot \mathcal{B}(B^+ \to D_s^\pm X)\,],$$

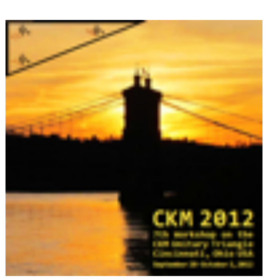
$D_s^+ l^+$

$$\mathcal{F}_{D_s^+\ell^+}(B_s^{0(*)}\bar{B}_s^{0(*)}) = 2 \cdot f_s \cdot \mathcal{B}(B_s^0 \to X^-\ell^+\nu_\ell) \cdot [\, \chi_s \cdot \mathcal{B}(B_s^0 \to D_s^+ X) + (1-\chi_s) \cdot \mathcal{B}(B_s^0 \to D_s^- X)\,]$$

$$\mathcal{F}_{D_s^+\ell^+}(B^{0*}\bar{B}^0\pi) = 2 \cdot f_{ud} \cdot \frac{1}{6} \cdot (1 - F_2) \cdot F'_{B^*\bar{B}\pi} \, \mathcal{B}(B^0 \to X\ell^+\nu_\ell) \cdot [\, \chi_d^{(+)} \cdot \mathcal{B}(B^0 \to D_s^+) + (1-\chi_d^{(+)}) \cdot \mathcal{B}(B^0 \to D_s^-)\,].$$

'External parameter' Systematic Errors

Parameter	Value	$\frac{\Delta\mathcal{B}}{\mathcal{B}}$ [%]
$f_s/f_{u,d}$	$(26.2 \pm 5.1)\%$	3.2
$\mathcal{B}(B_s \to D_s^\pm X)$	$(93 \pm 25)\%$	4.4
$\mathcal{B}(B^+ \to D_s^+ X)$	$(7.9 \pm 1.4)\%$	2.4
$\mathcal{B}(B^0 \to D_s^+ X)$	$(10.3 \pm 2.1)\%$	1.5
$\mathcal{B}(B^0 \to D_s^- X)$	$(1.50 \pm 0.84)\%$	1.2
$\mathcal{B}(B^+ \to D_s^- X)$	$(1.1 \pm 0.4)\%$	1.0
$\mathcal{B}(B^0 \to X\ell^+\nu_\ell)$	$(10.33 \pm 0.28)\%$	0.4
$\mathcal{B}(B^+ \to X\ell^+\nu_\ell)$	$(10.99 \pm 0.28)\%$	0.2
$\Gamma(B^+B^-)/\Gamma(B^0\bar{B}^0)$	(1.0 ± 0.2)[17]	0.3
$F_{B^*\bar{B}^*}$	$(38.1 \pm 3.4)\%$	0.1
$F_{B^*\bar{B}}$	$(13.7 \pm 1.6)\%$	0.1
$F_{B\bar{B}}$	(5.5 ± 1.6)	0.1
$F'_{B^*\bar{B}^*\pi}$	$(5.9 \pm 7.8)\%$ [14]	0.2
$F'_{B^*\bar{B}\pi}$	$(41.6 \pm 12.1)\%$ [14]	0.4
$F'_{B\bar{B}\pi}$	$(0.2 \pm 6.8)\%$ [14]	0.1
x_d	(0.771 ± 0.008)	0.1
x_s	(26.49 ± 0.29)	< 0.1



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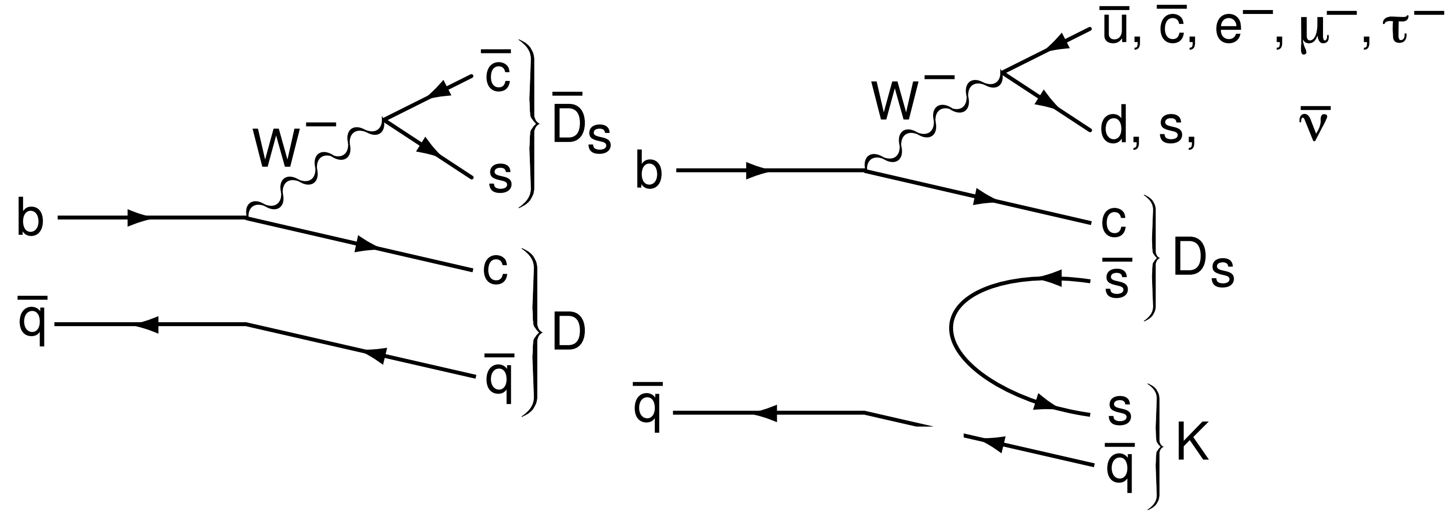
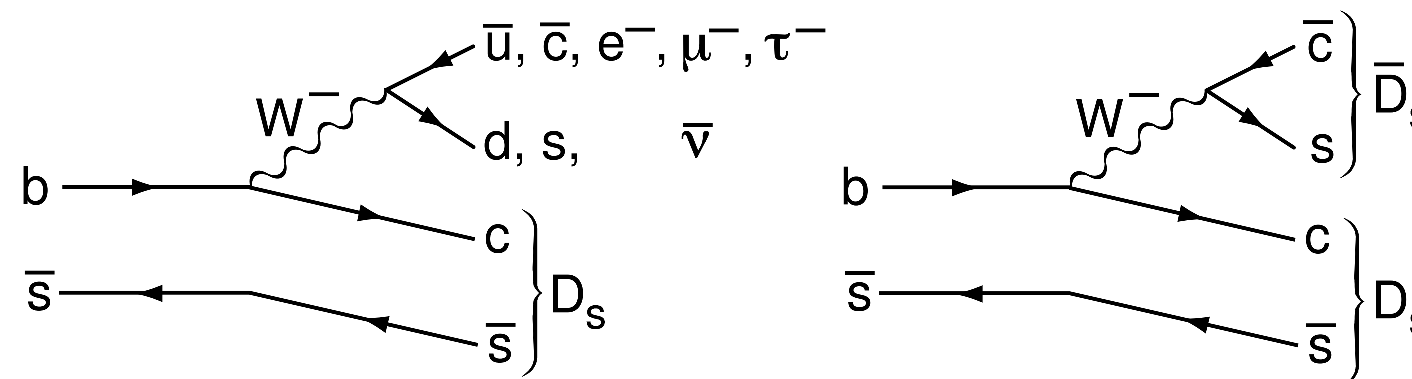
Systematics: $B_s \rightarrow D_s X$

- **$B_s \rightarrow D_s X$** error dominates measurements, but PDG has **3 main issues:**
  - **D_s BF's outdated**: Most use **$BF(D_s^- \rightarrow \varphi\pi^-)=3.5\pm0.9$**, but **$BF(D_s^- \rightarrow \varphi\pi^-)=(4.66\pm0.25)\%$** in PDG.
  - S-wave contributions treated inconsistently (different helicity requirements)
  - **Multiplicities** and **BFs** combined despite differences in definition, i.e. **upper vertex part.** Large for **B_s!**
  - Inconsistent f_s.
  - **$BF(B_s^0 \rightarrow D_s^{\pm}X)$**
    - PDG 2012: **= (93 ± 25)%**
    - Theory **= (91 ± 11)%**
- **f_s**: Issue for most ***B_s*** measurements at 5S, correlated to **$B_s \rightarrow D_s X$**!

B Diagrams

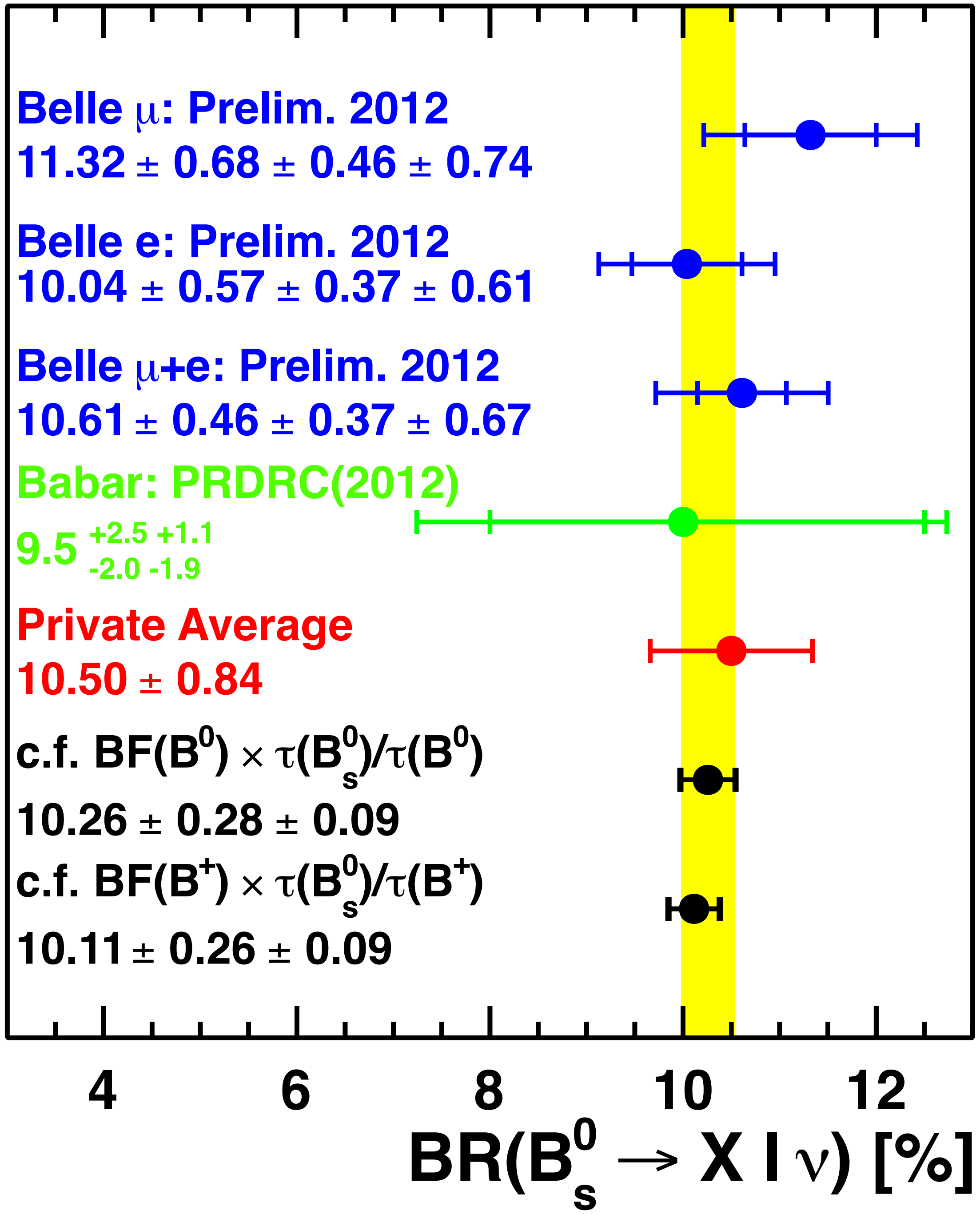


B_s Diagrams



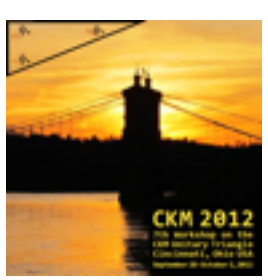
PRL.95.261801

Inclusive Summary



- Belle: Model independent
- ~10% limit on SU3 symmetry breaking
- Systematics limited!
  - Due to tagging techniques.
  - **B_s full reconstruction** (particularly >1 ab^{-1}) will help, but there is still some kinematic smearing
- Can still improve ***f_s & D_sX*** with current 5S data. (not yet measured for 121 fb^{-1})

$$\frac{\Gamma(B_s^0 \to X\ell\nu)}{\Gamma(B_d^0 \to X\ell\nu)} \cdot \frac{\tau(B_s^0)}{\tau(B_d^0)} = \frac{\mathcal{B}(B_s^0 \to X\ell\nu)}{\mathcal{B}(B_d^0 \to X\ell\nu)}$$



Exclusives

- Semileptonic decays to heavier excited charm states, **more of the available phase space near zero recoil**, increasing importance of corrections in HQET.
- Theory expects **large SU(3) symmetry breaking**, but inconsistent predictions.
- Exclusive measurements:
  - **K l ν**...eventually
  - **Isolating charm states, D_s^{**}, D_{sJ}.**
  - Calibration for **QCD factorisation** predictions

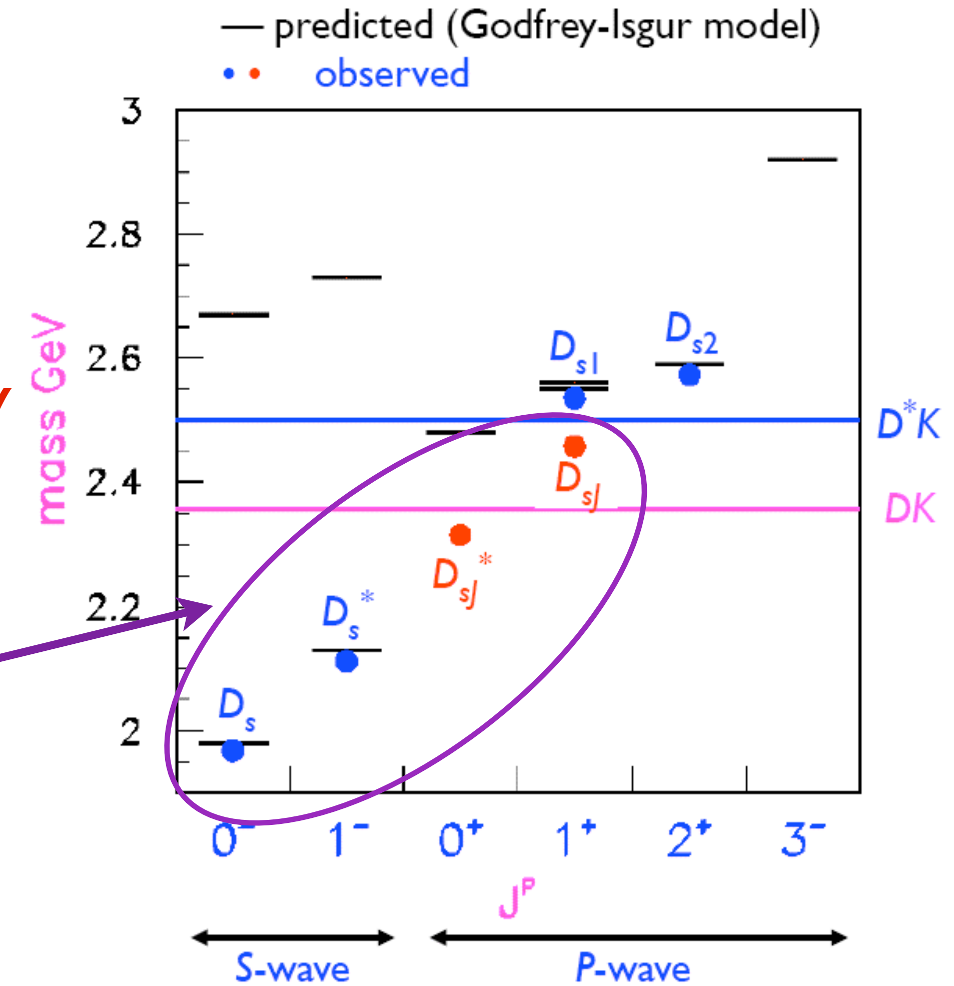
- Predictions:

$BF(B_s)$ (%)	$D_s\mu\nu$	$D_s^*\mu\nu$
Zhang, Wang, 1003.5576	2.9±0.4	7.1±0.9
Chen, Fu, Kim, Wang J. Phys G 39 045002, (2012)	1.4 – 1.7	5.1 – 5.8
SU(3) Symmetry, $B(B^0)\times\tau_{B_s}/\tau_{B0}$ [HFAG 2012 values]	2.12±0.12	4.92±0.11

$D_{s1}', D_{s2}^* \to D^{(*)} K$, $D_s^{(*)+}\, n\, \pi$

$D_{sj}^{(*)} \to D_s^{(*)+}\, n\, \pi^0/\gamma$

No prior measurements



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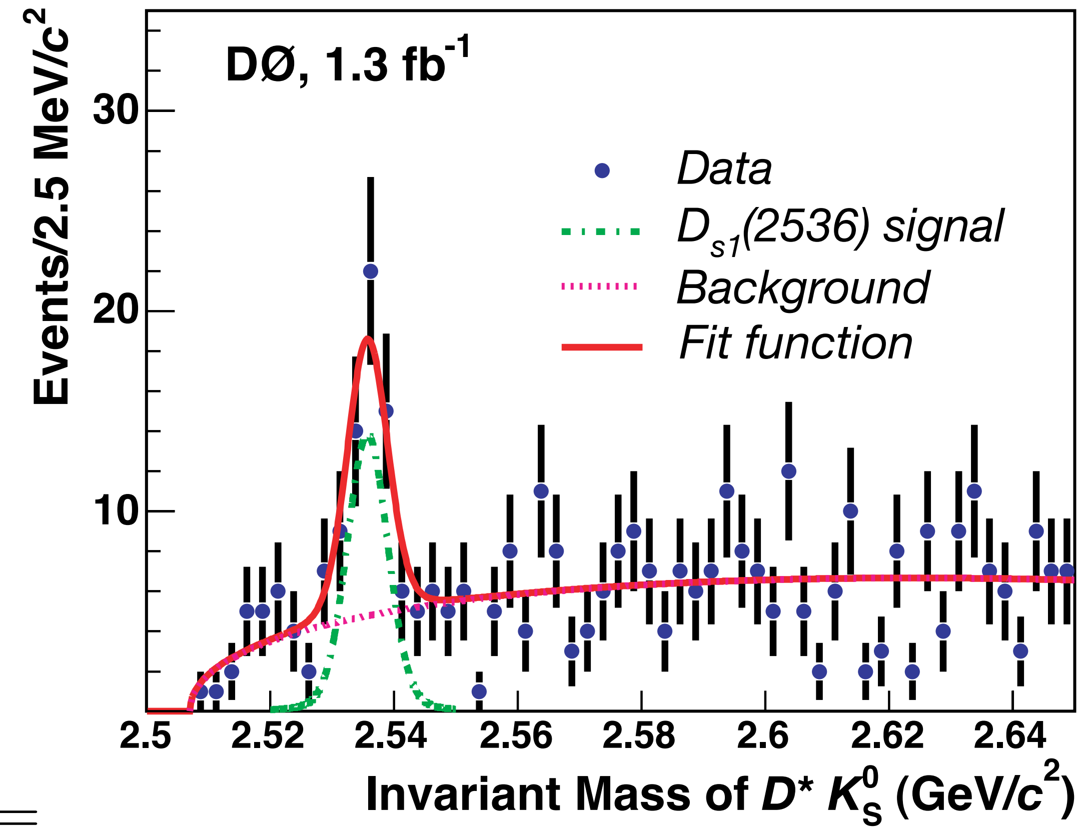
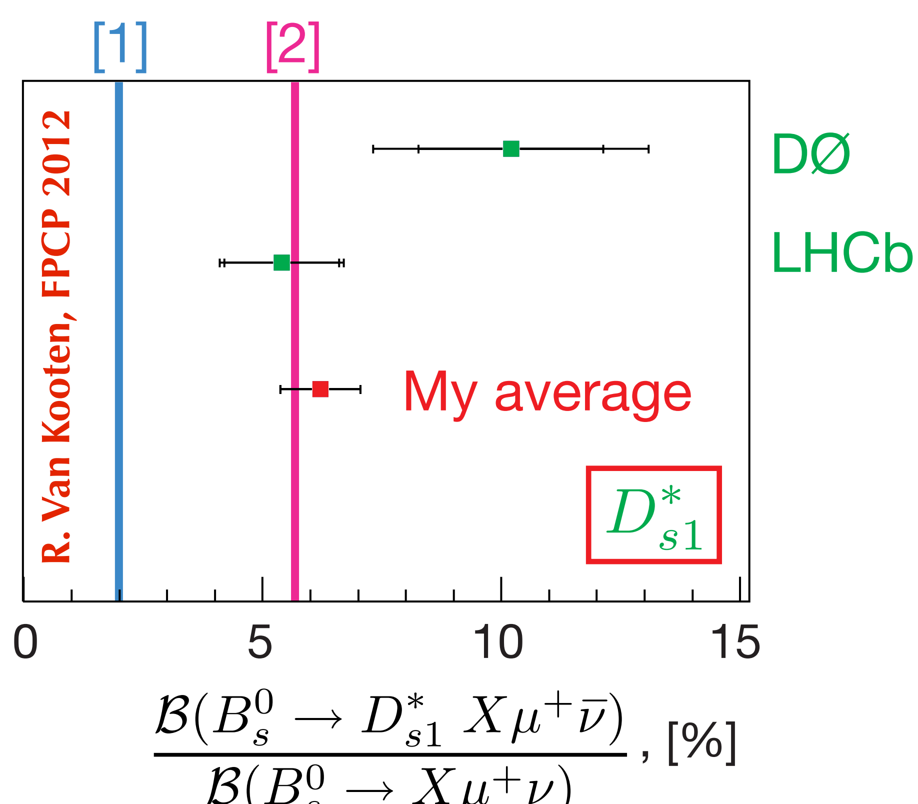
Exclusives @ D0: $B_s \to D_{s1}^{-}\mu^{+}\nu X$

- D^* associated with μ, and add K_S^0 to isolate
  - $D_{s1}(2536) \to D^{*-} K_S^0$
- Normalise to
  - $BF(b \to D^{*-}\mu\nu X) = (2.75 \pm 0.19)$ %, assume $BF(D_{s1}) \sim 25\%$ (assumed)
- First observation



$$f(\bar{b} \to B_s^0) \cdot Br(B_s^0 \to D_{s1}^{-}\mu^{+}\nu_\mu X) \cdot Br(D_{s1}^{-} \to D^{*-}K_S^0) = \\ = [2.66 \pm 0.52\,(\text{stat}) \pm 0.45\,(\text{syst})] \times 10^{-4}.$$

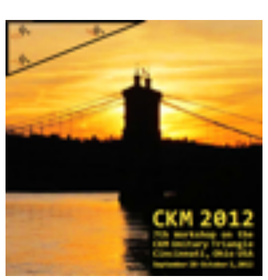
$$\mathcal{B}(B_s^0 \to D_{s1}^{-}(2536)\mu^{+}\nu_\mu X) = (1.03 \pm 0.20 \pm 0.17 \pm 0.14_{\text{prod}})\%$$



- More details on D_{s2}^* in C. Bozzi's talk

[1] ISGW2, Phys. Rev. D **52**, 2783 (1995)

[2] ISGW + Non-relativ. HQET, J. Phys. G **29**, 2059 (2003)

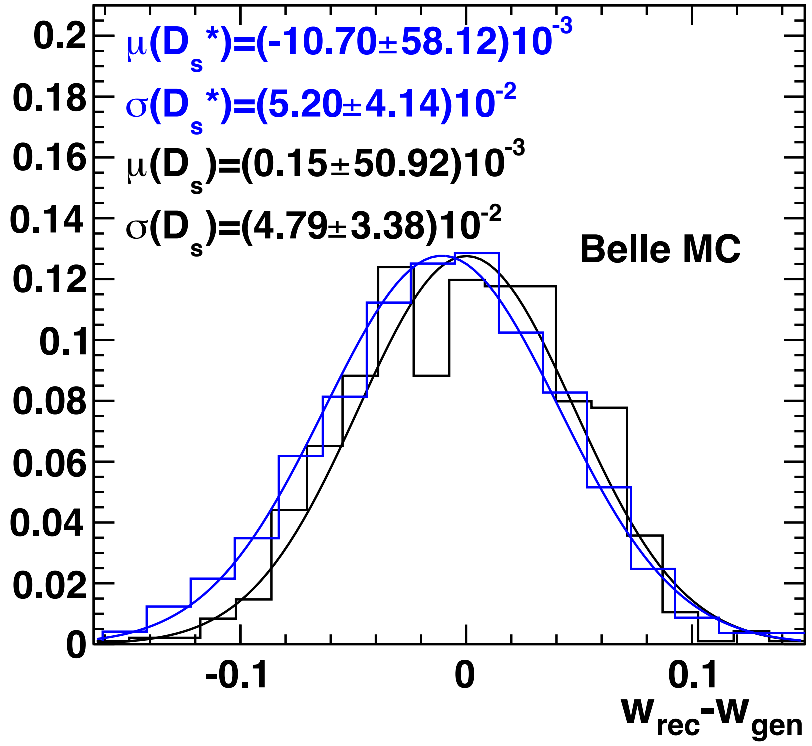


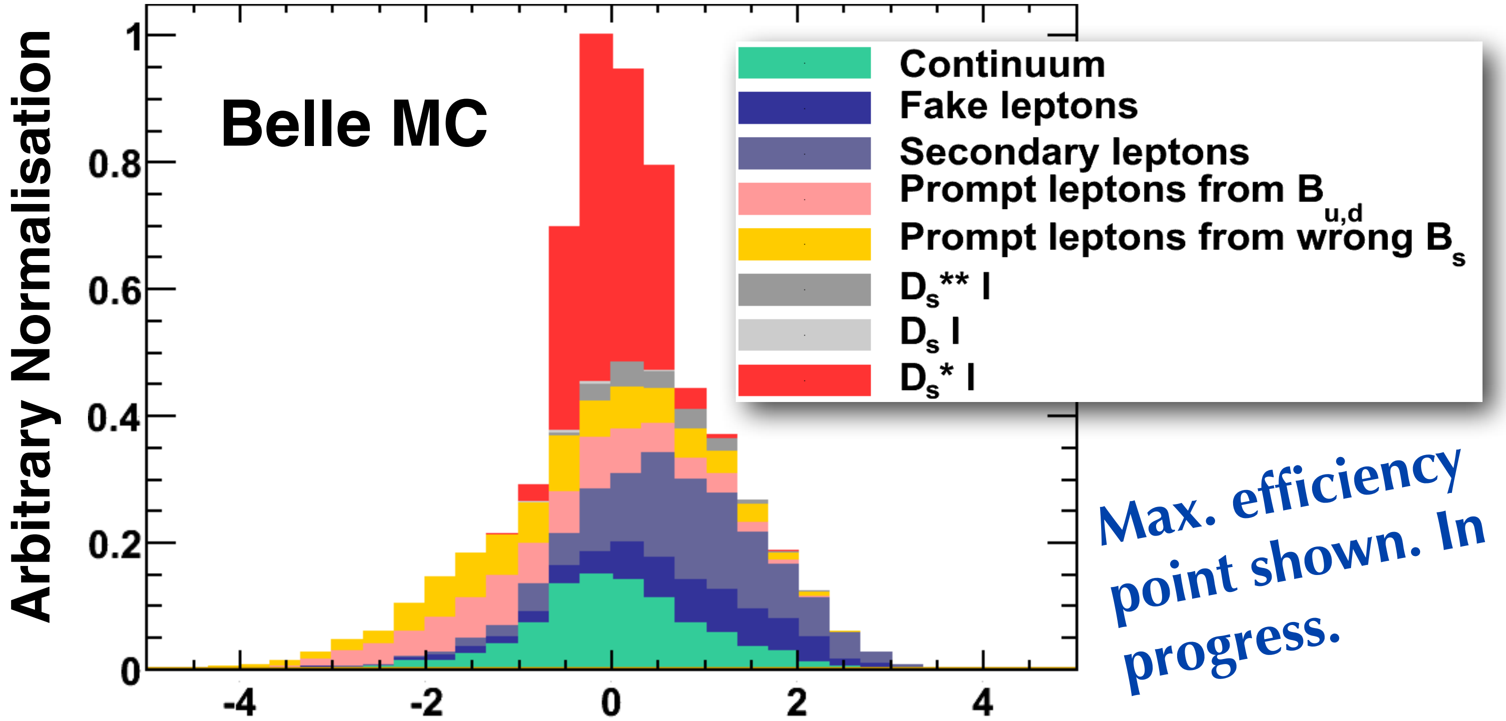
$B_s^0 \rightarrow D_s^{*\pm}\, l\, \nu$ @ 121 fb^{-1}, "*Publicity*"

- Untagged approach *to be* exploited at Belle: X_{miss}, $\cos\theta_{BY}$
- Suppression of B_{ud} cross feed for $D_s^{(*)}$ final states, with *some* peaking contamination from ~ $6 \cdot 10^{-4}$ BF($B \rightarrow D_s(*)\pm K l \nu$) × 4 (fud/fs)

- **Resolution**: **Kinematic smearing** due to Υ(5S) decay modes, and **γ in $D_s^* \rightarrow D_s \gamma$** (unfortunately), but **w resolution acceptable**

- **$B_s^0 \rightarrow D_s^{*\pm}\, l\, \nu$, $D_s^* \rightarrow D_s\, \gamma$, $D_s \rightarrow \Phi(KK)\pi$ (p_{lep}>0.5 GeV)**





Max. efficiency point shown. In progress.

$$w \equiv v_B \cdot v_{D^*} = E_{D^*}/m_{D^*} = \frac{m_B^2 + m_X^2 - q^2}{2 m_B m_{D^*}}$$

$$X_{\rm mis} = \frac{\left[E_{\rm beam} - E_{\Upsilon(5S)}(D_s^*\ell)\right] - |\vec{p}_{\Upsilon(5S)}(D_s^*\ell)|}{\sqrt{E_{\rm beam}^2 - m_{B_s}^2}}$$

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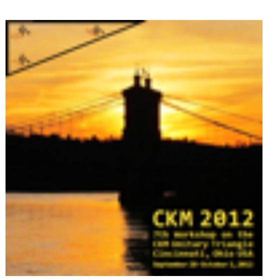
Yield projections

- (My) Rough estimates for Signal: $B_s \to D_s(\Phi\pi)l\nu$, $D_s(\Phi\pi)^*l\nu$, $Kl\nu$.
  - **D_s** tagging could be extended , e.g. ***($\Phi\pi$,K_SK,K^*K) (~x3 eff. w/r/t Belle result)***
    - *But, To be uncorrelated we must ignore opposite sign $D_s^-l^+$ pairs for inclusive analysis*
  - **B_s Full Recon & SL efficiencies**: take Eff(B^0) as a guide
  - Too early to quote precise, expected precision on exclusive modes,

Assume BF($Kl\nu$)~1.5×10^{-4}

			Yields (tagging x efficiency x BF)								
Tag Method	Tag Eff.	N_{Bs}/N_B	121 fb^{-1}(5 ab^{-1})								
			$Xl\nu$	$\Delta stat$	Δsys	$D_sl\nu$		$D_s^*l\nu$		$Kl\nu$	
Untagged	2	**$f_s/f_{d,u}$≃0.25**	2.7M	-	-	7200		10900		2500	
Φ	0.12	**$4.4\cdot f_s/f_{d,u}$**	160k	-	-	450		650		150	
D_s:$\Phi\pi$,K_SK,K^*K	0.04	**$10\cdot f_s/f_{d,u}$**	**27k**	**3%**	**7%**	140	(6,000)	200	(8,500)	47	(2,000)
SL tag (D_s l)	0.01	**≫10**	**6800**	**3%**	**~5%**	40	(1,500)	50	(2,200)	12	(500)
B_s Full Recon.	0.004	**≫10**	5400	2%	~4%	15	**(620)**	20	**(880)**	5	**(200)**

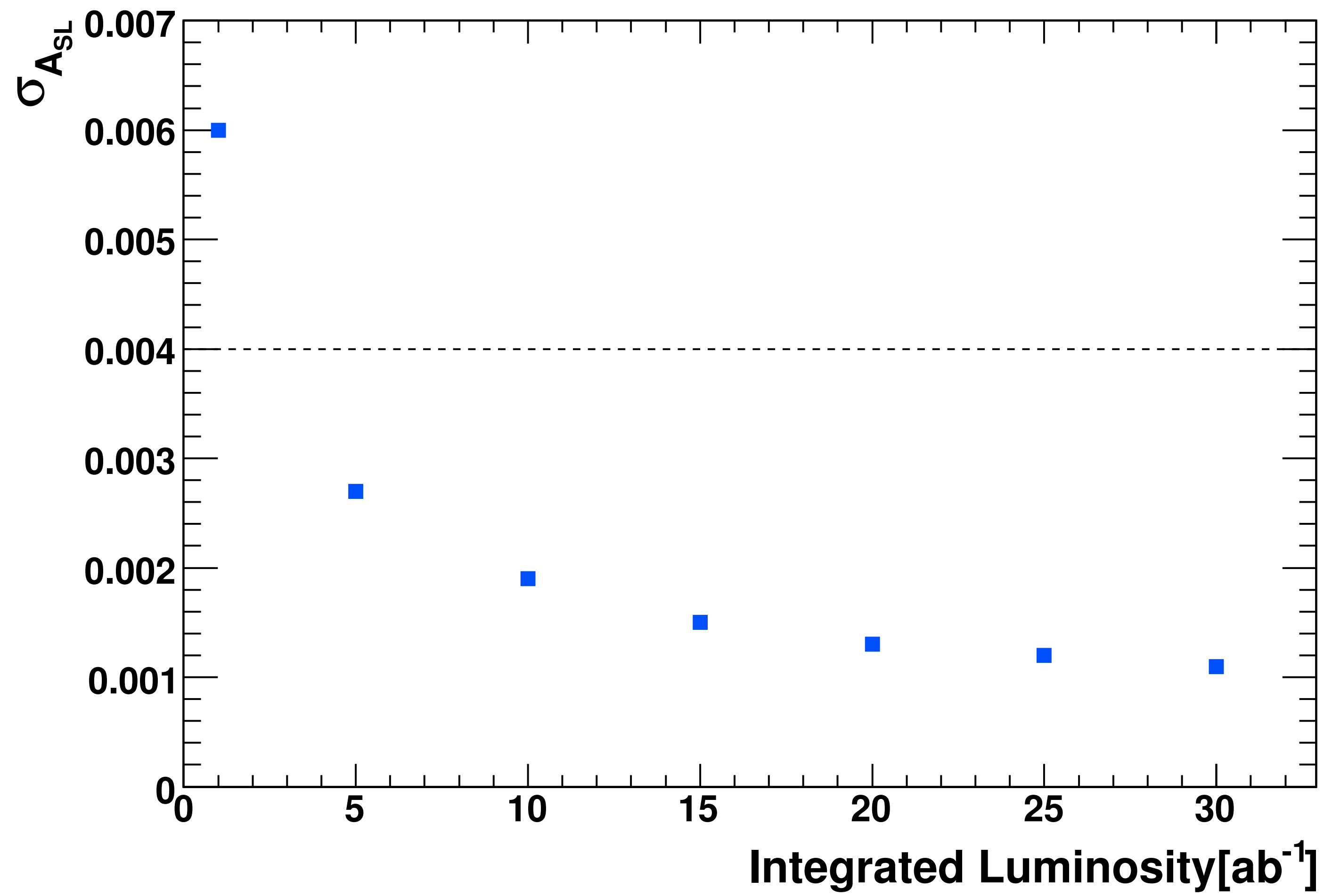
(My) Expected error @ 5 ab^{-1}~ 10%



Other B_s semileptonic measurements: L>1 ab^{-1}

- Time integrated A^{SL}_{CP}
  - SuperB (design report): Δa_{sl}^s, = (0.1)% (ultimate 75 ab-1)
  - c.f. LHCb, 1fb^{-1} a_{sl}^s= (-0.24±0.54±0.33)%

$$A^s_{\mathrm{SL}} = \frac{\mathcal{B}(B_s \to \overline{B}_s \to D_s^{(*)-} l^+ \nu_l) - \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+} l^- \nu_l)}{\mathcal{B}(B_s \to \overline{B}_s \to D_s^{(*)-} l^+ \nu_l) + \mathcal{B}(\overline{B}_s \to B_s \to D_s^{(*)+} l^- \nu_l)} = \frac{1 - |q/p|^4}{1 + |q/p|^4}.$$



- Other than |V_{ub}| **with Klν**: (expect smaller Lattice errors than πlν), What else can we **uniquely** learn from the ***B*$_s$ system** with **semileptonic**, **charged weak current *B*$_s$** decays?
  - **K* l ν**: polarisation?
  - **Tauonic** modes?

Summary

- Most precise *model independent* absolute B_s branching fraction measurements. Systematics limited but can be reduced with B_s tagging.
  - **BF($B_s \to X\, l\, \nu$)**=(10.5 ± 0.8)%
  - Consistent with SU3 and u-spin symmetry
  - Important calibration for B_s, as f_s<<1

- Semileptonic $\mathbf{B_s}$ physics a$\sqrt{}$**s=Υ(5S)** may be quite promising: **plans to measure more exclusive modes**, and use these for f_s.

- B_s full reconstruction **will** allow access to rare, BF O(1%) modes even with 121 fb^{-1}.

- **Belle II** plans to pursue rare and charmless modes.

Backup

Systematics Babar Analysis

Multiplicative Systematics	Relative Uncertainty (%)
$\mathcal{B}(B_s \to D_s^{(*)} X)$	$+8.72/-13.58$
$\mathcal{B}(B_s \to c\bar{c}\phi)$ (Unmeasured)	± 3.20
$\mathcal{B}(B_s \to DD_s X)$ (Unmeasured)	$+1.12/-1.16$
Other Branching Fractions	$+0.52/-0.54$
Event and Lepton Selection	$+1.99/-2.85$
Fixed Fit Parameters	$+0.49/-0.15$
Background Parameterization	± 0.93
PID and Lepton Fake Rate	± 3.21
$P(B_{u,d}\overline{B}_{u,d} \to \phi)$	$+1.47/-1.69$
Simulation Branching Fractions	± 2.59
ISR and 2γ Background	$+1.57/-7.14$
Correction to Event Subtraction	$+1.88/-4.59$
Technique bias	$+0.39/-10.00$
Total Multiplicative	$(+10.87/-19.92)\%$
Additive Systematics	**Uncertainty** $(\times 10^{-3})$
Other Branching Fractions	$+0.56/-0.64$
$P(B_{u,d}\overline{B}_{u,d} \to \phi\ell\nu)$	$+4.30/-3.90$
Total Additive	$(+4.34/-3.95) \times 10^{-3}$
Total Systematic	$(+11.20/-19.34)\times 10^{-3}$