Measurements at the Υ(5S) Resonance

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Outline

- Why the Υ(5S) Resonance?
- Experimental Challenges @ Υ(5S);
- The Belle Pioneer Runs;
- The Super-B scenario *(JHEP 0708:005,2007)*;
- What could be done now.

Why the $\Upsilon(5S)$ resonance?

$b \to d$

- Many precision measurement already available;
- More measurements with a SuperB at the $\Upsilon(4S)$;

BUT...

- At present, no evidence for NP.

$b \to s$

- Large NP effects not ruled out by present measurements;
- Can be studied using through Radiative Penguins and CP asymmetries in the B_d sector

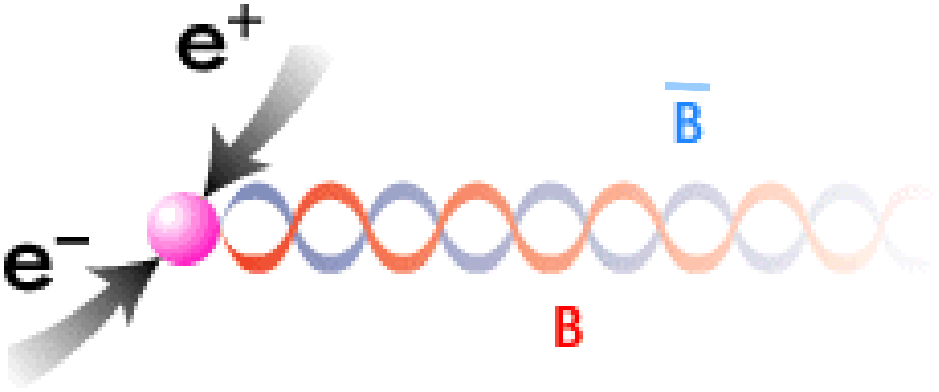
BUT...

- Large theoretical uncertainties in the B_d sector w.r.t. the experimental reach

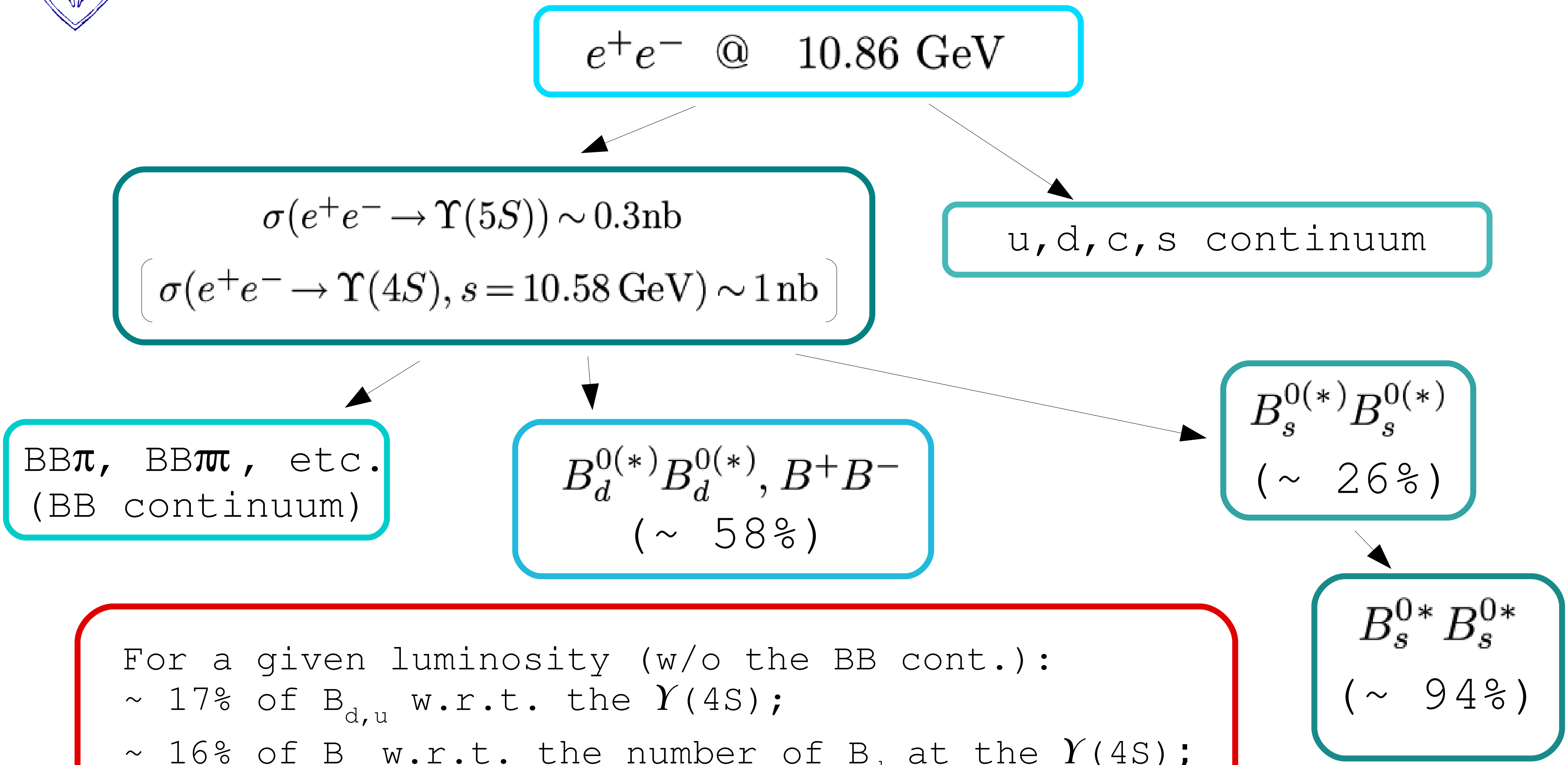
- A new approach – *constraining the Bs mixing phase*:
  - lifetime difference $\Delta\Gamma_s$;
  - CP asymmetry in mixing (A_{SL});

$\Big\}$ **Running at the $\Upsilon(5S)$ resonance!**

Experimental Challenges



$\Upsilon(5S)$ Production & Decays



e^+e^- @ 10.86 GeV

$\sigma(e^+e^- \to \Upsilon(5S)) \sim 0.3\,\mathrm{nb}$

$\sigma(e^+e^- \to \Upsilon(4S), s = 10.58\,\mathrm{GeV}) \sim 1\,\mathrm{nb}$

u,d,c,s continuum

BBπ, BBππ, etc.
(BB continuum)

$B_d^{0(*)}B_d^{0(*)}, B^+B^-$
(~ 58%)

$B_s^{0(*)}B_s^{0(*)}$
(~ 26%)

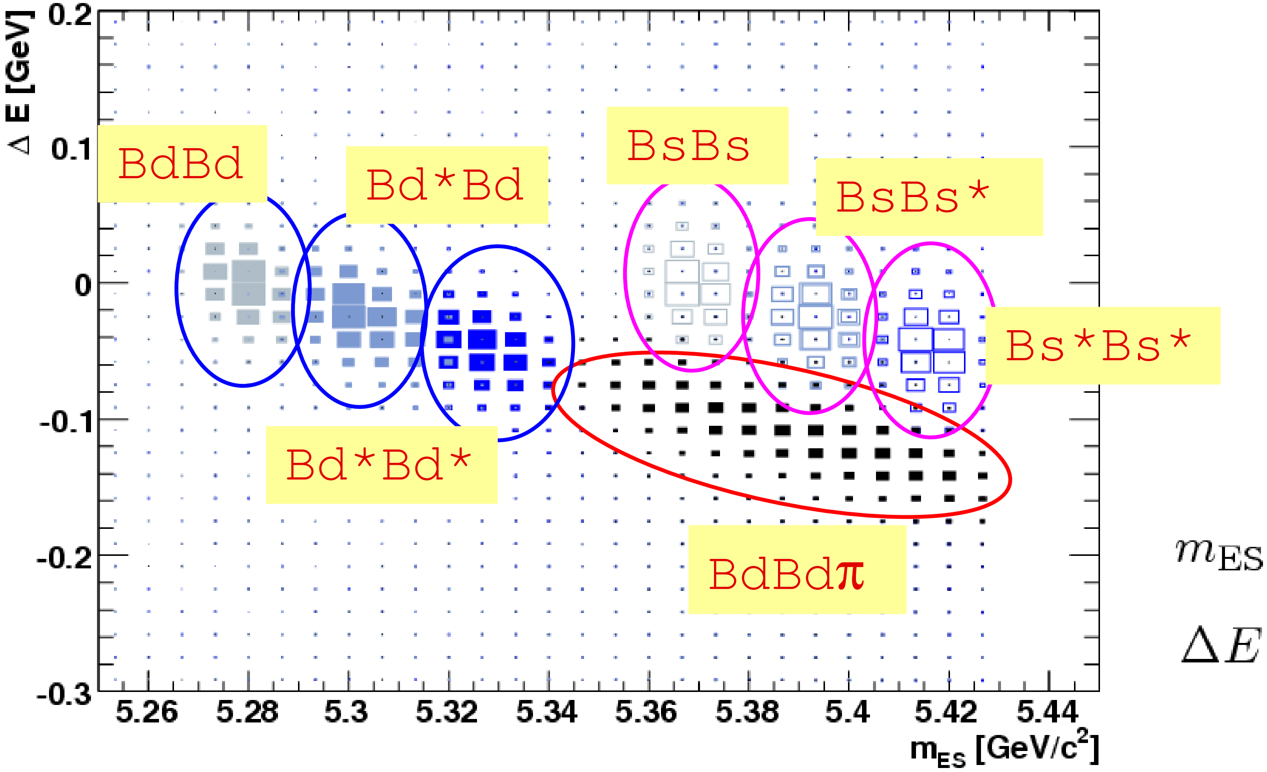
$B_s^{0*}B_s^{0*}$
(~ 94%)

For a given luminosity (w/o the BB cont.):
~ 17% of $B_{d,u}$ w.r.t. the $\Upsilon(4S)$;
~ 16% of B_s w.r.t. the number of B_d at the $\Upsilon(4S)$;

References: CLEO (hep-ex/0607080) & Belle (hep-ex/0605110)

Event reconstruction

- Reconstruction techniques inherited from current B-*factories*:
  - We don't reconstruct the additional particles (π, γ) produced in the Υ(5S) decay chain;
  - separation of different components using kinematic variables.



- Good separation between Bd and Bs in mES
- BBπ discriminated by the (continuum like) mES shape

$$m_{\rm ES} = \sqrt{(s/2 + \mathrm{p}_i \cdot \mathrm{p}_B)^2/E_i^2 + p_B^2}$$

$$\Delta E = E_B^* - \sqrt{s}/2$$

B pairs coherence

- B pairs at the $\Upsilon(5S)$ mainly produced in association with photons;
- What about the coherence of the B pairs?
- It can be shown that:

In the $B_{s,d}^*B_{s,d}^*$ case and in the $B_{s,d}B_{s,d}$ case the final pair is in an antisymmetric state → the time evolution of the B pair is the same than at the Y(4S);

↓

B_d TD analyses still possible

$B_{s,d}^*B_{s,d}$ the state is symmetric → different time evolution;

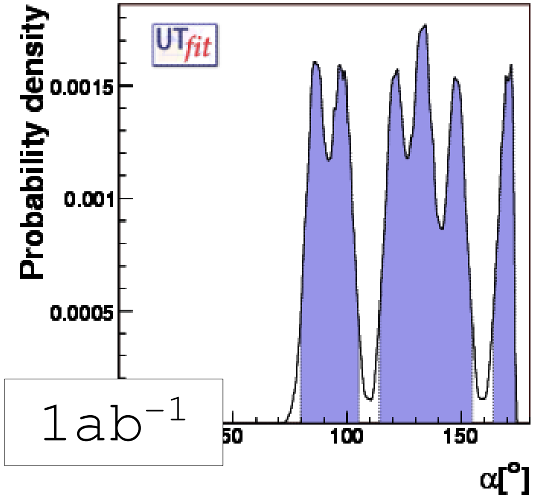
↓

New $B_{s,d}$ Time Integrated measurement

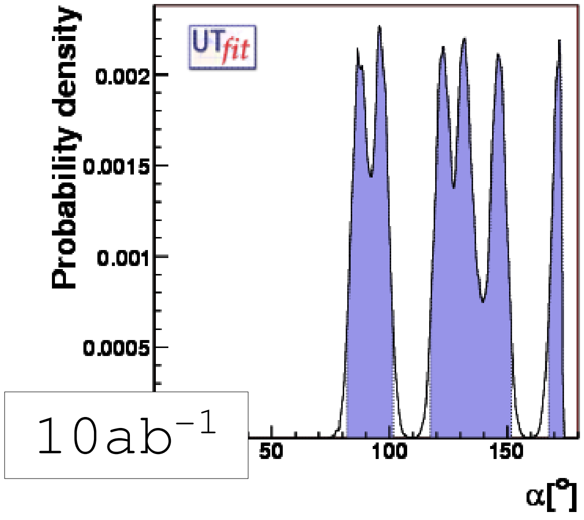
The Super-B scenario (just few examples)

Time Integrated Analysis

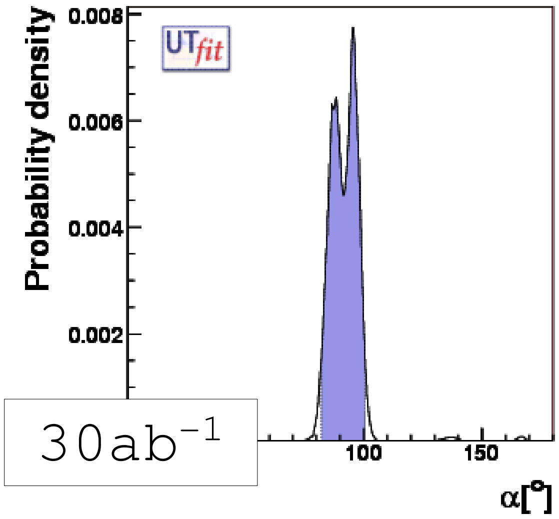
- $B_d \to \pi^0\pi^0$:
  - Rate and asymmetry used to determine a through an isospin analysis → ambiguity;
  - TD analysis at the Υ(4S) not enough sensitive to extract both Re(λ) and Im(λ) (or equivalently S and C);
  - Time Integrated Analysis with B*B events at the Υ(5S) allow to constraint Im(λ) and reduce the ambiguity.



$1ab^{-1}$



$10ab^{-1}$



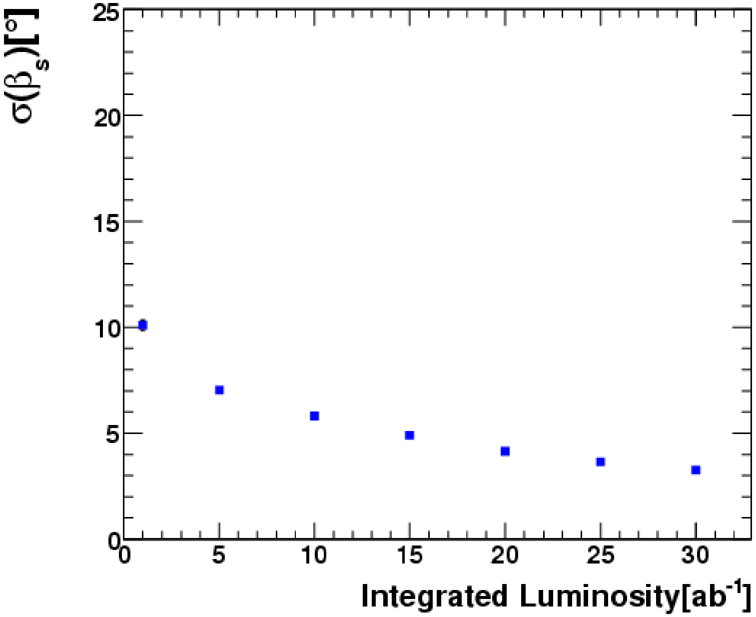
$30ab^{-1}$

Using the Δt sign

- Δt distribution for Bs*Bs* events, with one B into a CP eigenstate and the other one into a tagging state:

$$P(\Delta t) \propto e^{\frac{-|\Delta t|}{\tau}} \left[\kappa_1 \cosh\left(\frac{\Delta\Gamma_s \Delta t}{2}\right) + \kappa_2 \cos\left(\Delta m_s \Delta t\right) + \kappa_3 \sinh\left(\frac{\Delta\Gamma_s \Delta t}{2}\right) + \kappa_4 \sin\left(\Delta m_s \Delta t\right)\right]$$

sine and hyp. sine terms give a $\Delta t > 0$ vs. $\Delta t < 0$ asymmetry



Toy MC studies:
Sensitivity to β_s from
$B \rightarrow J/\psi\ \phi$

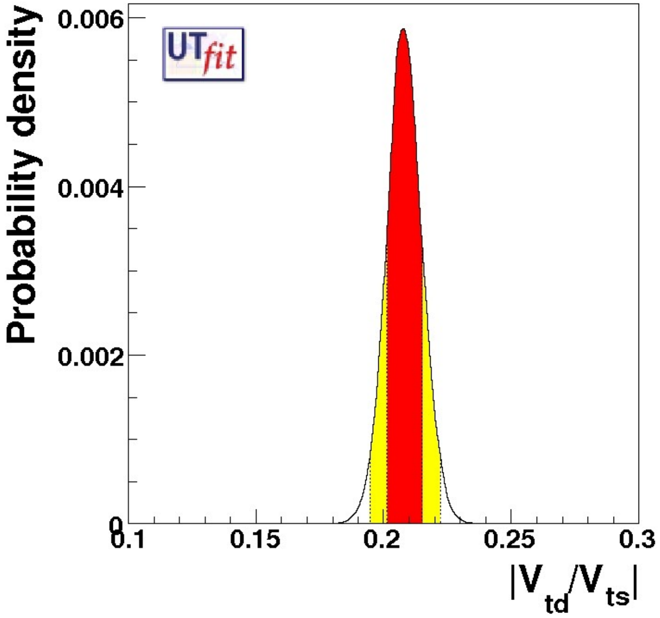
V_{td}/V_{ts}

$|V_{td}/V_{ts}|$ measurement

- Sensitive to NP;
- Clean determination from UT fit via:

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d} f_{B_d} \hat{B}_{B_d}}{m_{B_s} f_{B_s} \hat{B}_{B_s}} \frac{|V_{td}|^2}{|V_{ts}|^2}$$

- Additional constraint could come from radiative decays:



$\Upsilon(4S)$

$$\frac{\mathcal{BR}(B^0 \to \rho^0 \gamma)}{\mathcal{BR}(B^0 \to K^* \gamma)} = \frac{|V_{td}|}{|V_{ts}|} \frac{1}{\xi^2} (1 + ???)$$

SU(3) breaking

theo. uncertainty on additional contribution

$\Upsilon(5S)$

$$\frac{\mathcal{BR}(B^0_s \to K^{*0} \gamma)}{\mathcal{BR}(B^0_d \to K^{*0} \gamma)} = \frac{|V_{td}|}{|V_{ts}|} \frac{1}{\xi^2}$$

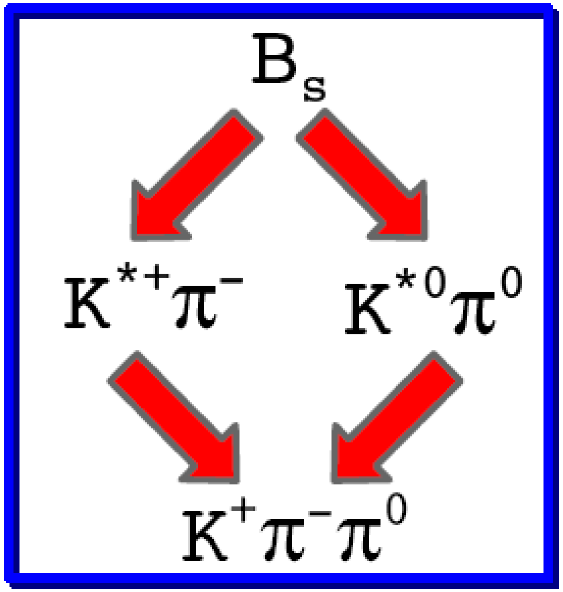
No theo. uncertainties from additional contributions

γ from Kππ

Ciuchini et al.
(hep-ph/0602207)

- $B_s \to K\pi\pi$ Dalitz analysis can access the amplitudes:

$$\begin{aligned} A_s^{K^*\pi} &= A(B_s \to K^{*-}\pi^+) + \sqrt{2}A(B_s \to \bar{K}^{*0}\pi^0) \\ &= -V_{ub}^* V_{ud}(E_1 + E_2)\,, \\ \bar{A}_s^{K^*\pi} &= A(\bar{B}_s \to K^{*+}\pi^-) + \sqrt{2}A(\bar{B}_s \to K^{*0}\pi^0) \\ &= -V_{ub} V_{ud}^*(E_1 + E_2)\,, \end{aligned}$$



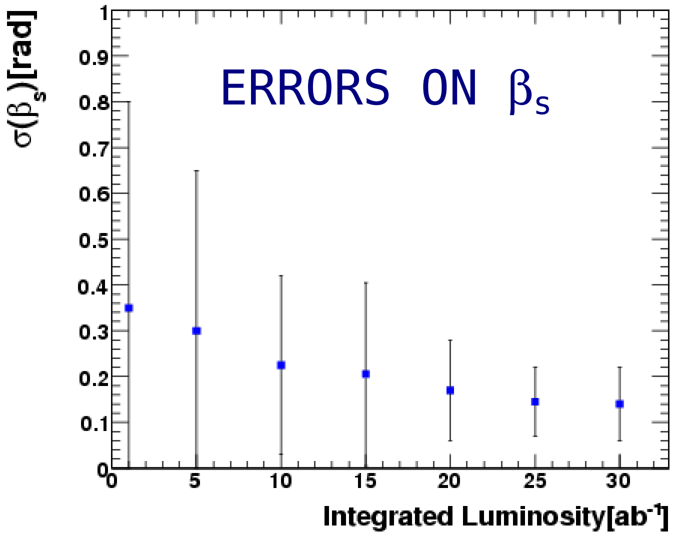
- γ from the ratio:

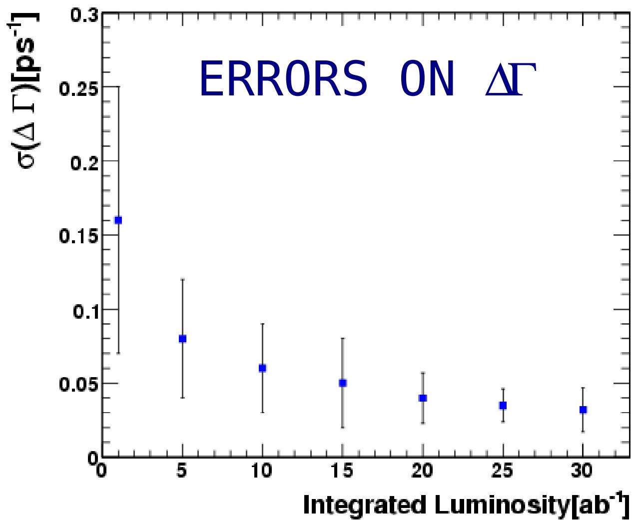
$$R_d = \frac{\bar{A}_s^{K^*\pi}}{A_s^{K^*\pi}} = \frac{V_{ub}V_{ud}^*}{V_{ub}^*V_{ud}} = e^{-2i\gamma}$$

- NP can generate a different result w.r.t. the tree level estimate of γ ;
- in a Super-B factory, better π^0 resolution than LHCb
- relative phase between B and $\bar{B}$ amplitudes needed (TD or LHCb)

Lifetime difference $\Delta\Gamma_s$

- Sensitive to NP phase;
- Different experimental methods:
  - we investigated the sensitivity of an angular analysis of Bs → $J/\Psi\,\phi$ **(Dighe *et al.* hep-ph/9804253)**.





ATTENTION: Alternative methods could be effective even at low luminosity (see Drutskoy talk at BNM2006)

Interesting Measurements at present B-Factories

Semileptonic Asymmetries → *NP in the Bs mixing*

Semileptonic BR → *Fundamental normalizations for had. colliders*

Bs → $\gamma\gamma$ *decay* → *complementarity with* $b \rightarrow s\gamma$

2-body Bs decays → *Bd – Bs SU(3) tests*

Spectroscopy → *tetraquarks*

Belle Pioneer Runs (I)

- Belle realized 2 Runs (1.86 fb^{-1} + 23.6 fb^{-1}) at the Y(5S);

Engineering Run (1.86 fb^{-1} in 3 days)

- Energy scan to find the Y(5S) peak (10.869 GeV);
- ~100% of Y(4S) typical luminosity;
- Results:
  - $BR(Bs \rightarrow Ds^{*(-)}\pi^{+}) = (0.68 \pm 0.22 \pm 0.16)\%$
  - $BR(Bs \rightarrow J/\psi\phi) = (0.9 \pm 0.6 \pm 0.2)\%$
  - *Observation of* $Bs \rightarrow Ds^{*(-)}\rho^{+}$ *and* $Bs \rightarrow J/\psi\eta$
  - $\sigma(e^{+}e^{-}\rightarrow Bs^{*}Bs^{*})/\sigma(e^{+}e^{-}\rightarrow Bs^{(*)}Bs^{(*)}) = (93_{-9}^{+7} \pm 1)\ \%$
  - $M(Bs^{*}) = (5418\pm1\pm3)\,\mathrm{MeV}$ *and* $M(Bs)=(5370\pm1\pm3)\ \mathrm{MeV}$
  - *Bs(*) production ratio:* $fs = (18 \pm 1.3 \pm 3.2)\%$

Phys. Rev. D 76 012002 (2007)

Belle Pioneer Runs (II)

$23.6\ \mathrm{fb}^{-1}$ Run

arXiv:0710.1647

- Results:
  - $BR(Bs \rightarrow X^{+} e^{-} \nu) = (10.9 \pm 1.0 \pm 0.9)\%$
  - $BR(Bs \rightarrow X^{+} \mu^{-} \nu) = (9.2 \pm 1.0 \pm 0.8)\%$
  - $BR(Bs \rightarrow \gamma\gamma) < 8.7 \times 10^{-6}$ → better than PDG!
  - $BR(Bs \rightarrow \phi\gamma) = (5.7_{-1.5}^{+1.8}{}_{-1.1}^{+1.2}) \times 10^{-5}$

Belle Pioneer Runs (II)

23.6 fb^{-1} Run

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- Results:
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Radiative Bs decays can be accessed

Semileptonic Asymmetry

$$A_{\mathrm{SL}} \equiv \frac{\Gamma(\overline{B^0} \rightarrow l^+ X) - \Gamma(\overline{B^0} \rightarrow l^- X)}{\Gamma(\overline{B^0} \rightarrow l^+ X) - \Gamma(\overline{B^0} \rightarrow l^- X)} =$$

$$= -\mathrm{Re}(\frac{\Gamma_{12}}{M_{12}})^{\mathrm{SM}} \frac{\sin(2\phi_{\mathrm{Bd}})}{C_{\mathrm{Bd}}} + \mathrm{Im}(\frac{\Gamma_{12}}{M_{12}})^{\mathrm{SM}} \frac{\cos(2\phi_{\mathrm{Bd}})}{C_{\mathrm{Bd}}}$$

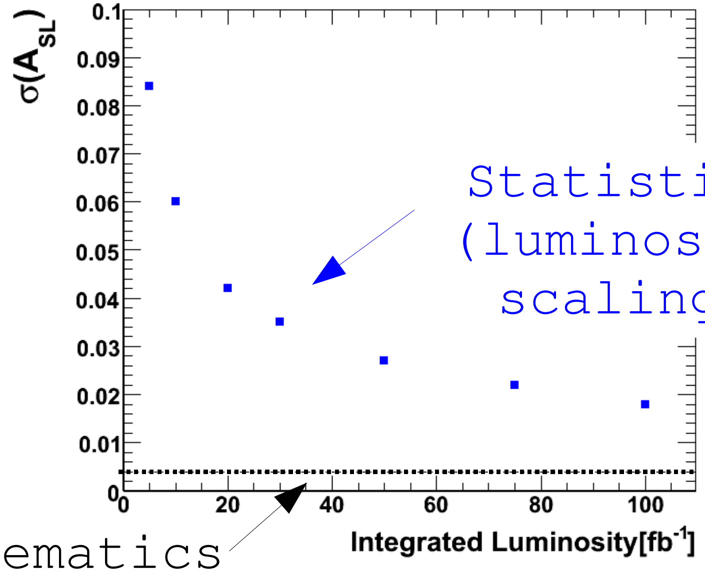
- $B_{d,s}$ sector:
  - Current experimental sensitivity cannot bound CKM in the SM;
  - Bounds on NP parameter space;
- B_d – B_s admixture:
  - measurements from D0 (dimuons charge asymm.);
  - A_{CH} sensitive to NP effects.

Semileptonic Asymmetry

A B-Factory at the $\Upsilon(5S)$ can access both A_{CH} and $A^{s,d}_{SL}$

Ds(*) l ν

- Counting $Ds(*)^{+} l^{-} \nu$ and $Ds(*)^{-} l^{+} \nu$ events against semilept. or hadronic tag;

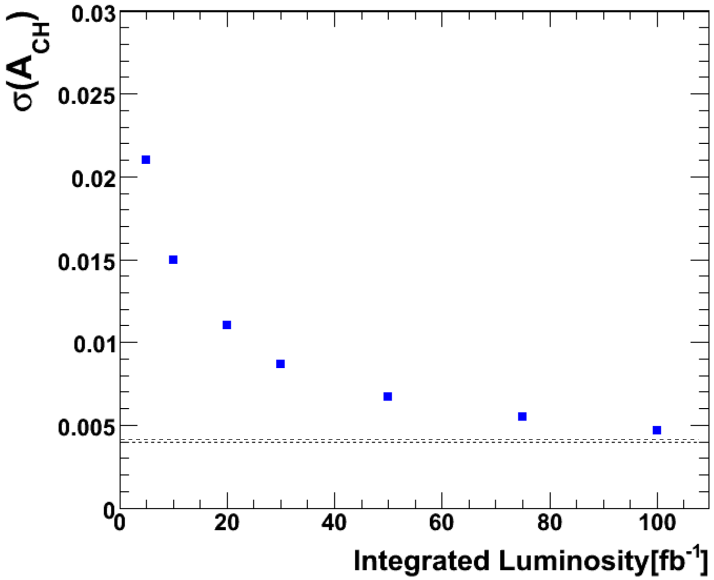


Statistics (luminosity scaling)

Systematics

DILEPTONS

- Counting dilepton pairs;
- Possibility to access A_{CH};



Semileptonic Bs Decays

- Semileptonic Bs decays:
  - *Fundamental Normalization* for had. colliders;
  - if a reasonable error is reachable, it would justify *by itself* a Y(5S) run;
- Exclusive Bs → $D_s(*)$ l ν :
  - No published result from Belle Runs;
  - Expected errors with 25 fb^{-1} should be ~10% (according to Drutskoy talk at BNM 2006).

~ 10% error in 25 fb^{-1} → ~ 5% error in 100 fb^{-1}

B_s 2-body Decays (I)

- Several Bs decays can be compared with the corresponding Bd decays to test SU(3);
- Interesting channels:
  - $B_s \rightarrow D_s^- \pi^+$ (BR ~ 3×10^{-3});
  - $B_s \rightarrow D^0 K^0$ (BR ~ 3×10^{-4});
  - ...
- Efficiency and yields:
  - few percent efficiency;
  - ~ 0.1M Bs pairs per fb^{-1};

⇒

$D_s\pi$ ~ 5 evts / fb^{-1}

DK ~ 0.5 evts / fb^{-1}

More studies (theory & experiments) needed

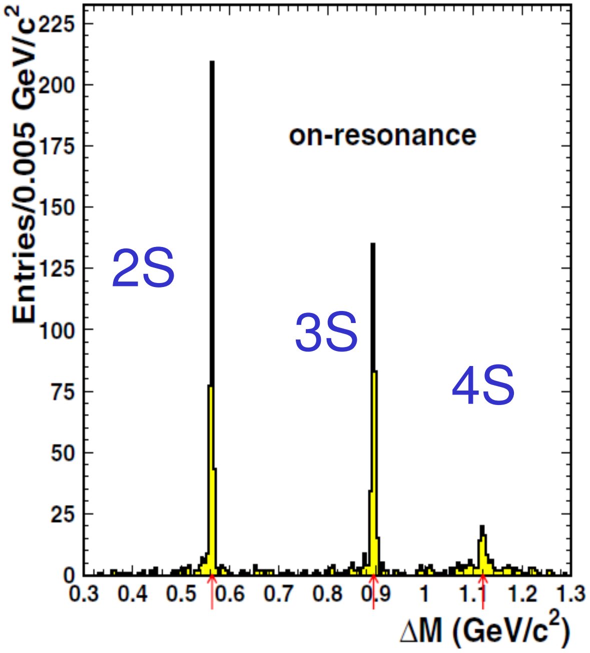
$B_s \to \gamma\gamma$

- Complementarity with $b \to s\gamma$;
- SM BR ~ 10^{-6}, NP could enhance it up to 1 order of magnitude (SUSY with R-parity violation BR ~ 5×10^{-5}, *hep-ph/0404152*);
- Belle results:
  - BR < 8.7×10^{-6} @ 23.6 fb^{-1} → *discovery could be around the corner*;
  - Efficiency (Belle): ~20% (BaBar and Belle $Bd \to \gamma\gamma$ efficiency was ~10%...);
  - Background under-fluctuation: Nsig = -6 ± 2 → could have drawn down the UL;
- UL well below 5×10^{-5} at 100 fb^{-1} seems to be possible.

Spectroscopy (I)

- Belle observed a *huge* and *completely unexpected signal* for $\Upsilon(5S) \to \Upsilon(1S)\pi\pi$:

$\Upsilon(1S)\pi^+\pi^-$ at the $\Upsilon(4S)$
($477\ fb^{-1}$)



From S.L.Olsen at the
BES-Belle-CLEO-BaBar Joint
Workshop on Charm Physics
and arXiv:0710.2577

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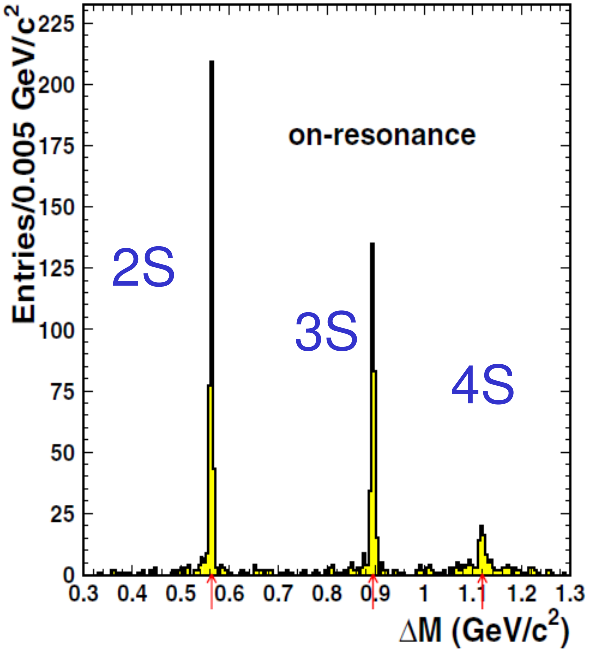
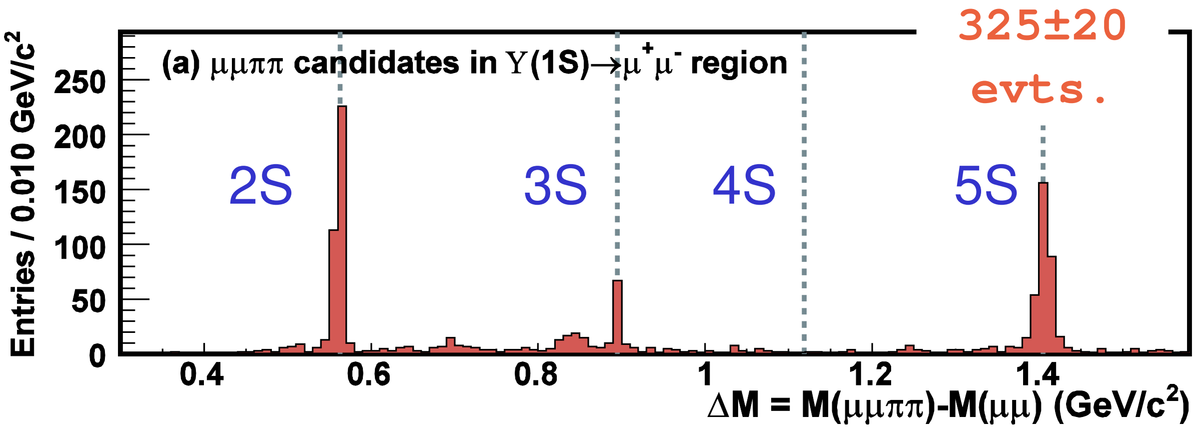
$\Upsilon(1S)\,\pi^+\pi^-$ at the Y(4S) (477 fb^{-1})



$\Upsilon(1S)\,\pi^+\pi^-$ at the Y(5S) (23.6 fb^{-1})



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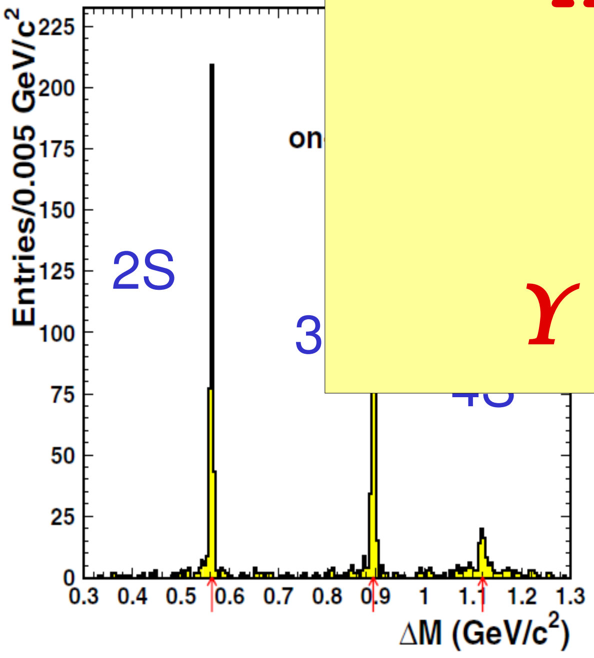
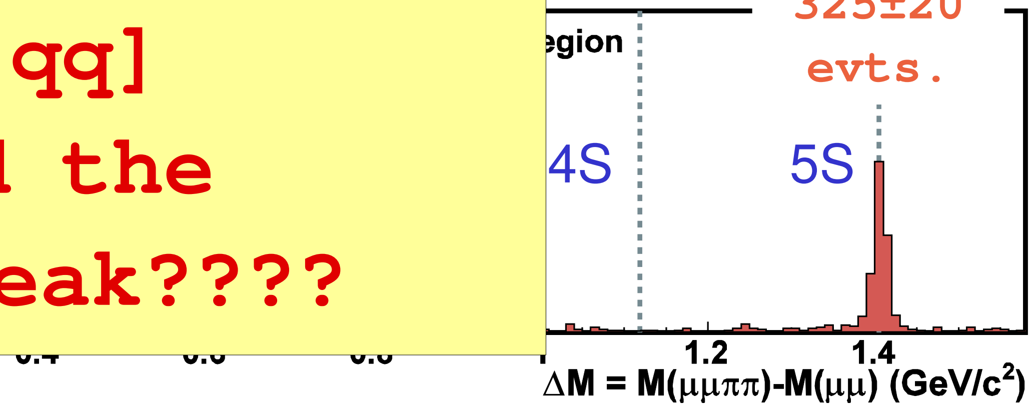
(477

e Y(5S)
-1)



A Tetraquark
[bb][qq]
around the
Υ(5S) peak????



325±20 evts.

From S.L.Olsen at the BES-Belle-CLEO-BaBar Joint Workshop on Charm Physics and arXiv:0710.2577

Spectroscopy (II)

Many Thanks to R. Faccini and M. Gaspero!

- A tetraquark around the Y(5s)?
  - Scan of energy around the peak & look at $B_{s,d}(*)B_{s,d}(*)/Y(1s)$ ratio.
- Other tetraquarks:
  - Look at Y(5s) → Y(1s) + X and look at the invariant mass of Y(1s) + nπ (various states expected).
- Resonant structures in the dipion mass spectrum?
  - e.g. Y(5s) → Y(1s)f_0(1370)

► π π

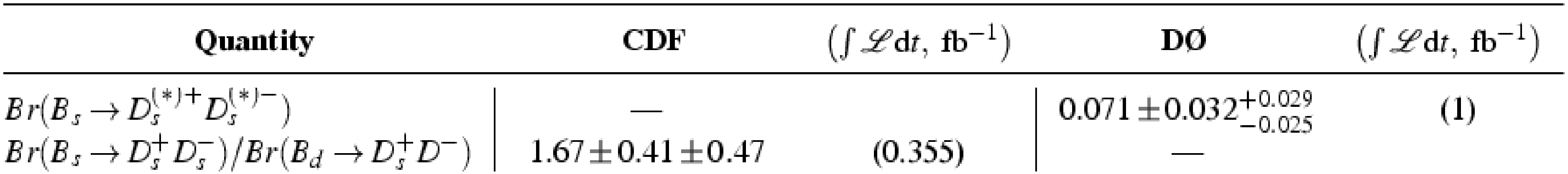
► 4 π

Look for the 4π state

  - hints on the nature of the f_0(1370);
  - glue-rich environment (glueballs?).

B-Factories vs. Tevatron

- SL asymmetries (hep-ph/0702163):
  - A^s_{SL} can be accessed at Tevatron subtracting A^d_{SL} to A_{CH};
  - $\sigma(A^s_{SL})$ at Tevatron ~ 0.02 → we can be competitive (and much more clean) with ~50 fb^{-1};
- Branching Ratios (arXiv:0707.1509):



Quantity	**CDF**	$(\int \mathscr{L} dt,\ \mathrm{fb}^{-1})$	**DØ**	$(\int \mathscr{L} dt,\ \mathrm{fb}^{-1})$
$Br(B_s \to D_s^{(*)+} D_s^{(*)-})$	—		$0.071 \pm 0.032^{+0.029}_{-0.025}$	(1)
$Br(B_s \to D_s^+ D_s^-)/Br(B_d \to D_s^+ D^-)$	$1.67 \pm 0.41 \pm 0.47$	(0.355)	—	

  - ~30 fb^{-1} needed to be competitive;
- Rare decays:
  - They do Bs → $\mu\mu$ (UL ~ 10^{-7}) but not Bs → $\gamma\gamma$;

Conclusions

- The Υ(5S) offers a rich physics case, mainly related to b → s transitions;
- Although a Super-B factory would be needed to completely exploit these potentialities, even ~ 100 fb^{-1} sample could provide:
  - Semileptonic Asymmetries;
  - NP in $Bs \rightarrow \gamma\gamma$;
  - Bs Semileptonic Decays;
  - Bs radiative decays ($Bs \rightarrow \phi\gamma$);
  - some hadronic decays (2-body) up to few 10^{-4} BR;
  - Spectroscopy;
- The Semileptonic Bs BR can be measured with good precision → *fundamental normalization* for had. colliders;

If one of the present B-Factories takes the positive decision to run at Υ(5S), we suggest to collect ~100 fb^{-1} to ensure interesting results and competitiveness with Tevatron

  - Semileptonic Asymmetries;
  - NP in Bs → $\gamma\gamma$;
  - Bs Semileptonic Decays;
  - Bs radiative decays (Bs → $\phi\gamma$);
  - some hadronic decays (2-body) up to few 10^{-4} BR;
  - Spectroscopy;
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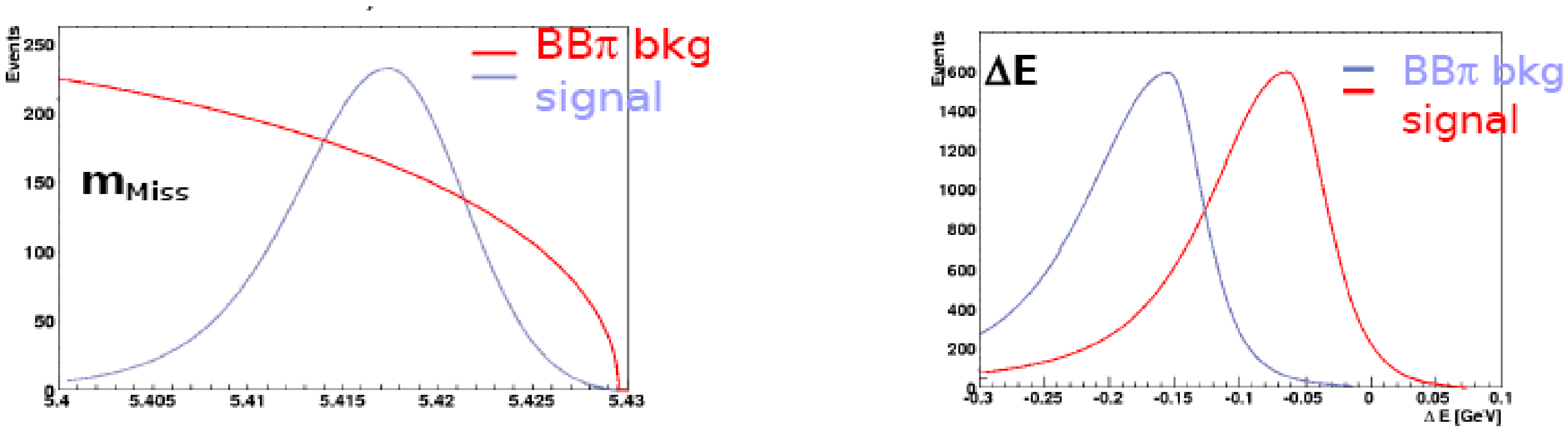
Backup Slides

Event reconstruction

BBπ vs. BB SEPARATION



CAVEAT: the BBπ background can be important in final states with an odd number of s quarks (KKπ, etc.):

- B_s decays CKM suppressed w.r.t. B_d decays;
- B_s decays (sometimes) suppressed by dynamic (penguins or annihilation vs tree).

NOTE: Only UL for the BBπ BR – We use the UL (worst case).

$\Delta\Gamma_s/\Gamma_s$ measurement from *Bf* ($B_s \to D_s^{+(*)} D_s^{-(*)}$)

$\Delta\Gamma_s = 2\,|\,\Gamma_{12}|\cos\phi_s$ $\Delta\Gamma_s^{SM} = \Delta\Gamma_{CP}^{S} = 2\,|\,\Gamma_{12}|$

Since $\Delta\Gamma_{CP}^{S}$ is unaffected by NP, NP effects will decrease $\Delta\Gamma_s$.

$\Delta\Gamma_{CP}^{S} = \Sigma\,\Gamma(CP=+) - \Sigma\,\Gamma(CP=-)$

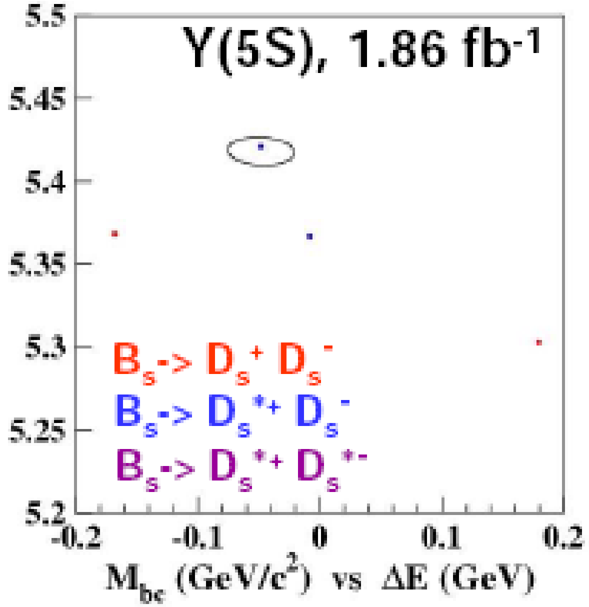
$B_s \to D_s^{(*)+} D_s^{(*)-}$ decays have *CP*- even final states with largest *BF's* of ~ (1-3)% each, saturating $\Delta\Gamma_s/\Gamma_s$.

$$\frac{\Delta\Gamma_{CP}^{S}}{\Gamma_S} \approx \frac{Bf(B_s \to D_s^{(*)+} D_s^{(*)-})}{1 - Bf(B_s \to D_s^{(*)+} D_s^{(*)-})\,/\,2}$$

To prove this formula experimentally : a) Contribution of $B_S \to D_S^{+(*)} D_S^{-(*)} n\pi$ is small b) Most of $B_S \to D_S^{+} D_S^{-\,*}$ and $B_S \to D_S^{+*} D_S^{-\,*}$ states are CP- even.

Assuming corrections are small (~5-7%), *Bf* measurement will provide information about $\Delta\Gamma_{CP}^{S}$ or $|\Gamma_{12}|$.

$\Delta\Gamma_s/\Gamma_s$ measurement from *Bf* ($B_s \to D_s^{+(*)} D_s^{-(*)}$)



$D_s^+ \to \phi\pi^+$, $K^{*0} K^+$, $K_s K^+$

Expected with 25 fb^{-1} at Y(5S):

$Eff(B_s \to D_s^+ D_s^-) \sim 2\times10^{-4}$ $N \sim 2.5\times10^6 \times 2\times10^{-4} \times 10^{-2} \sim 5$ ev

$Eff(B_s \to D_s^{*+} D_s^-) \sim 1\times10^{-4}$ $N \sim 2.5\times10^7 \times 10^{-4} \times 2\times10^{-2} \sim 5+5$ ev

$Eff(B_s \to D_s^{*+} D_s^{*-}) \sim 5\times10^{-5}$ $N \sim 2.5\times10^7 \times 5\times10^{-5} \times 3\times10^{-2} \sim 4$ ev

=>Accuracy of *Bf* ($B_s \to D_s^{(*)+} D_s^{(*)-}$) has to be ~30%.

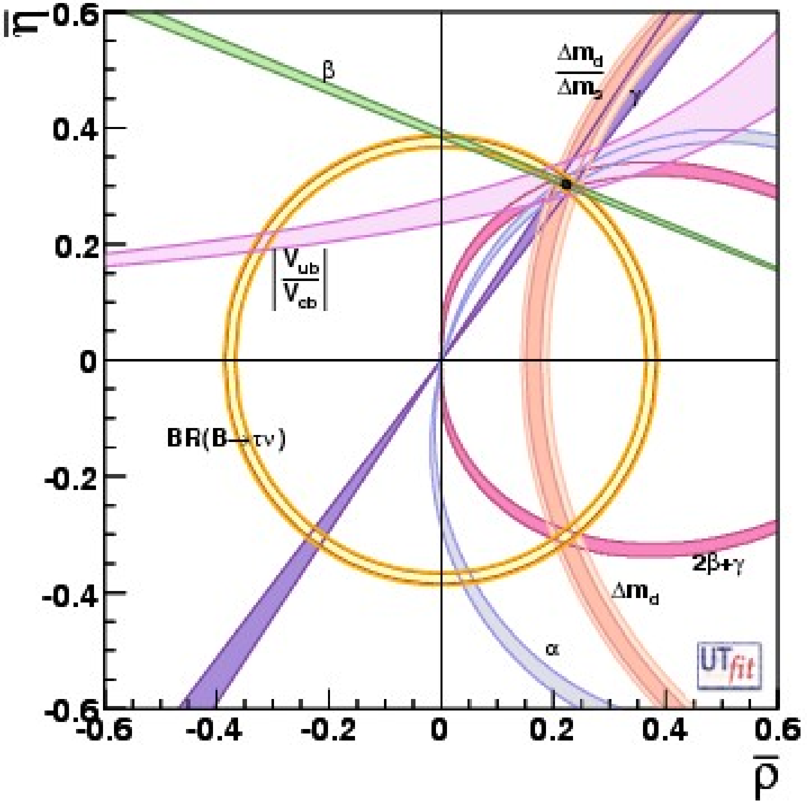
$$\frac{\Delta\Gamma_{CP}^{S}}{\Gamma_S} \approx \frac{Bf(B_s \to D_s^{(*)+} D_s^{(*)-})}{1 - Bf(B_s \to D_s^{(*)+} D_s^{(*)-}) / 2} \quad \Leftarrow$$

should be compared with direct $\Delta\Gamma_s/\Gamma_s$ measurement to test SM.

$\Delta\Gamma_s/\Gamma_s$ lifetime difference can be measured directly with high accuracy at Y(5S) and also at Tevatron and LHC experiments.

UT in the SM

ASSUMING 75ab^{-1} at the $\Upsilon(4S)$ and 30ab^{-1} at the $\Upsilon(5S)$

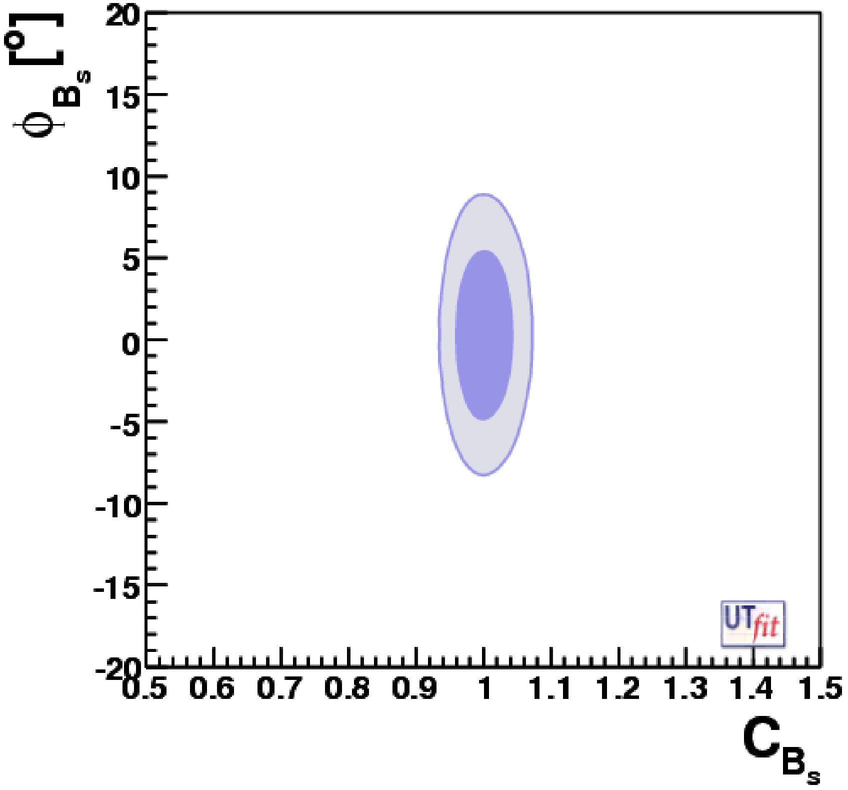


$\delta\rho = 2.3\%$

$\delta\eta = 1.8\%$

UT beyond the SM

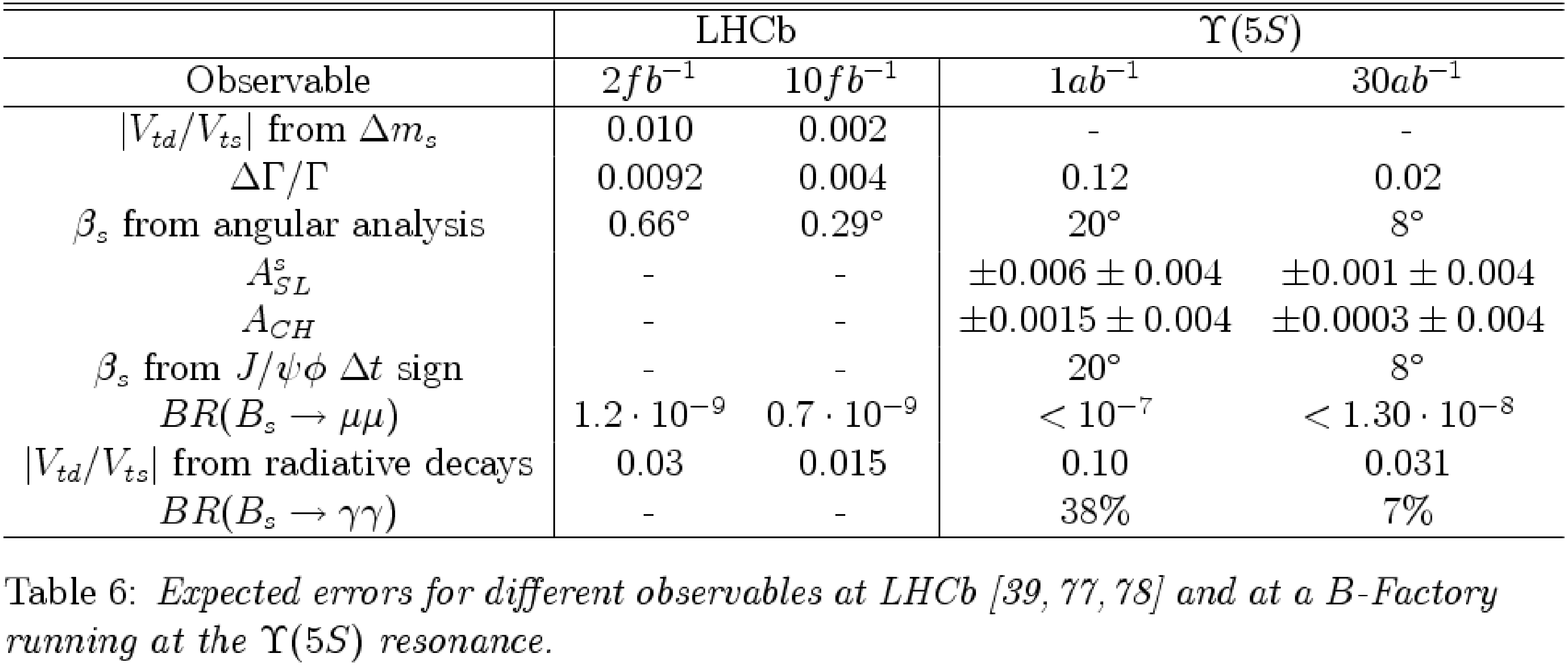
ASSUMING $75ab^{-1}$ at the $\Upsilon(4S)$ and $30ab^{-1}$ at the $\Upsilon(5S)$



$\delta\phi = 1.9°$

$\delta C = 0.026$

Super-B vs. LHCb



	LHCb		$\Upsilon(5S)$	
Observable	$2fb^{-1}$	$10fb^{-1}$	$1ab^{-1}$	$30ab^{-1}$
$\lvert V_{td}/V_{ts}\rvert$ from Δm_s	0.010	0.002	-	-
$\Delta\Gamma/\Gamma$	0.0092	0.004	0.12	0.02
β_s from angular analysis	0.66°	0.29°	20°	8°
A^s_{SL}	-	-	$\pm 0.006 \pm 0.004$	$\pm 0.001 \pm 0.004$
A_{CH}	-	-	$\pm 0.0015 \pm 0.004$	$\pm 0.0003 \pm 0.004$
β_s from $J/\psi\phi$ Δt sign	-	-	20°	8°
$BR(B_s \to \mu\mu)$	$1.2 \cdot 10^{-9}$	$0.7 \cdot 10^{-9}$	$< 10^{-7}$	$< 1.30 \cdot 10^{-8}$
$\lvert V_{td}/V_{ts}\rvert$ from radiative decays	0.03	0.015	0.10	0.031
$BR(B_s \to \gamma\gamma)$	-	-	38%	7%

Table 6: *Expected errors for different observables at LHCb [39, 77, 78] and at a B-Factory running at the $\Upsilon(5S)$ resonance.*