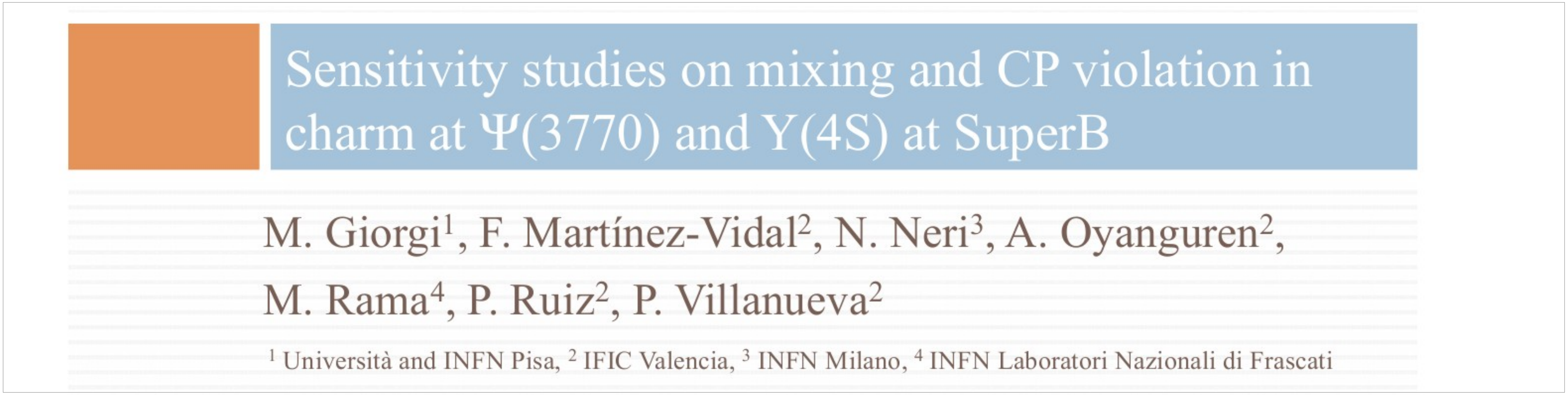
3rd SuperB Collaboartion Meeting- LNF- ITALY 19-23/03/2012

Time-Dependent Studies Comparison



Sensitivity studies on mixing and CP violation in charm at $\Psi(3770)$ and $\Upsilon(4S)$ at SuperB

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The Time-Dependent CPV in Charm

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22-03-2012

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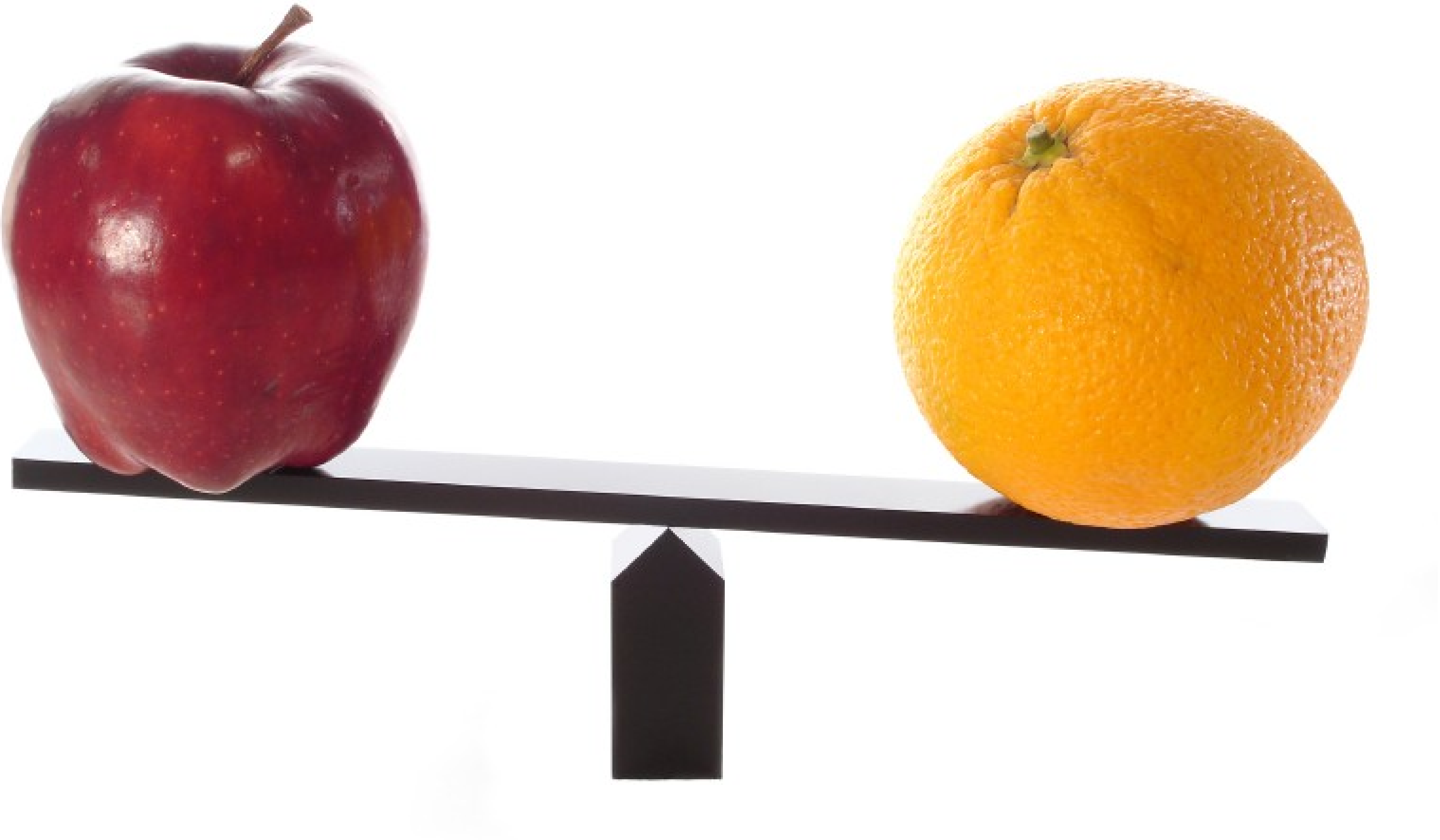
Are we comparing apples to apples?



N. Neri et al. Work.
From N. Neri - December Collaboration Meeting

Example: flavor tag

At y(3770):

Identical time-dependence wrt Υ(4S) when using flavor tag !

$$\frac{d\Gamma[V_{\rm phys}(t_1,t_2)\to f_1f_2]/dt}{e^{-\Gamma|\Delta t|}\mathcal{N}_{f_1f_2}} =$$

$$\left(|a_+|^2+|a_-|^2\right)\cosh(y\Gamma\Delta t)+\left(|a_+|^2-|a_-|^2\right)\cos(x\Gamma\Delta t)$$
$$-2\mathcal{R}e((a_+^*a_-)\sinh(y\Gamma\Delta t)+2\mathcal{I}m(a_+^*a_-)\sin(x\Gamma\Delta t)$$

$$a_+\equiv \bar A_{f_1}A_{f_2}-A_{f_1}\bar A_{f_2},$$
$$a_-\equiv -\sqrt{1-{\rm z}^2}\left(\frac{q}{p}\bar A_{f_1}\bar A_{f_2}-\frac{p}{q}A_{f_1}A_{f_2}\right)+{\rm z}\left(\bar A_{f_1}A_{f_2}+A_{f_1}\bar A_{f_2}\right)$$

z = CPT violation parameter
q, p = indirect CP violation parameters

At Υ(4S) using D^{*+} tagged events:

$$\frac{d\Gamma[M^0_{\rm phys}(t)\to f]/dt}{e^{-\Gamma t}\mathcal{N}_f} =$$

$$\left(|A_f|^2+|(q/p)\bar A_f|^2\right)\cosh(y\Gamma t)+\left(|A_f|^2-|(q/p)\bar A_f|^2\right)\cos(x\Gamma t)$$
$$+2\mathcal{R}e((q/p)A_f^*\bar A_f)\sinh(y\Gamma t)-2\mathcal{I}m((q/p)A_f^*\bar A_f)\sin(x\Gamma t)$$

General considerations

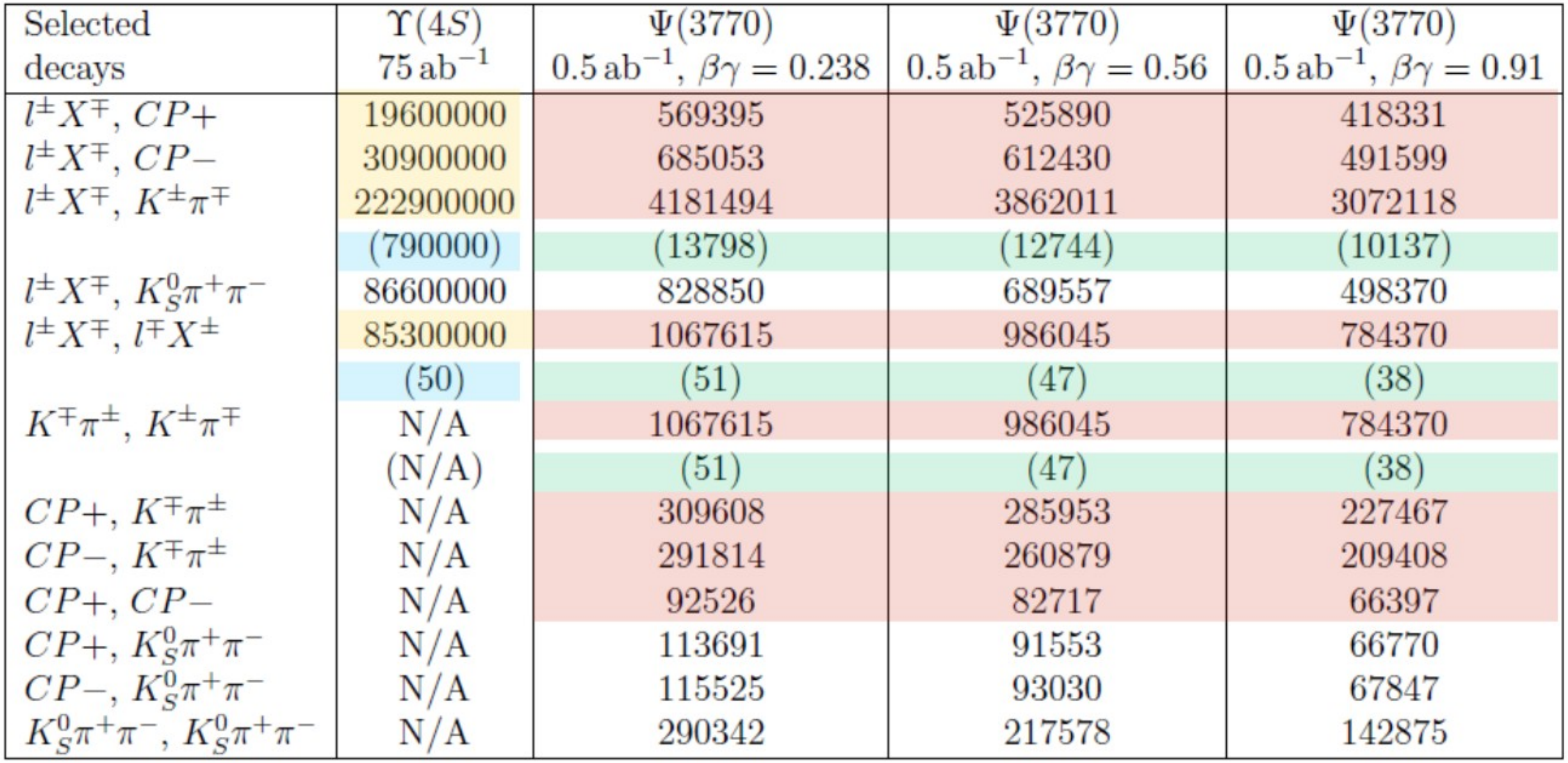
- At Y(4S)
  - Flavor tagged D^0 through D$^{*+}\to$D$^0\pi^+$ decay. We denote the D* flavor tag with the label *l*X
  - D^0 can be reconstructed in flavor *l*X, CP, Kπ and multibody (e.g. Ks$\pi\pi$) final states. Relatively high purity due to m(D^0) and Δm=m(D^{*+})-m(D^0)
  - Flavor mistag ~0.2%
  - Proper time resolution is about τ(D^0)/4 $\approx$ 0.1 ps
- At Ψ(3770)
  - Coherent D^{0}D^0 production
  - Both D mesons can be reconstructed in *l*X, CP, Kπ and Ks$\pi\pi$ final states, with very low background
  - Flavor mistag ~0.2% with eX,
  - Time-dependent measurements require larger CM boost compared to the Y(4S) case to achieve similar time resolution, but reconstruction efficiency decreases with large CM boost. Need to determine the optimal boost range.

Double tags @ Ψ(3770)

Modes with D* tag @ Υ(4S)

	CP−	Kπ	*l*X	Ks$\pi\pi$
CP+	X	X	XX	X
CP−		X	XX	X
Kπ		X	XX	X
*l*X			XX	XX
Ks$\pi\pi$				X

Sensitivity studies: expected num. of events



		LB $\Psi(3770)$	IB $\Psi(3770)$	HB $\Psi(3770)$
Selected decays	$\Upsilon(4S)$ $75\,\mathrm{ab}^{-1}$	$\Psi(3770)$ $0.5\,\mathrm{ab}^{-1}$, $\beta\gamma = 0.238$	$\Psi(3770)$ $0.5\,\mathrm{ab}^{-1}$, $\beta\gamma = 0.56$	$\Psi(3770)$ $0.5\,\mathrm{ab}^{-1}$, $\beta\gamma = 0.91$
$l^\pm X^\mp$, $CP+$	19600000	569395	525890	418331
$l^\pm X^\mp$, $CP-$	30900000	685053	612430	491599
$l^\pm X^\mp$, $K^\pm\pi^\mp$	222900000	4181494	3862011	3072118
	(790000)	(13798)	(12744)	(10137)
$l^\pm X^\mp$, $K^0_S\pi^+\pi^-$	86600000	828850	689557	498370
$l^\pm X^\mp$, $l^\mp X^\pm$	85300000	1067615	986045	784370
	(50)	(51)	(47)	(38)
$K^\mp\pi^\pm$, $K^\pm\pi^\mp$	N/A	1067615	986045	784370
	(N/A)	(51)	(47)	(38)
$CP+$, $K^\mp\pi^\pm$	N/A	309608	285953	227467
$CP-$, $K^\mp\pi^\pm$	N/A	291814	260879	209408
$CP+$, $CP-$	N/A	92526	82717	66397
$CP+$, $K^0_S\pi^+\pi^-$	N/A	113691	91553	66770
$CP-$, $K^0_S\pi^+\pi^-$	N/A	115525	93030	67847
$K^0_S\pi^+\pi^-$, $K^0_S\pi^+\pi^-$	N/A	290342	217578	142875

🟨	🟥	Favored # of events
🟦	🟩	Suppressed # of events
Υ (4S)	$\Psi(3770)$	

Summary

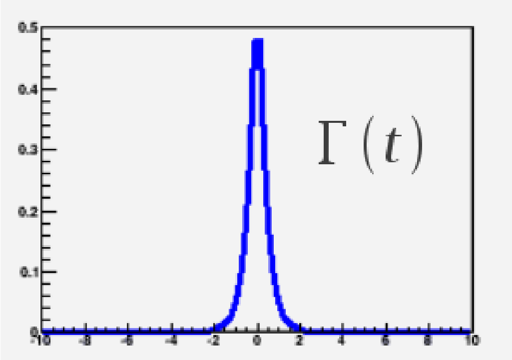
- Flavor tag at $D\bar{D}$ threshold provides identical time-dependence than at Υ(4S) using D* tagging, and less events, although in a different environment
- $D\bar{D}$ threshold is unique to provide CP, Kπ and Ksππ tags
- Variation of Δt resolution and geometrical acceptance vs CM boost was evaluated
- Estimated the impact on physics with 2-body decays
  - Combined fit to all 2-body double-tags allows determination of x, y, arg(q/p), |q/p|
  - Best sensitivity at Ψ(3770) for intermediate boost, bg ~ 0.3-0.6

Parameter	**Sensitivity @ Υ (4S) with time resolution, no mistag. 75 ab^{-1}**	**Best sensitivity @ Ψ(3770) with time resolution (bg=0.56), no mistag. 0.5 ab^{-1}**
x	0.017%	0.11%
y	0.008%	0.05%
Arg(q/p)	0.8 deg	4.8 deg
|q/p|	0.5%	3.7%

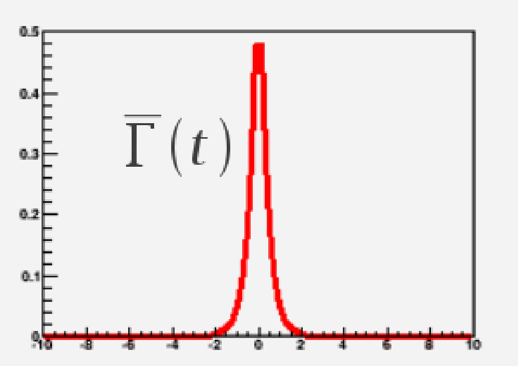
Relative effect of flavor mistag similar at Ψ(3770) and Υ(4S)

- error per ab^{-1} at Ψ(3770) ~ ½ error per ab^{-1} at Y(4S) (2-body only, no mistag)
- error at Ψ(3770) [0.5ab^{-1}] ~ 6x error at Υ (4S) [75ab^{-1}] (2-body only, no mistag)

A. Bevan et al. Work.
From G. I. - December Collaboration Meeting



Time-dependent formalism (ii)



The time-dependence of decays of P^0 (P^0) to final state |f > are:

$$\Gamma(P^0 \to f) \propto e^{-\Gamma_1|\Delta t|}\left[\frac{h_+}{2} + \frac{\Re(\lambda_f)}{1+|\lambda_f|^2}h_- + e^{[\Delta\Gamma\,\Delta t/2]}\left(\frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos\Delta M\Delta t - \frac{2\Im(\lambda_f)}{1+|\lambda_f|^2}\sin\Delta M\Delta t\right)\right]$$

$$\overline{\Gamma}(\overline{P^0} \to f) \propto e^{-\Gamma_1|\Delta t|}\left[\frac{h_+}{2} + \frac{\Re(\lambda_f)}{1+|\lambda_f|^2}h_- - e^{[\Delta\Gamma\,\Delta t/2]}\left(\frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos\Delta M\Delta t - \frac{2\Im(\lambda_f)}{1+|\lambda_f|^2}\sin\Delta M\Delta t\right)\right]$$

$$where: \quad h_{+-} = 1 \pm e^{\Delta\Gamma\Delta t}, \quad \lambda_f = \frac{q}{p}\frac{\overline{A}}{A}$$

λ_f very important!

We now obtain the time-dependent CP asymmetry

$$A^{Phys}(\Delta t) = \frac{\overline{\Gamma}^{Phys}(\Delta t) - \Gamma^{Phys}(\Delta t)}{\overline{\Gamma}^{Phys}(\Delta t) + \Gamma^{Phys}(\Delta t)} = -\Delta\omega + \frac{(D+\Delta\omega)e^{\Delta\Gamma\Delta t/2}(|\lambda_f|^2 - 1)\cos\Delta M\Delta t + 2\Im(\lambda_f)\sin\Delta M\Delta t}{(1+|\lambda_f|^2)h_+/2 + h_-\Re(\lambda_f)}$$

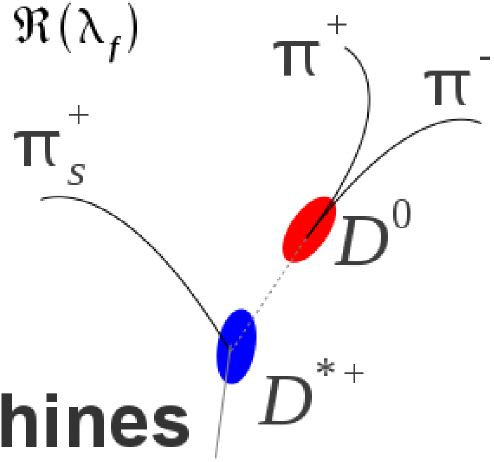
Where we include mistag probability

Uncorrelated D^0 mesons

$$A(t)=\frac{\overline{\Gamma}(t)-\Gamma(t)}{\overline{\Gamma}(t)+\Gamma(t)}=2e^{\Delta\Gamma t/2}\frac{(|\lambda_f|^2-1)\cos\Delta M\, t+2\Im(\lambda_f)\sin\Delta M\, t}{(1+|\lambda_f|^2)(1+e^{\Delta\Gamma t})+2\Re(\lambda_f)(1-e^{\Delta\Gamma t})}$$

Mistag probability and dilution become important

$$A^{Phys}(t)=\frac{\overline{\Gamma^{Phys}}(t)-\Gamma^{Phys}(t)}{\overline{\Gamma^{Phys}}(t)+\Gamma^{Phys}(t)}=+\Delta\omega+\frac{(D-\Delta\omega)e^{\Delta\Gamma t/2}(|\lambda_f|^2-1)\cos\Delta M\, t+2\Im(\lambda_f)\sin\Delta M\, t}{(1+|\lambda_f|^2)h_+/2+h_-\Re(\lambda_f)}$$



The flavour tagging is accomplished by identifying a "slow" pion in the processes (CP and CP conjugated):

$$D^{*+}\rightarrow D^0\pi_s^+$$
$$D^{*-}\rightarrow \overline{D}^0\pi_s^-$$

e$^+$e$^-$ machines at Υ(4S) and hadron machines

D* from $e^+e^-\rightarrow c\bar{c}$ can be separated from those coming from B's by applying a momentum cut.
Clean environment.
More easier to separate prompt D* from B cascade than LHCb

D* mesons are produced both promptly or as secondary particles from primary decay of a B meson.
High background level to keep under control.
Trigger efficiency.

Expected number of (tagged) events

LHC*b* *5.0 fb^{-1}* Estimated from arXiv:1112.0938 [hep-ex]	4.9×10^{6} 1.9×10^{7}	$D^0\to\pi^+\pi^-$ $D^0\to K^+K^-$	**π-T**
Belle II *50.0 ab^{-1}* Estimated from Phys. Rev. D 78, 011105 (2008)	4.4×10^{6} 1.0×10^{7}	$D^0\to\pi^+\pi^-$ $D^0\to K^+K^-$	**π-T**
Super*B* *1.0 ab^{-1}* $\Psi(3770)$ Estimated from Phys. Rev. D 78, 012001 (2008)	9.8×10^{5} 4.8×10^{6} 2.5×10^{6} 1.2×10^{7}	$D^0\to\pi^+\pi^-$ $D^0\to\pi^+\pi^-$ $D^0\to K^+K^-$ $D^0\to K^+K^-$	**SL-T** **K-T** **SL-T** **K-T**
Super*B* *75.0 ab^{-1}* $\Upsilon(4S)$ Estimated from Phys. Rev. D 78, 011105 (2008)	6.6×10^{6} 1.5×10^{7}	$D^0\to\pi^+\pi^-$ $D^0\to K^+K^-$	**π-T**

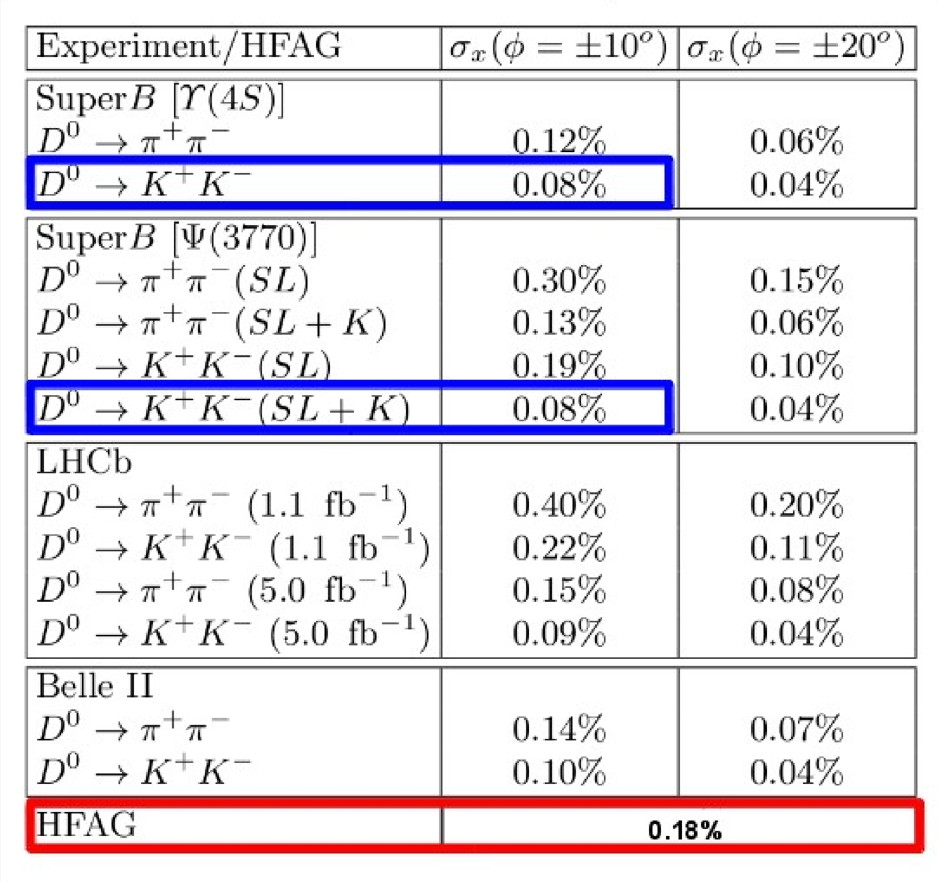
π-T indicates that the D^0 mesons are tagged using the electrical charge of the associated short pion (LHC*b*/Belle/Super*B*)

SL-T refers to semi-leptonic tag at charm threshold and **K-T** to the Kaon tag at charm thereshold (Super*B* only)

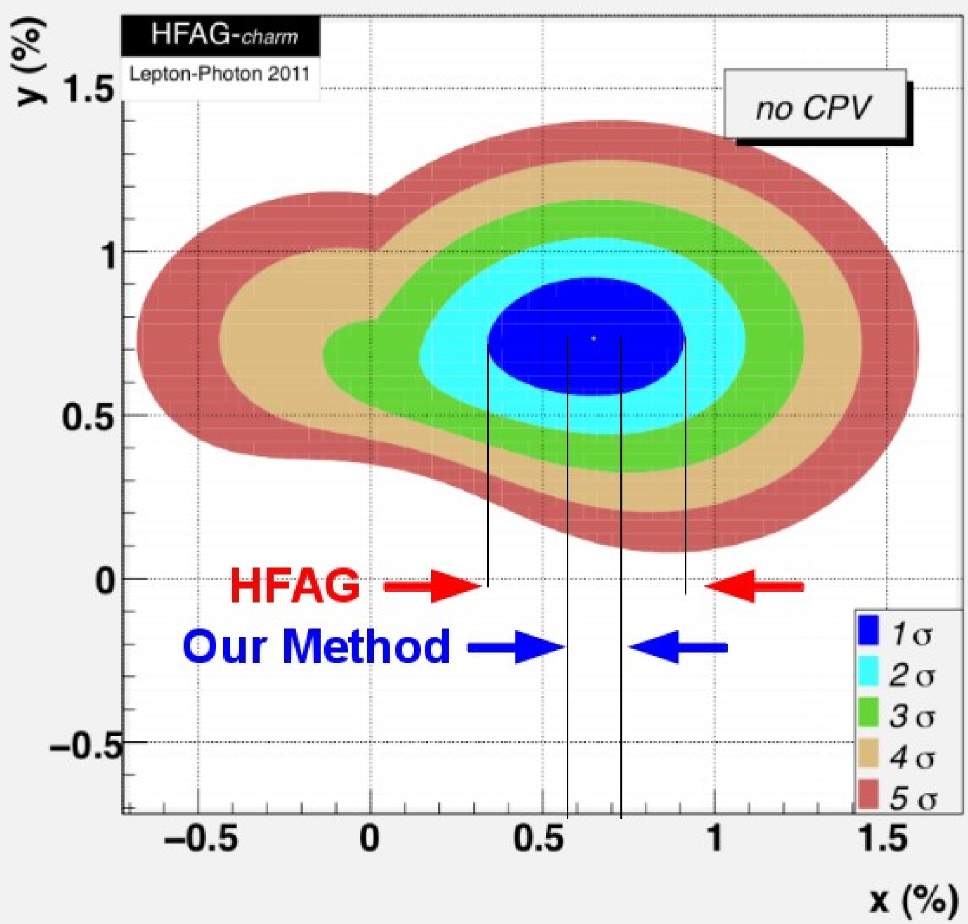
Precision II

$$x(\%) = x + \sigma_x$$

no CPV assumption



Experiment/HFAG	$\sigma_x(\phi = \pm 10^o)$	$\sigma_x(\phi = \pm 20^o)$
Super$B$ $[\Upsilon(4S)]$		
$D^0 \to \pi^+\pi^-$	0.12%	0.06%
$D^0 \to K^+K^-$	0.08%	0.04%
Super$B$ $[\Psi(3770)]$		
$D^0 \to \pi^+\pi^-(SL)$	0.30%	0.15%
$D^0 \to \pi^+\pi^-(SL+K)$	0.13%	0.06%
$D^0 \to K^+K^-(SL)$	0.19%	0.10%
$D^0 \to K^+K^-(SL+K)$	0.08%	0.04%
LHCb		
$D^0 \to \pi^+\pi^-$ $(1.1\ \text{fb}^{-1})$	0.40%	0.20%
$D^0 \to K^+K^-$ $(1.1\ \text{fb}^{-1})$	0.22%	0.11%
$D^0 \to \pi^+\pi^-$ $(5.0\ \text{fb}^{-1})$	0.15%	0.08%
$D^0 \to K^+K^-$ $(5.0\ \text{fb}^{-1})$	0.09%	0.04%
Belle II		
$D^0 \to \pi^+\pi^-$	0.14%	0.07%
$D^0 \to K^+K^-$	0.10%	0.04%
HFAG	0.18%	

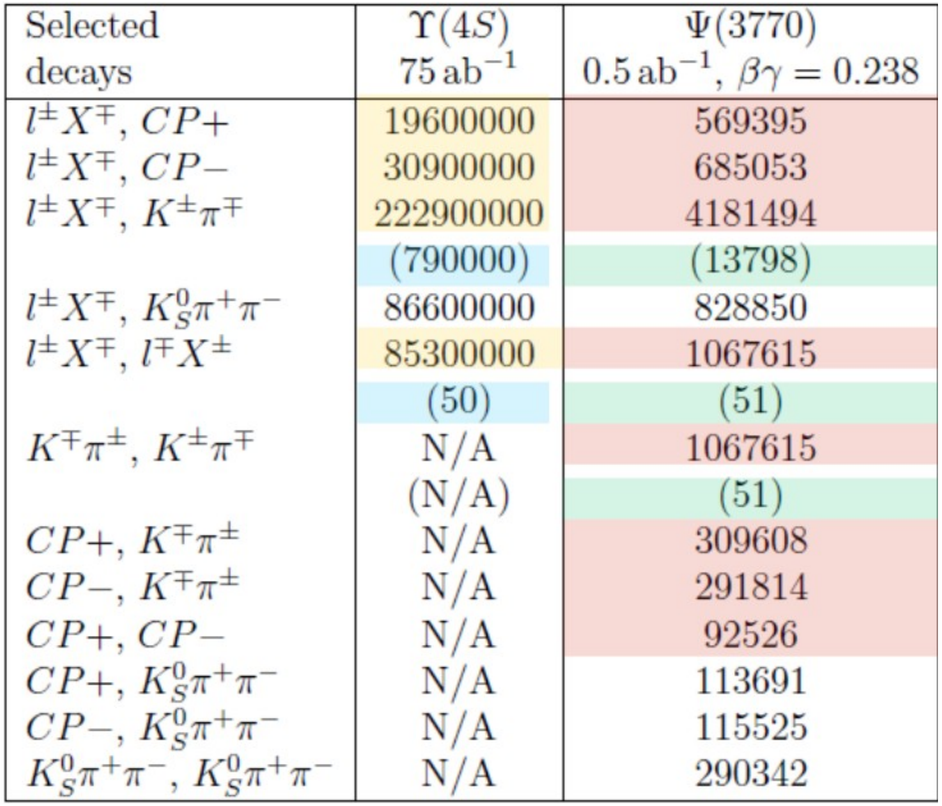


With the time-dependent analysis it is possible to add information on mixing of D^0 meson and improve the current limits

We now need to compare the two studies to understand if we are really comparing apples-to-apples.

Two different comparisons shown in the next slides...

1st comparison: expected number of events.



Selected decays	$\Upsilon(4S)$ $75\,\mathrm{ab}^{-1}$	$\Psi(3770)$ $0.5\,\mathrm{ab}^{-1}$, $\beta\gamma = 0.238$
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N. Neri, December Collaboration Meeting.

Super*B* *1.0 ab^{-1}*
$\Psi(3770)$
Estimated from
Phys. Rev. D 78, 012001 (2008)

9.8×10^5	$D^0\to\pi^+\pi^-$	**SL-T**
4.8×10^6	$D^0\to\pi^+\pi^-$	**K-T**
2.5×10^6	$D^0\to K^+K^-$	**SL-T**
1.2×10^7	$D^0\to K^+K^-$	**K-T**

Super*B* *75.0 ab^{-1}*
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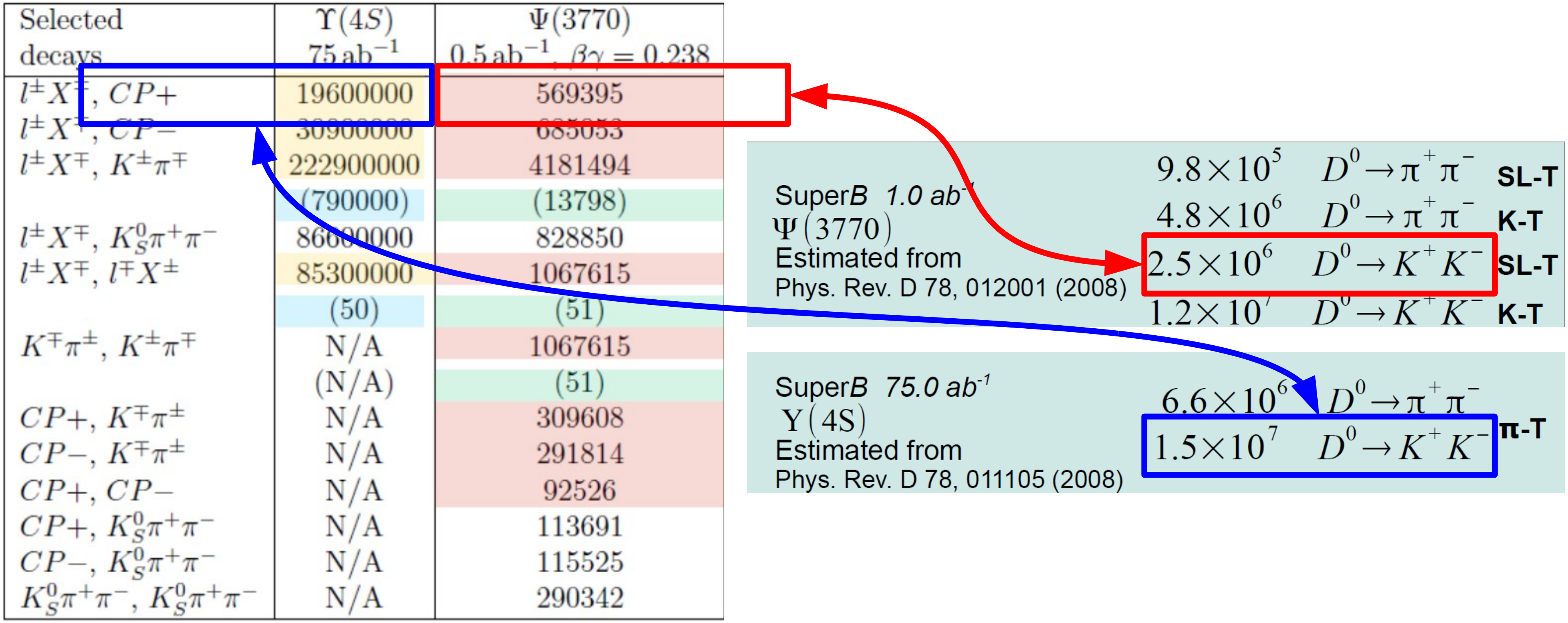
1.5×10^7	$D^0\to K^+K^-$	

A. Bevan et al. most up-to-date estimate (2012)

1^{st} comparison: expected number of events.



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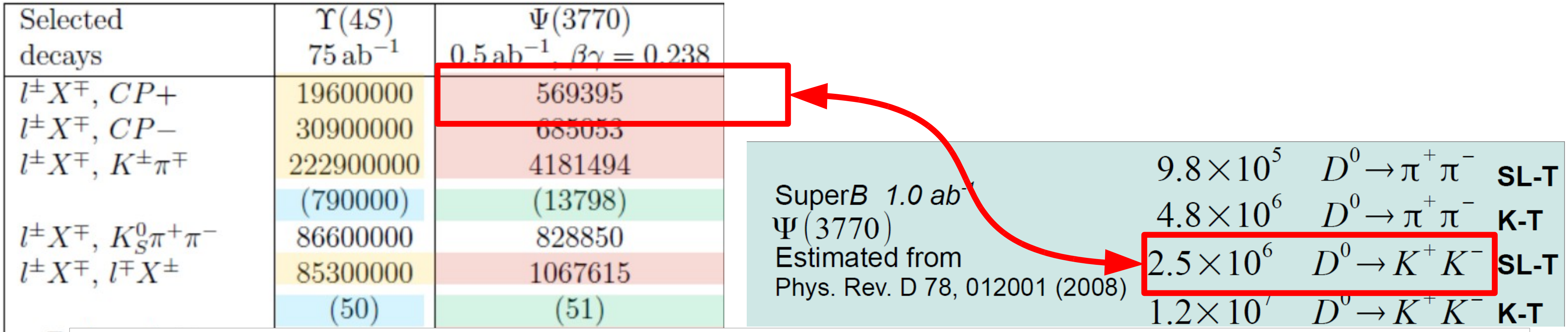
π-T

1^{st} comparison: expected number of events.



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$K^{\mp}$		
CP		
CP		
CP		
CP		
CP		
$K^0_S\pi$		

Super*B* *1.0 ab*$^{-1}$
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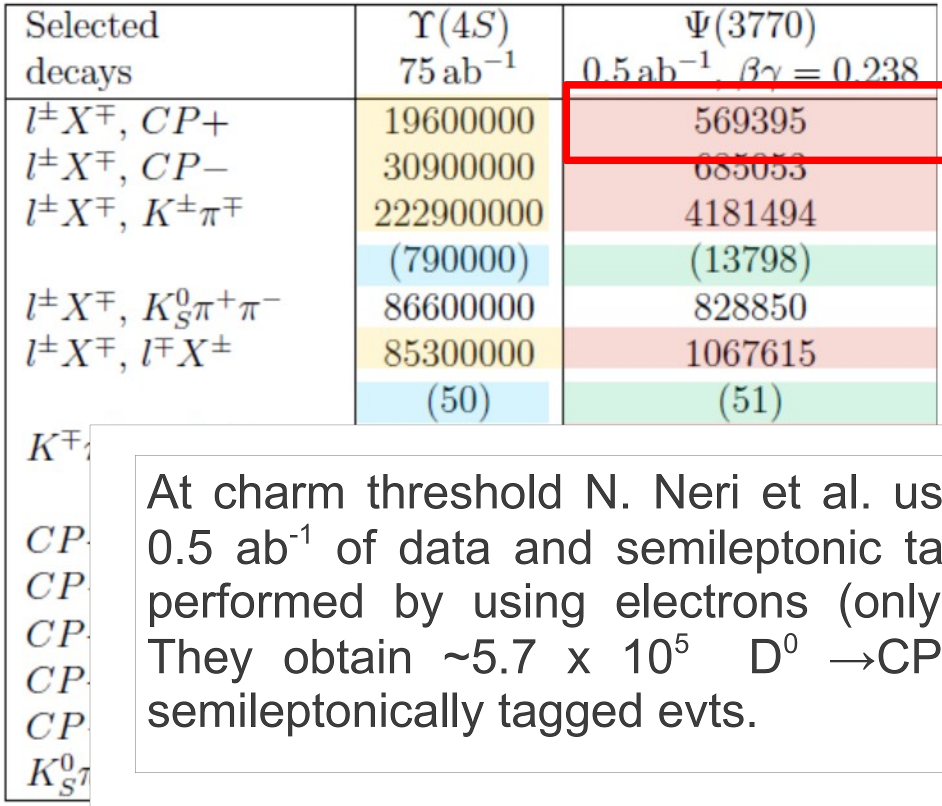
At charm threshold N. Neri et al. use 0.5 ab^{-1} of data and semileptonic tag performed by using electrons (only). They obtain ~5.7 x 10^5 D^0 →CP+ semileptonically tagged evts.

At charm threshold A. Bevan et al. use 1.0 ab^{-1} (luminosity x 2) and semileptonic tag performed by using both electrons and muons (x2 BR): ~2.5 x 10^6 D^0 →CP+ semileptonically tagged evts.

1^{st} comparison: expected number of events.



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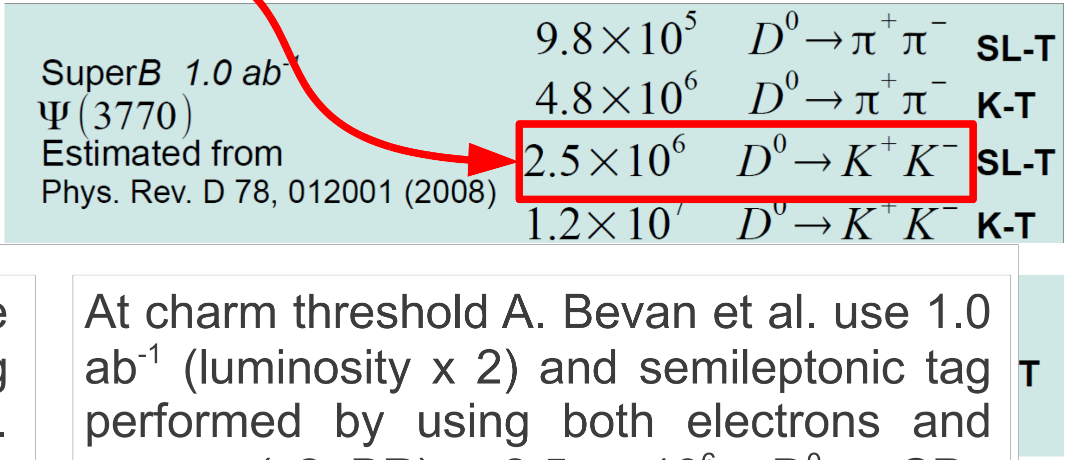
	(50)	(51)
$K^{\mp}$		
CP		
CP		
CP		
CP		
CP		
$K^0_S\pi$		



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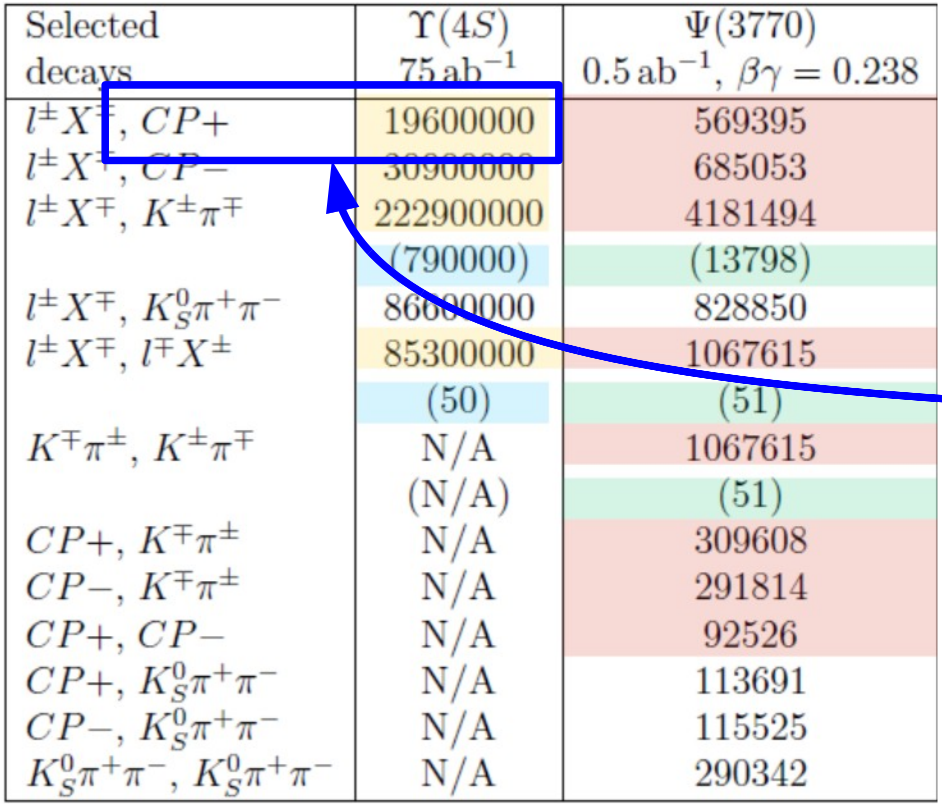
N.Neri et al. When applyng same consideration of A. Bevan et al. Obtain:
5.7×10^5 x 2 (luminosity) x2 (BR)~2.3×10^6

Conclusion: Agreement!

1st comparison: expected number of events.



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	(50)	(51)
$K^{\mp}\pi^{\pm}$, $K^{\pm}\pi^{\mp}$	N/A	1067615
	(N/A)	(51)
$CP+$, $K^{\mp}\pi^{\pm}$	N/A	309608
$CP-$, $K^{\mp}\pi^{\pm}$	N/A	291814
$CP+$, $CP-$	N/A	92526
$CP+$, $K^0_S\pi^+\pi^-$	N/A	113691
$CP-$, $K^0_S\pi^+\pi^-$	N/A	115525
$K^0_S\pi^+\pi^-$, $K^0_S\pi^+\pi^-$	N/A	290342

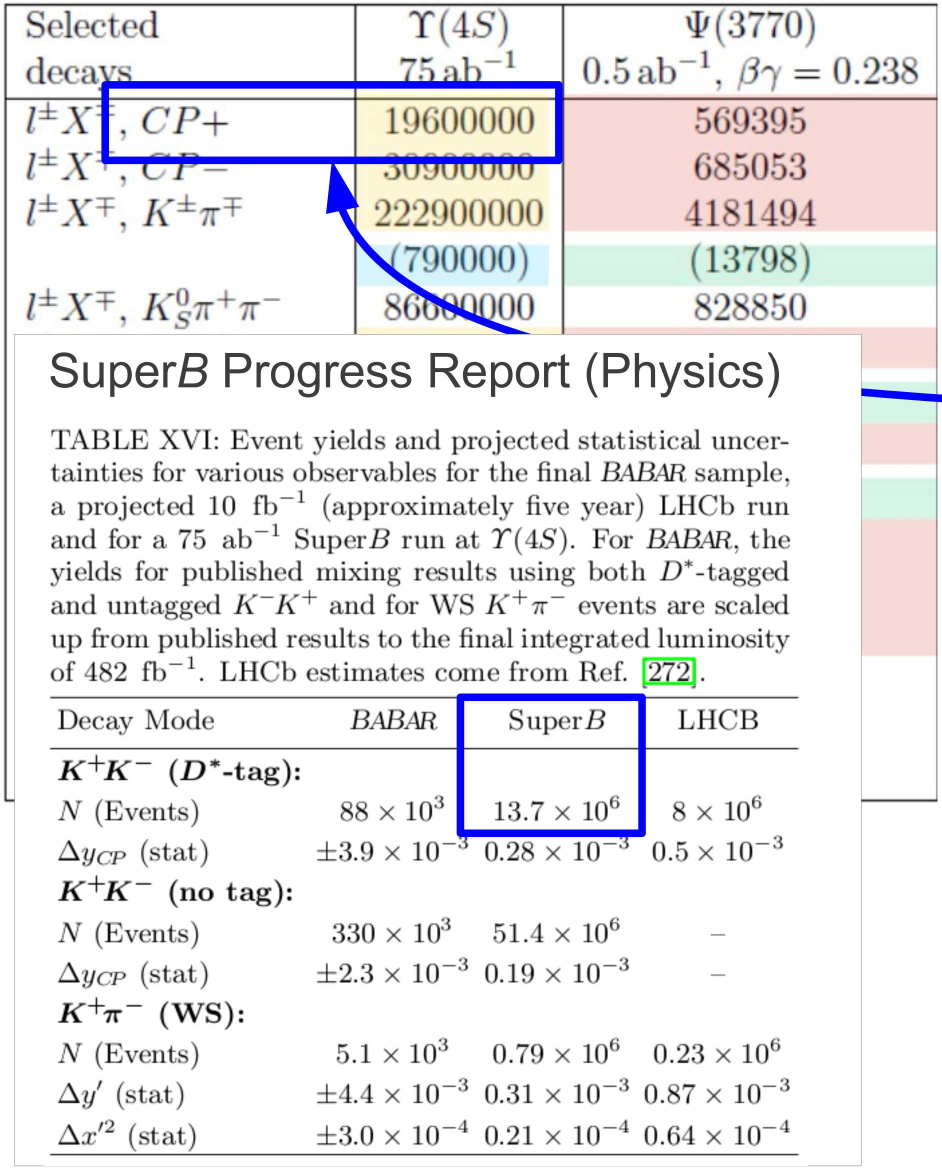
Super*B* *1.0 ab*$^{-1}$
$\Psi(3770)$
Estimated from
Phys. Rev. D 78, 012001 (2008)

9.8×10^5 $D^0\to\pi^+\pi^-$ **SL-T**
4.8×10^6 $D^0\to\pi^+\pi^-$ **K-T**
2.5×10^6 $D^0\to K^+K^-$ **SL-T**
1.2×10^7 $D^0\to K^+K^-$ **K-T**

Super*B* *75.0 ab*$^{-1}$
$\Upsilon(4S)$
Estimated from
Phys. Rev. D 78, 011105 (2008)

6.6×10^6 $D^0\to\pi^+\pi^-$
1.5×10^7 $D^0\to K^+K^-$ **π-T**

1^{st} comparison: expected number of events.



Selected decays	$\Upsilon(4S)$ $75\,\mathrm{ab}^{-1}$	$\Psi(3770)$ $0.5\,\mathrm{ab}^{-1}$, $\beta\gamma = 0.238$
$l^{\pm}X^{\mp}$, $CP+$	19600000	569395
$l^{\pm}X^{\mp}$, $CP-$	30900000	685053
$l^{\pm}X^{\mp}$, $K^{\pm}\pi^{\mp}$	222900000	4181494
	(790000)	(13798)
$l^{\pm}X^{\mp}$, $K^0_S\pi^+\pi^-$	86600000	828850

SuperB Progress Report (Physics)

TABLE XVI: Event yields and projected statistical uncertainties for various observables for the final *BABAR* sample, a projected 10 fb^{-1} (approximately five year) LHCb run and for a 75 ab^{-1} Super*B* run at $\Upsilon(4S)$. For *BABAR*, the yields for published mixing results using both D^*-tagged and untagged K^-K^+ and for WS $K^+\pi^-$ events are scaled up from published results to the final integrated luminosity of 482 fb^{-1}. LHCb estimates come from Ref. [272].

Decay Mode	*BABAR*	Super*B*	LHCB
K^+K^- (D^*-tag):			
N (Events)	88×10^3	13.7×10^6	8×10^6
Δy_{CP} (stat)	$\pm3.9\times10^{-3}$	0.28×10^{-3}	0.5×10^{-3}
K^+K^- (no tag):			
N (Events)	330×10^3	51.4×10^6	–
Δy_{CP} (stat)	$\pm2.3\times10^{-3}$	0.19×10^{-3}	–
$K^+\pi^-$ (WS):			
N (Events)	5.1×10^3	0.79×10^6	0.23×10^6
$\Delta y'$ (stat)	$\pm4.4\times10^{-3}$	0.31×10^{-3}	0.87×10^{-3}
$\Delta x'^2$ (stat)	$\pm3.0\times10^{-4}$	0.21×10^{-4}	0.64×10^{-4}

Super*B* *1.0 ab^{-1}*
$\Psi(3770)$
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Phys. Rev. D 78, 012001 (2008)

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Super*B* *75.0 ab^{-1}*
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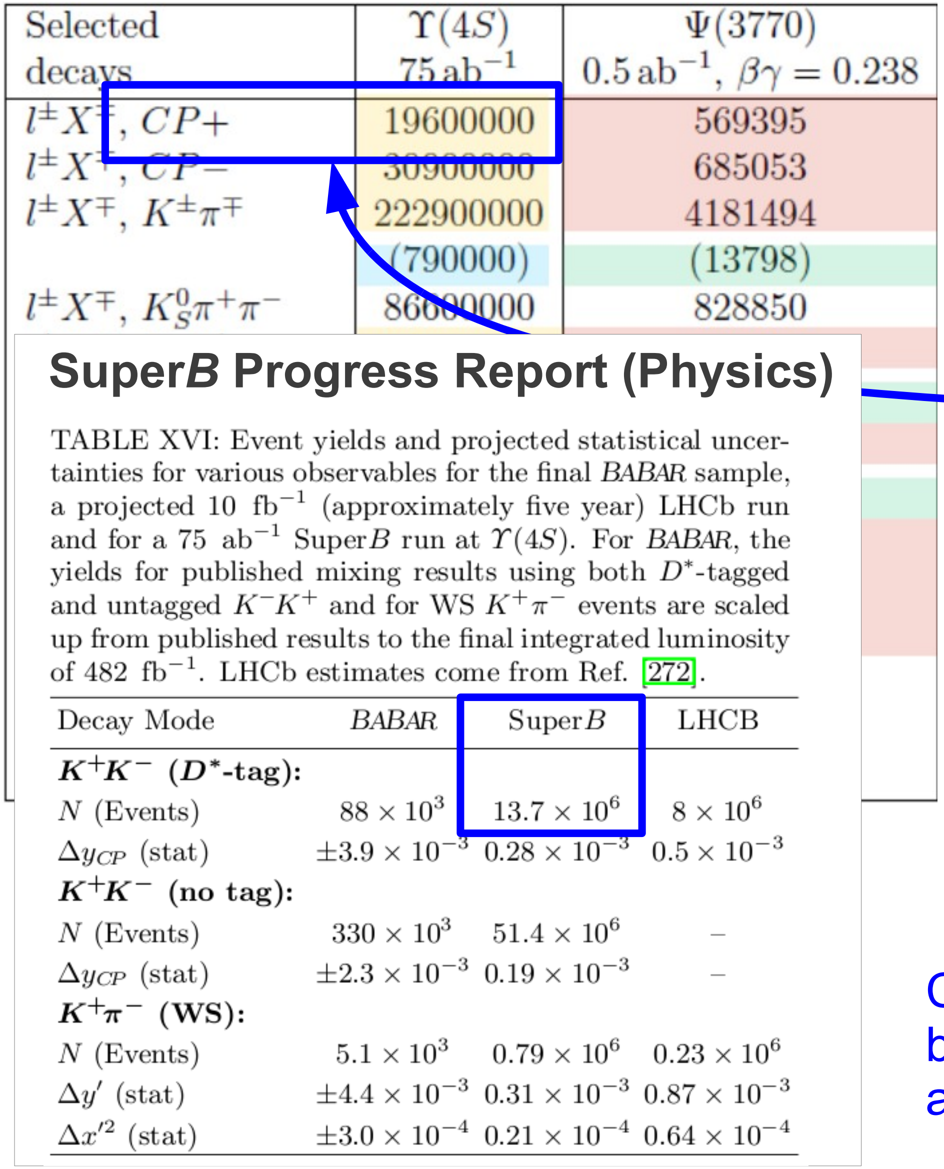
6.6×10^6 $D^0\to\pi^+\pi^-$
$\boxed{1.5\times10^7 \quad D^0\to K^+K^-}$ **π-T**

N. Neri et al. expect ~2.0 x 10^7 CP+ evts.
A. Bevan et al. Expect ~1.5 x 10^7 CP+ evts.
White paper ~ 1.4 x 10^7 CP+ evts.

1^{st} comparison: expected number of events.



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Super*B* Progress Report (Physics)

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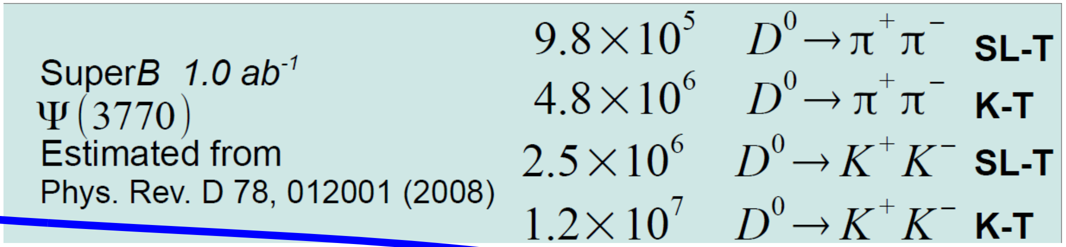

Super*B* *1.0 ab*$^{-1}$
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Phys. Rev. D 78, 012001 (2008)

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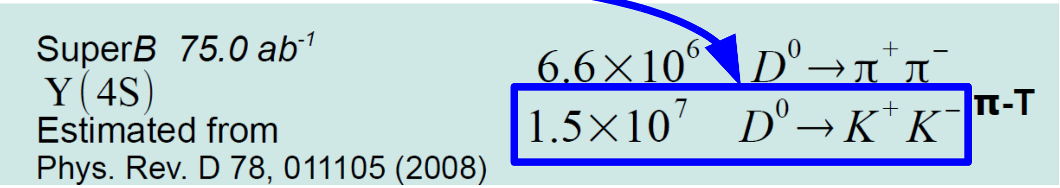

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White paper ~	1.4 x 10^7 CP+ evts.

Conclusion: There is a reasonable agreement between yields. However the difference here is about the 20%.

N. Neri et al. Obtain 0.017% sensitivity on *x* at the Y(4S) and 0.11% at ψ(3770) when using the full set (~3×10^6 expected events)of two-body decays (pion tag at Y(4S)~3×10^8, SL tag at charm threshold~7×10^6)

A. Bevan et al. obtain 0.08% sensitivity on *x* at the Y(4S) and 0.19% at ψ(3770) when using $D^0 \rightarrow K^+K^-$ (pion tag at Y(4S)~1.5×10^7, SL tag at charm threshold~2.5×10^6)

As a consistency check A. Bevan et al. analysis may be implemented using the same number of modes and expected events as for N. Neri et al.

2^{nd} comparison: Sensitivity

N. Neri et al. Obtain 0.017% sensitivity on *x* at the Y(4S) and 0.11% at ψ(3770) when using the full set (~3×10^6 expected events)of two-body decays (pion tag at Y(4S)~3×10^8, SL tag at charm threshold~7×10^6)

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As a consistency check A. Bevan et al. analysis may be implemented using the same number of modes and expected events as for N. Neri et al.

→A. Bevan et al. obtain ~0.018% sensitivity on *x* at the Y(4S) and ~0.12% at the ψ(3770)

Conclusion: there is consistency between results

General conclusion:

the two studies are consistent with each other given the same number of modes and expected events

The Neri et al. Approach combines many double tagged modes while the Bevan et al. approach is closer to a B_d time dependent analysis

...Many thanks...