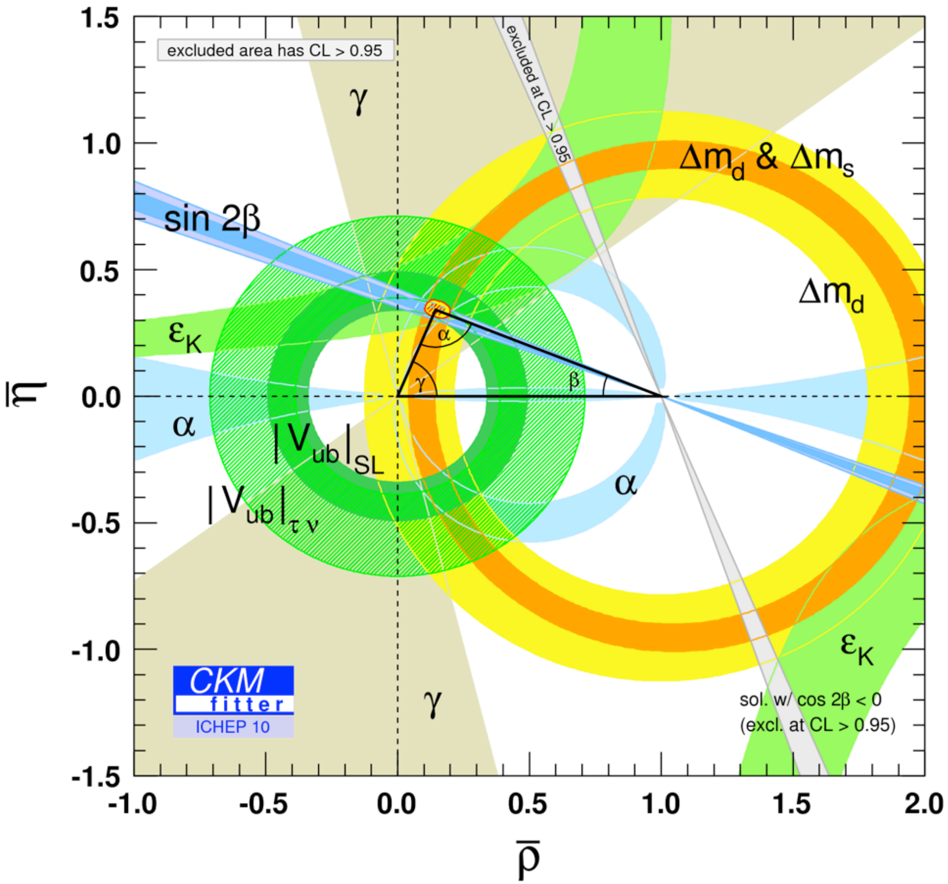
Time dependent γ @ LHCb

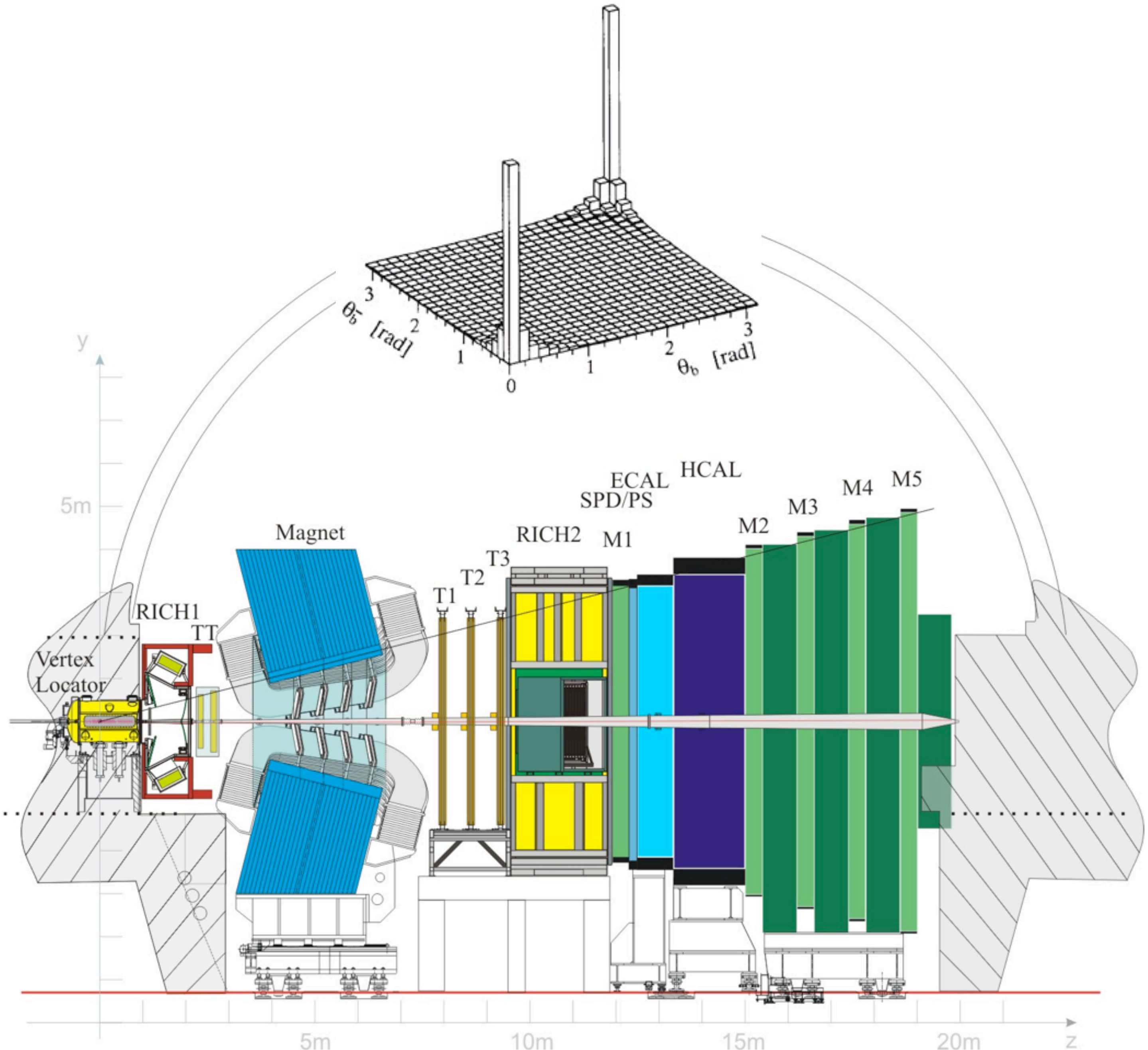


V. Gligorov, CERN

6th CKM Workshop, Warwick, September 2010

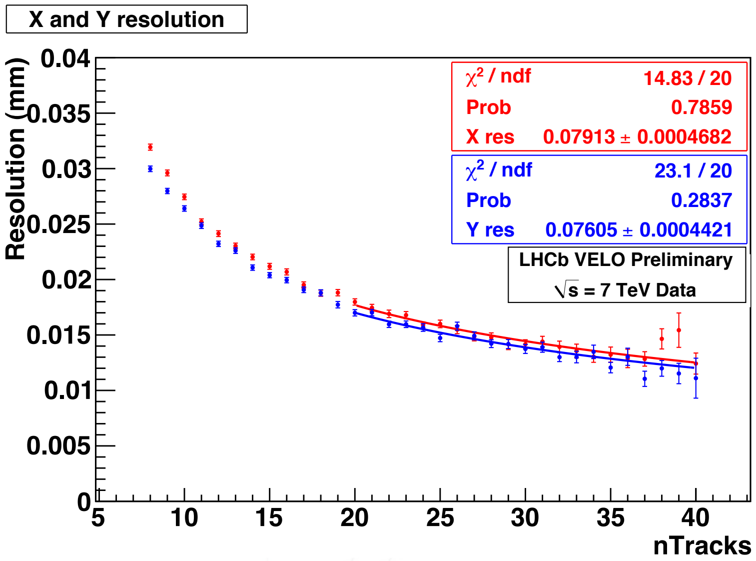
On behalf of the LHCb collaboration

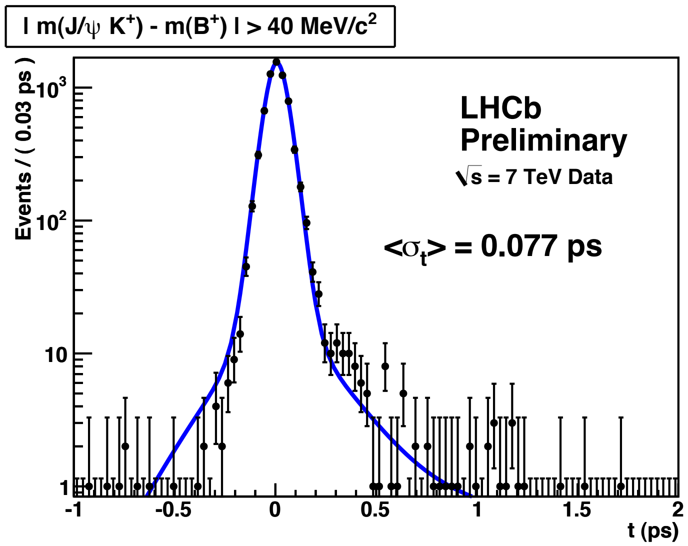
LHCb design

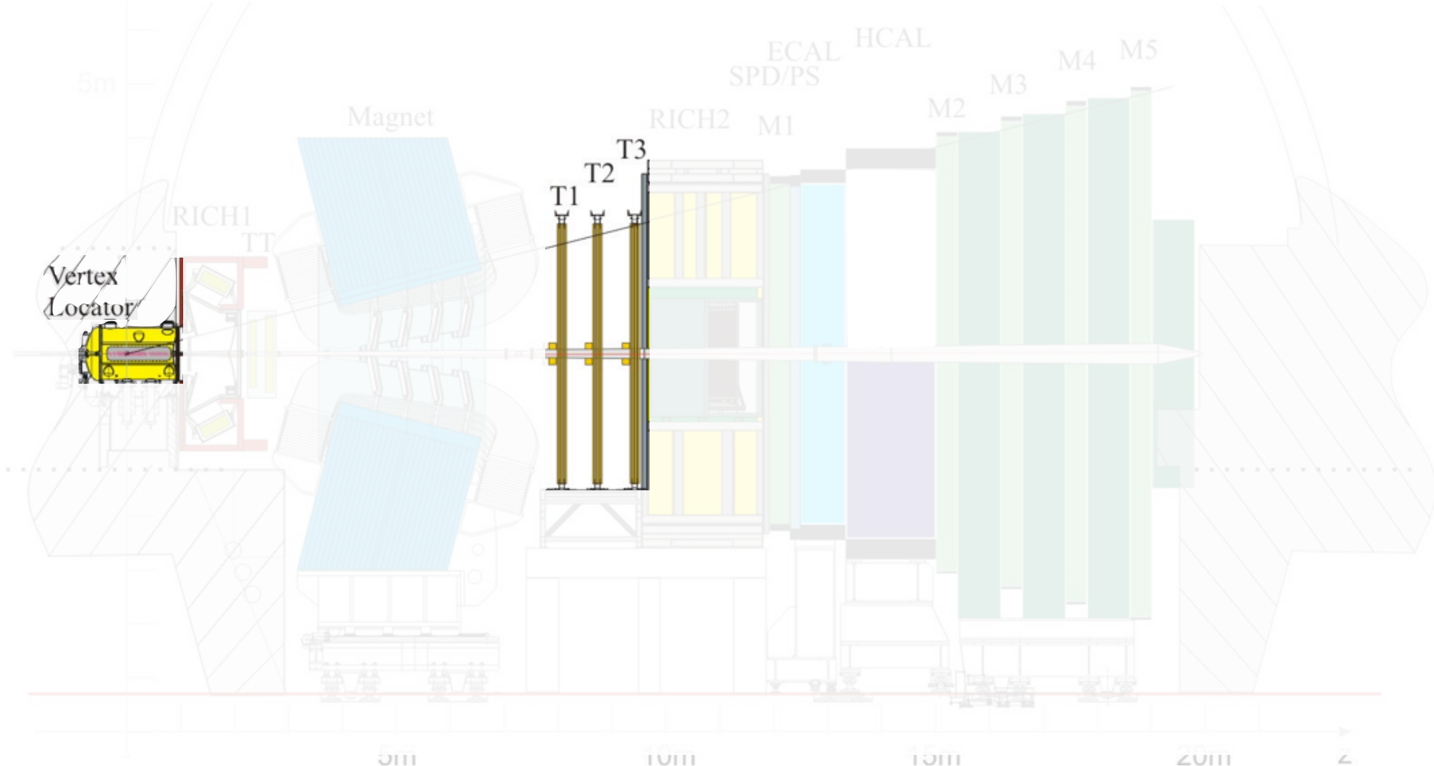


3
2
1
0
$\theta_{\bar{b}}$ [rad]
1
2
3
θ_b [rad]
y
5m
Magnet
RICH1
TT
Vertex
Locator
T1
T2
T3
RICH2
ECAL
SPD/PS
HCAL
M1
M2
M3
M4
M5
5m
10m
15m
20m
z

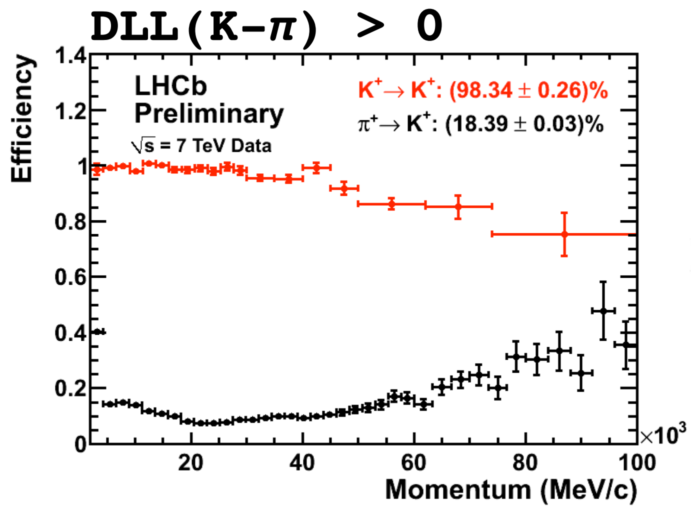
LHCb propertime resolution

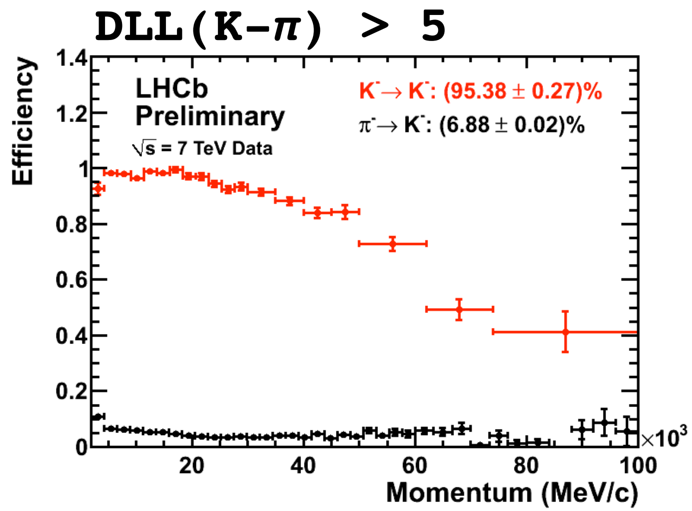


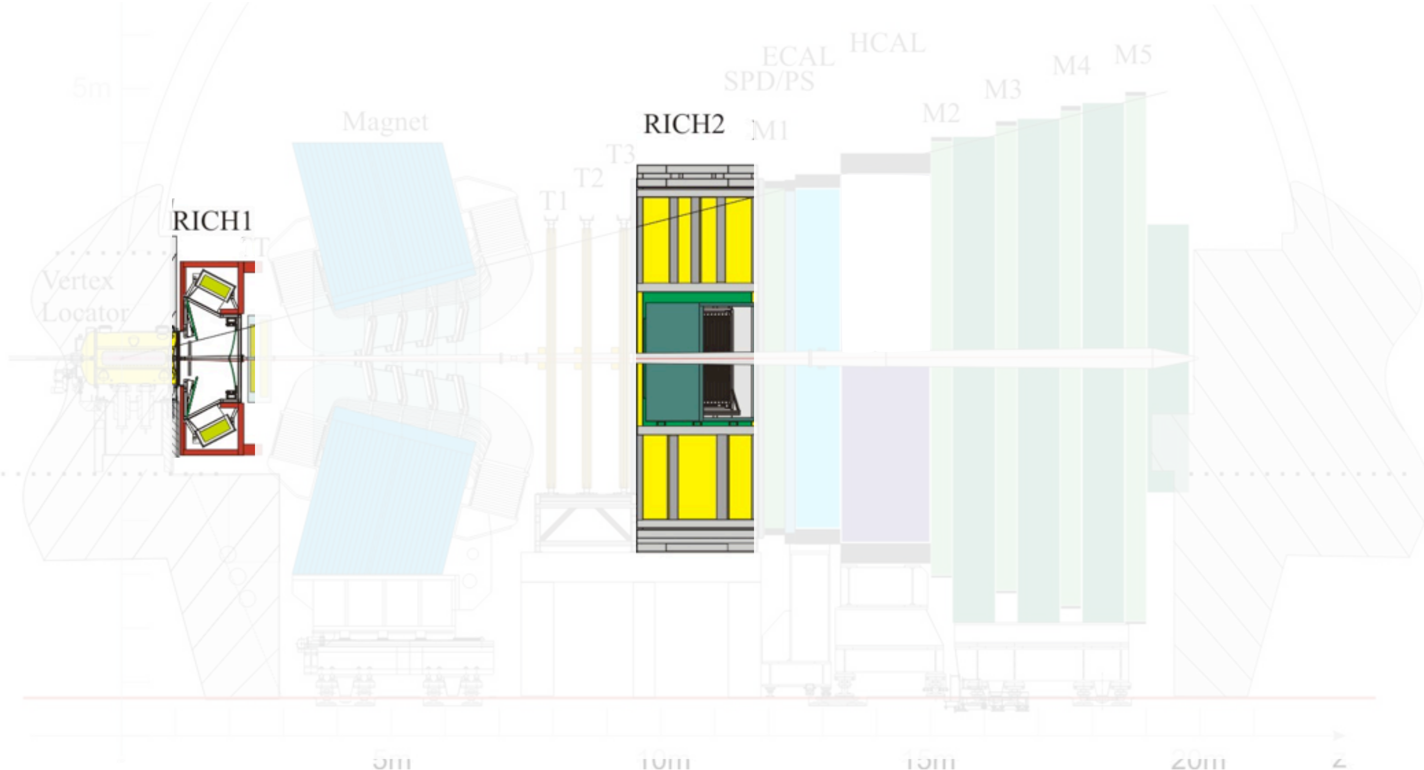




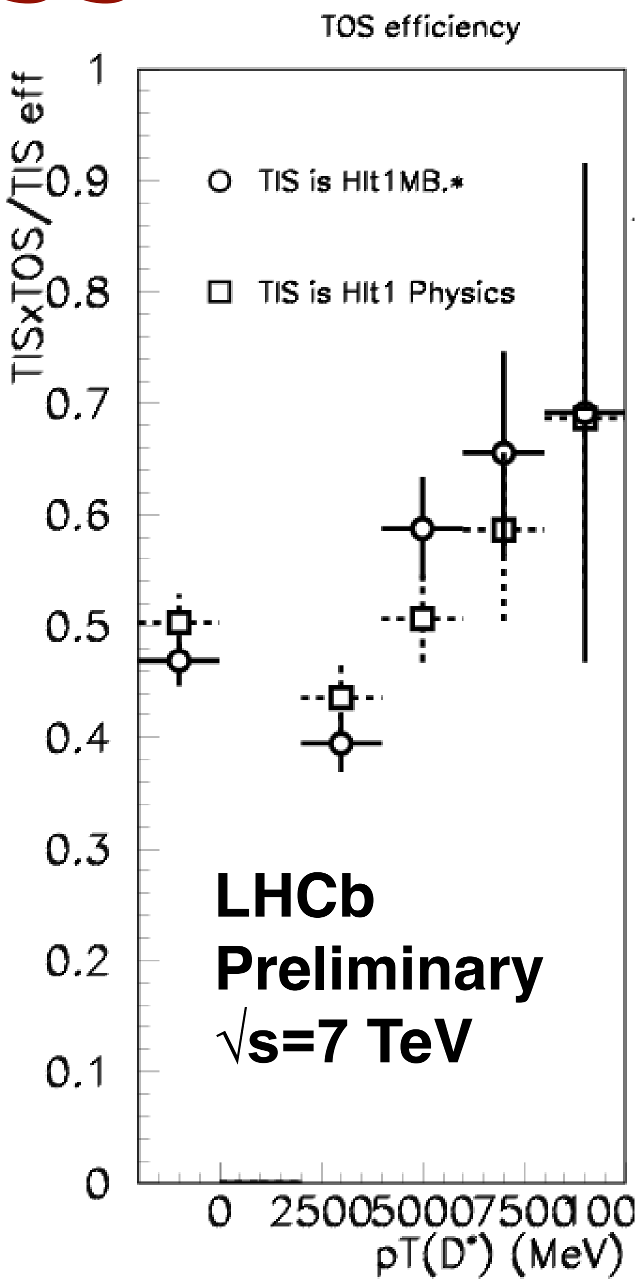
LHCb particle ID

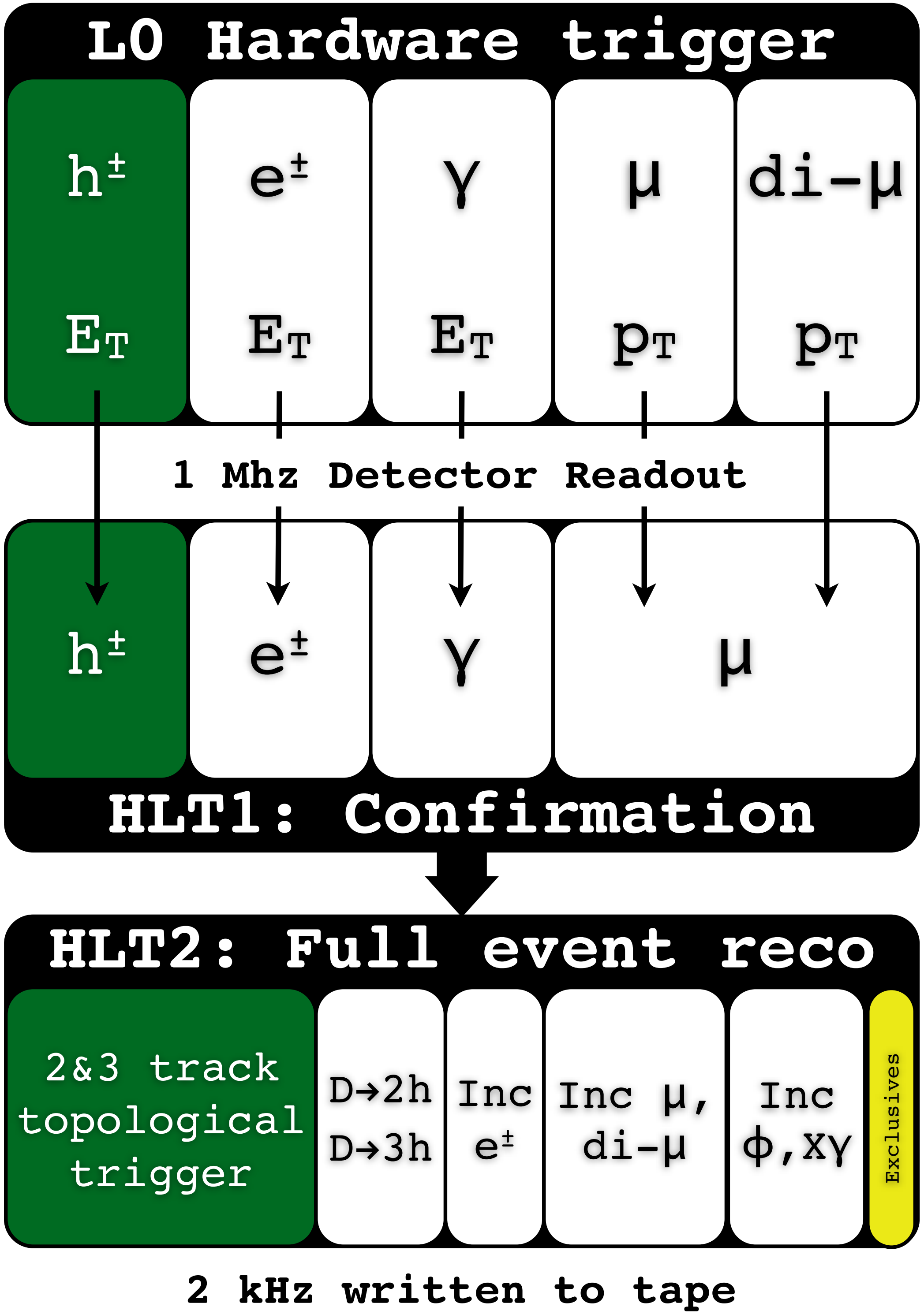




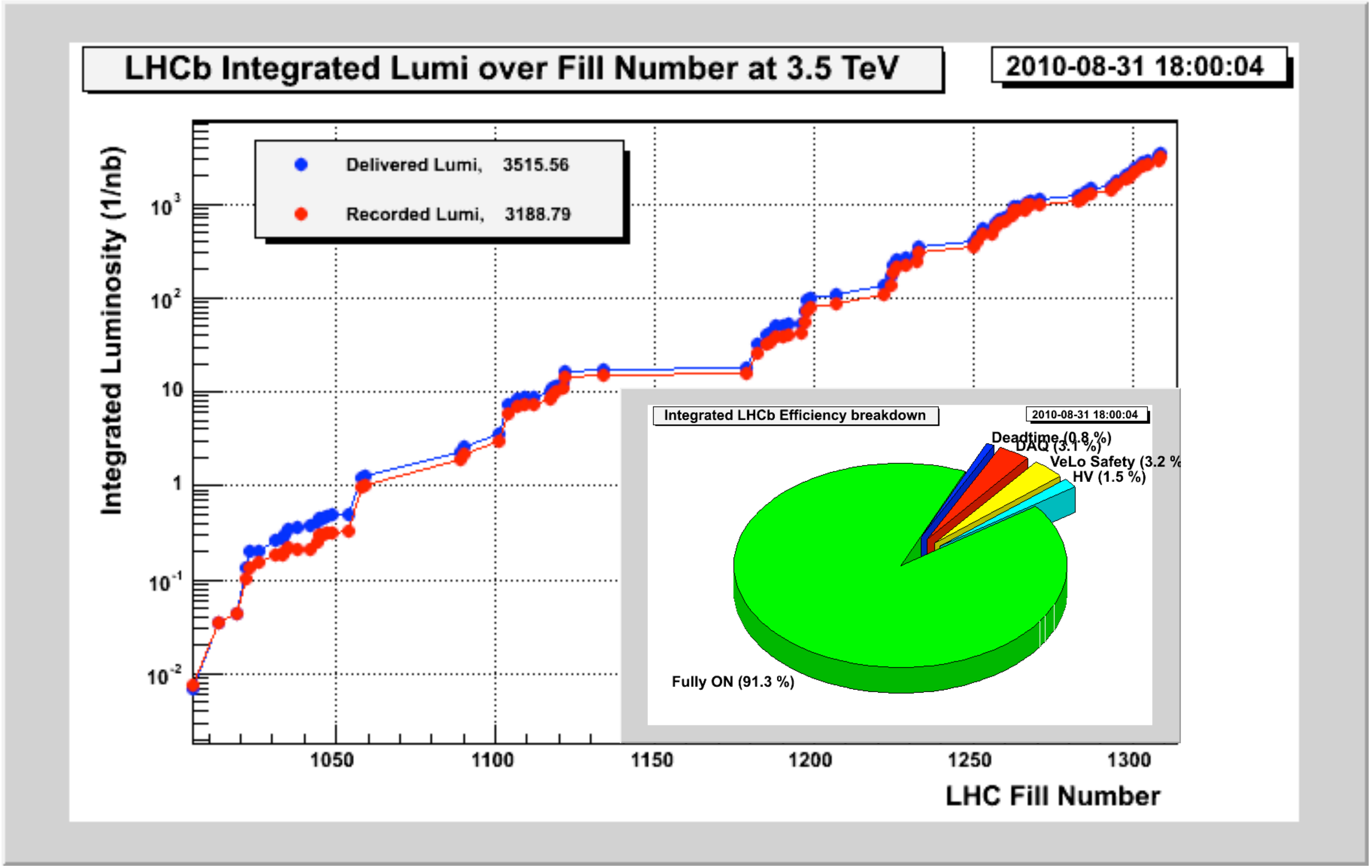


Trigger


TOS efficiency
TISxTOS/TIS eff
TIS is Hlt1MB.*
TIS is Hlt1 Physics
LHCb
Preliminary
√s=7 TeV
pT(D*) (MeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


L0 Hardware trigger
h±
e±
γ
μ
di-μ
ET
ET
ET
pT
pT
1 Mhz Detector Readout
h±
e±
γ
μ
HLT1: Confirmation
HLT2: Full event reco
2&3 track topological trigger
D→2h D→3h
Inc e±
Inc μ, di-μ
Inc φ,Xγ
Exclusives
2 kHz written to tape

DAQ



Lots of luminosity already : thanks LHC!

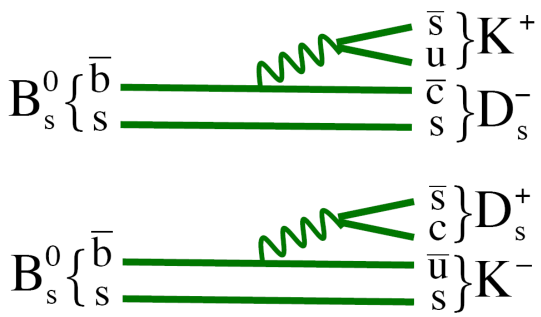
Expect 1 fb^{-1} in 2011

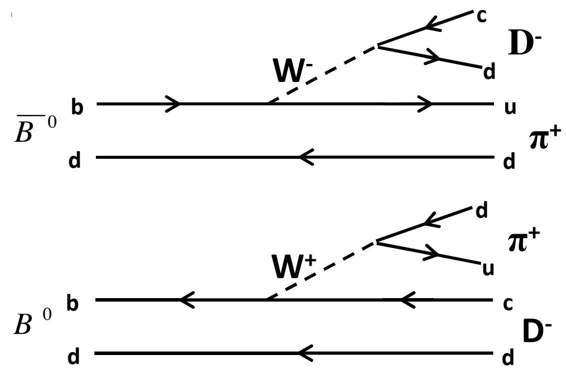
Time dependent γ methods

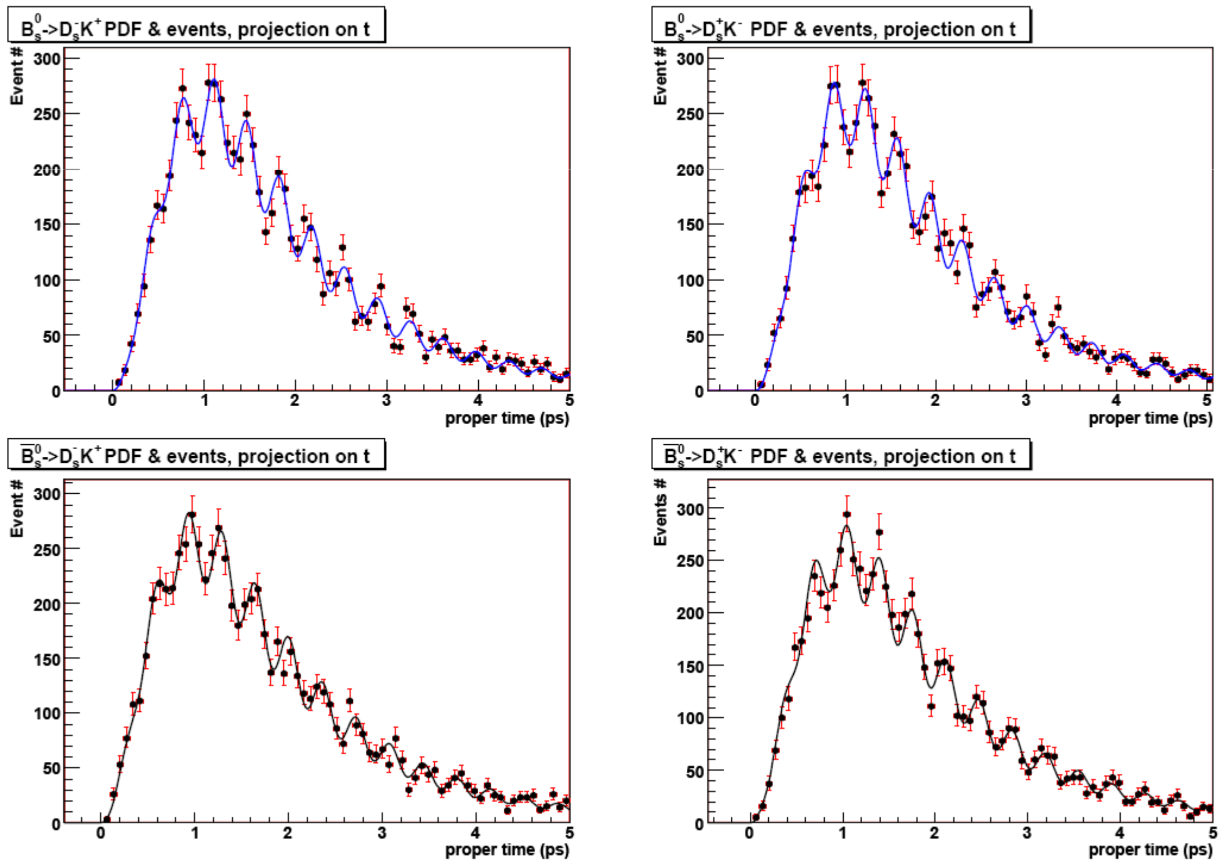
The golden mode is $B_s \rightarrow D_s K$ because of the much larger interference than in the B_d modes

Nature seems to have been very kind with our cross section at 7 TeV!

I'll concentrate on the B_s modes, specifically $D_s K$ in a combined fit with $D_s \pi$







pp->bbbarX cross section

Accept.	*LHCb preliminary*
$2<\eta<6$ $P_T<10$ GeV	$77.4 \pm 4.0 \pm 11.4$ μb
all	$292 \pm 15 \pm 43$ μb

B cross-section 300 μb

ANALYSIS
INGREDIENTS

Signals

Plots from 750 nb^{-1} of data

$D\pi$ yield from MC in 750 nb^{-1} with current trigger 370

Discrepancy to be understood

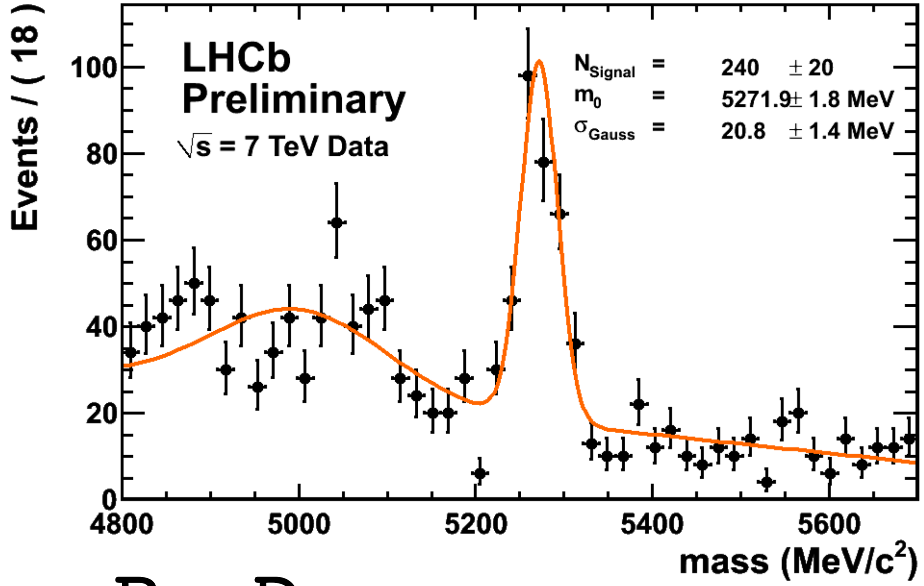
Assume the trigger efficiency stays the same next year and extrapolate D_sK, $D_s\pi$ from MC expectations

$B_s \to D_s\pi$ @LHCb^{2011} ~= 67 k

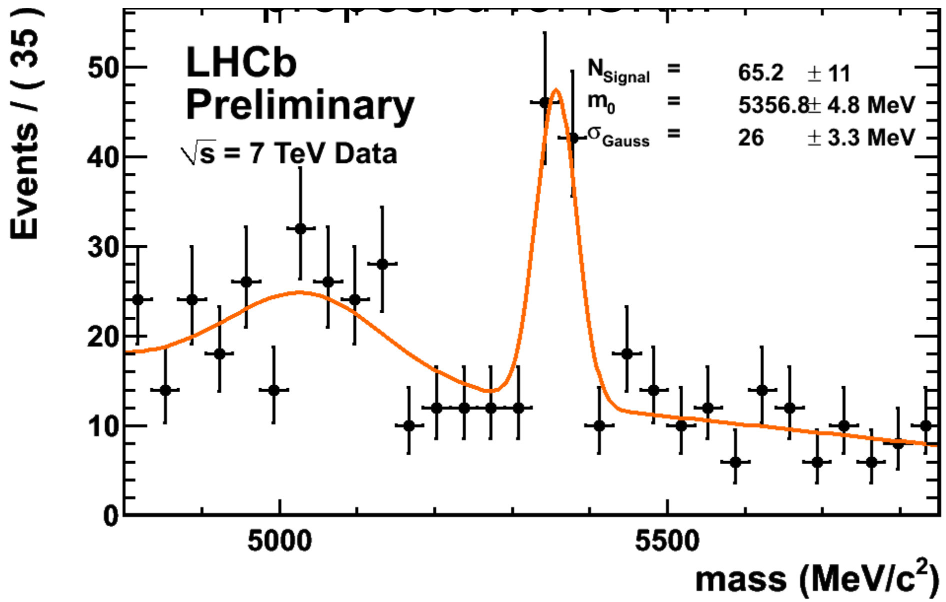
$B_s \to D_sK$ @LHCb^{2011} ~= 5.6 k

From MC sensitivity to γ is 10° with 6k $B_s \to D_sK$: we should not be far off this!

$B \to D\pi$



$B_s \to D_s\pi$

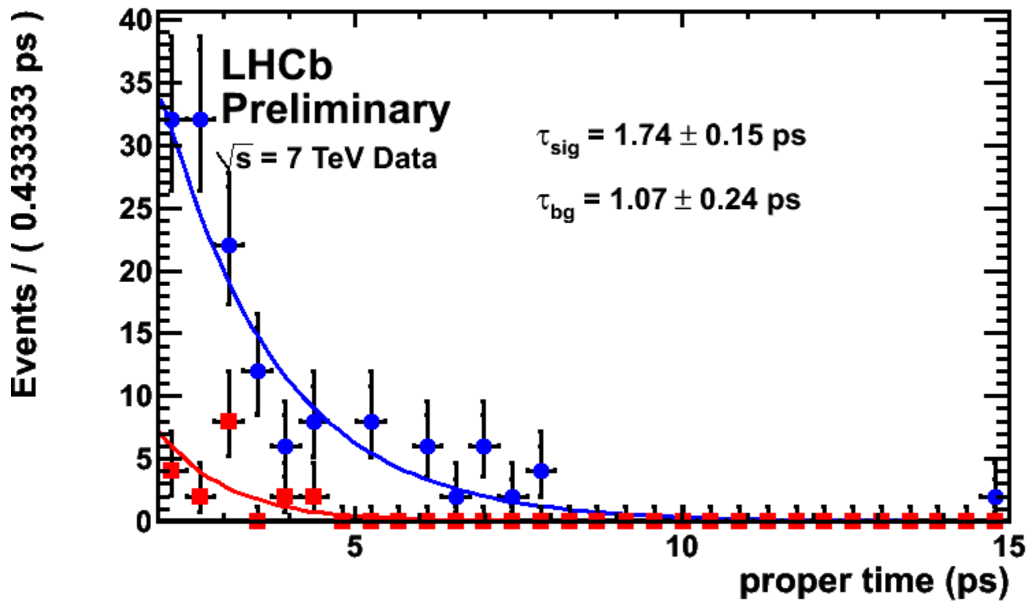


Lifetime and tagging

Apply lifetime cut of > 2 ps in order to eliminate acceptance function and fit to the signal sample

In agreement with the world average: lifetime measurements will be an important intermediate step on the road to γ

B→Dπ



	Category	εeff	εtag	ω %
**	OS muons	1.69+-0.21	9.51+-0.25	28.90+-1.26
**	OS elect	0.47+-0.11	3.04+-0.15	30.29+-2.25
**	OS kaons	1.64+-0.21	21.61+-0.35	36.21+-0.88
**	SS kaons	1.95+-0.23	21.69+-0.35	35.00+-0.88
**	VertexCh	1.38+-0.20	26.32+-0.38	38.56+-0.81

Tagging efficiency = 48.83 +- 0.43 %
Wrong Tag fraction = 30.69 +- 0.58 %
EFFECTIVE COMB. TE = 7.28 +- 0.40 %

Flavour tagging validation ongoing

D_sK and ambiguities

Access all five observables through the use of untagged events: unambiguous in the limit of infinite statistics

Relies on a sizeable ΔΓ/Γ, assumed 10% here

$$A\left(B_q^0 \to D_q \overline{u}_q\right) = \frac{C\cos(\Delta m\tau) + S\sin(\Delta m\tau)}{\cosh\left(\Delta\Gamma_q t/2\right) - A_{\Delta\Gamma}\sinh\left(\Delta\Gamma_q t/2\right)}$$

$$C = -\frac{1 - x_q^2}{1 + x_q^2}$$

Ratio of CKM-suppressed to CKM-favoured amplitudes, **~0.4 in $B_s \to D_s K$**

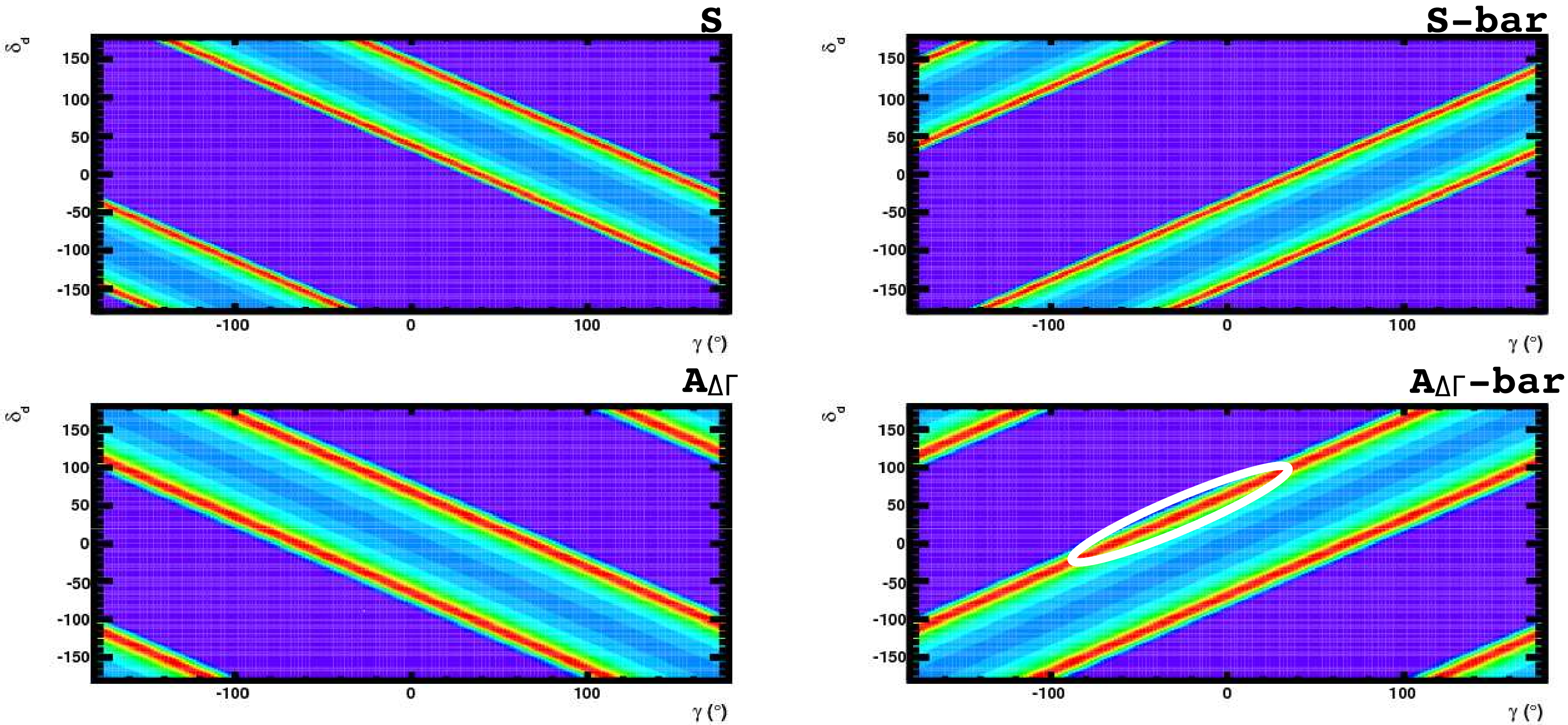
$$S = \frac{2x_q \sin\left(\gamma + \delta_q + \phi_q\right)}{\left(x_q^2 + 1\right)}$$

$$A_{\Delta\Gamma} = \frac{2x_q \cos\left(\gamma + \delta_q + \varphi_q\right)}{\left(x_q^2 + 1\right)}$$

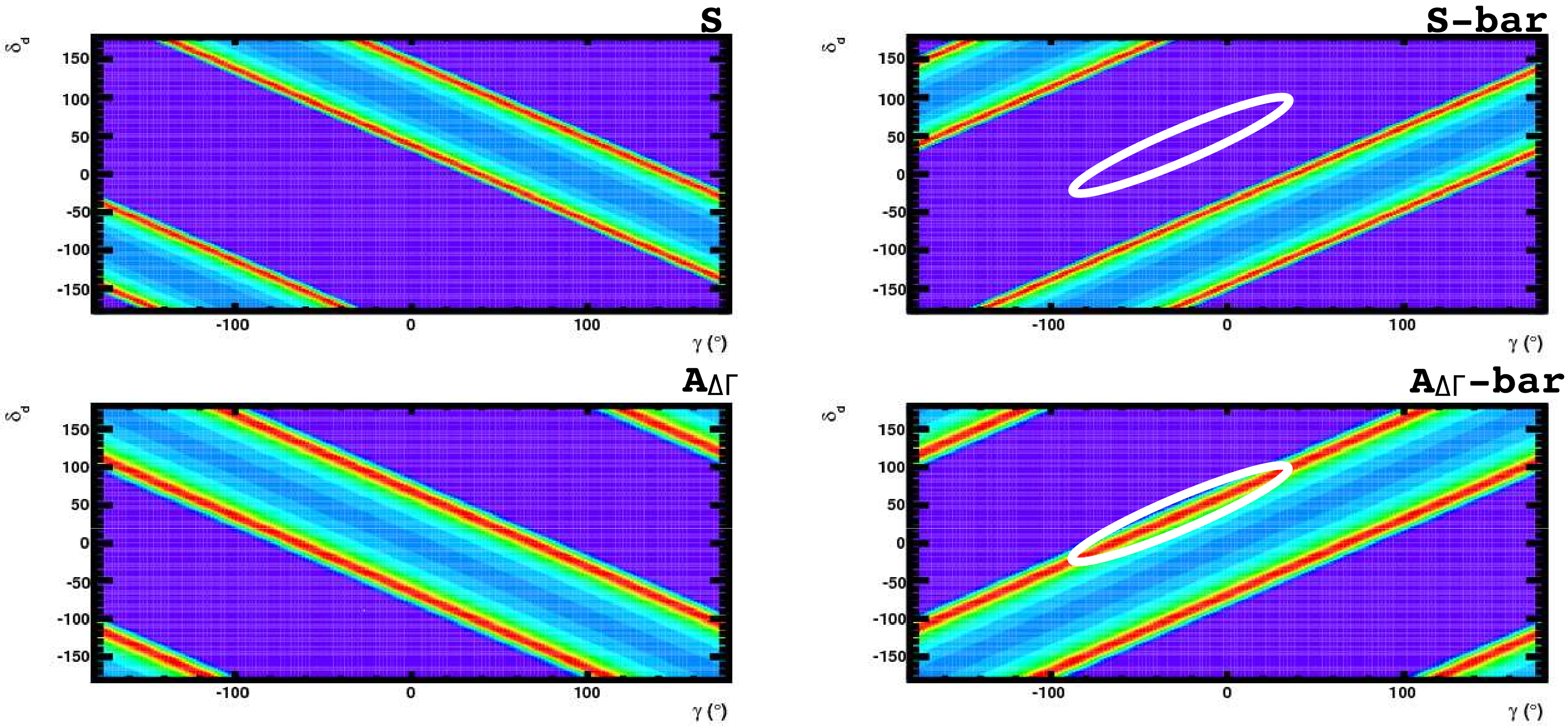
Strong phase

Weak mixing phase

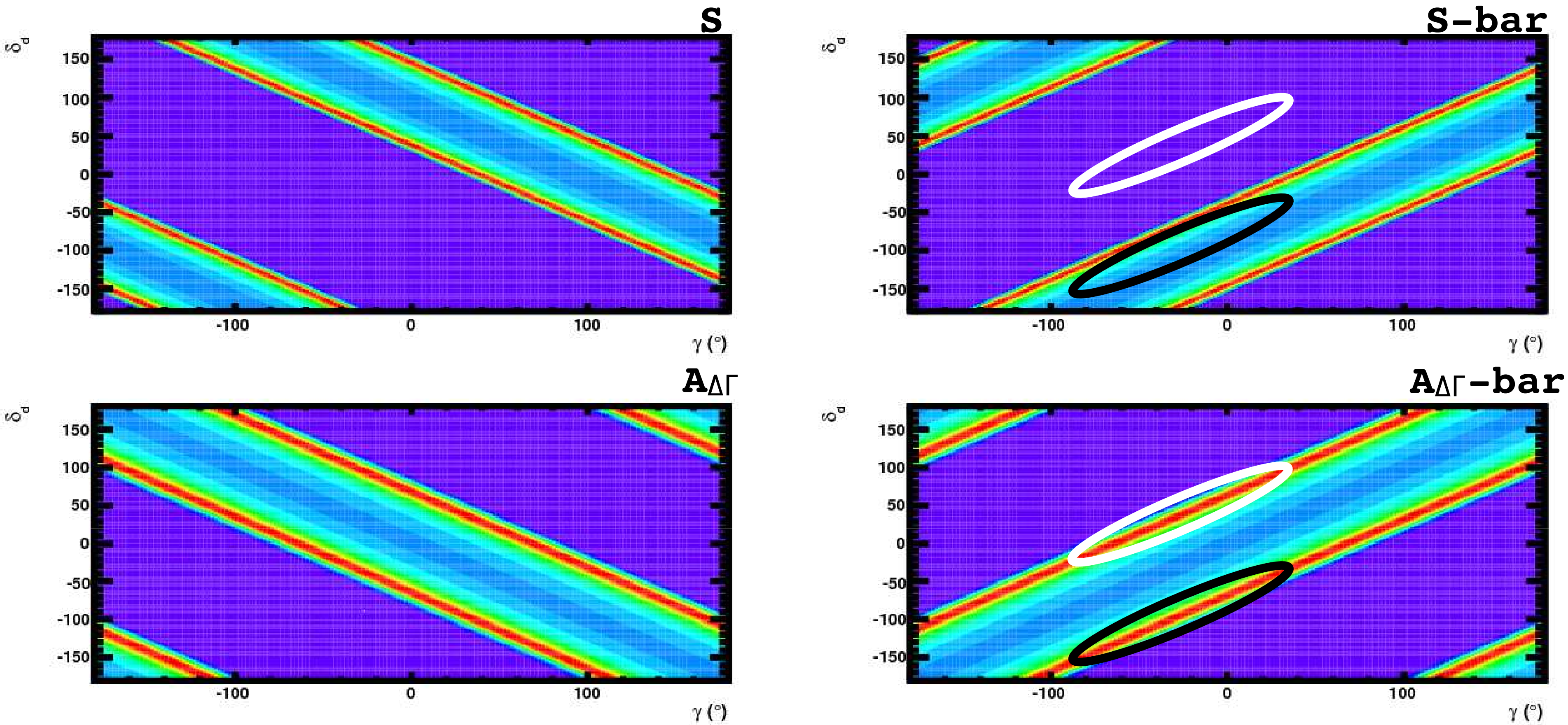
D_sK ambiguities @ 6 fb^{-1}



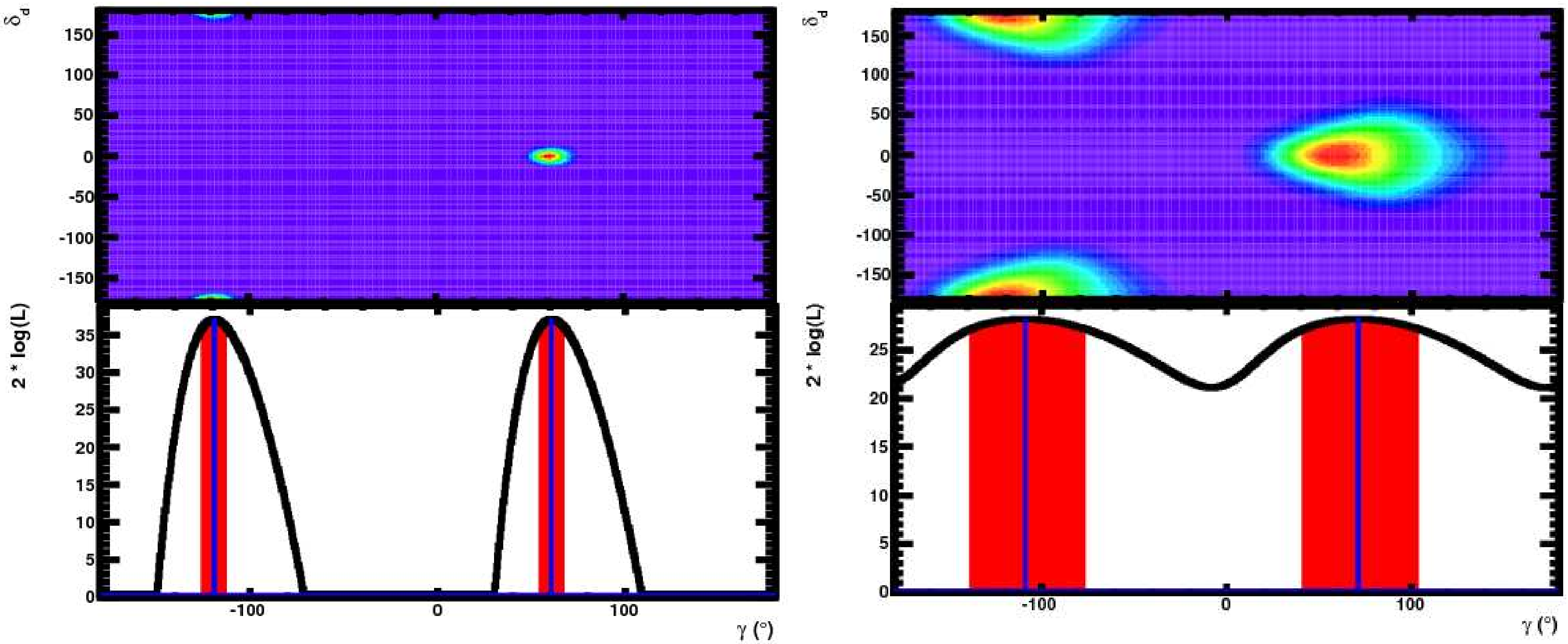
D_sK ambiguities @ 6 fb^{-1}



D_sK ambiguities @ 6 fb^{-1}



D_sK @ 6 fb^{-1} vs. 0.3 fb^{-1}



In the limit of infinite statistics this really is an "unambiguous" measurement (one irreducable ambiguity)

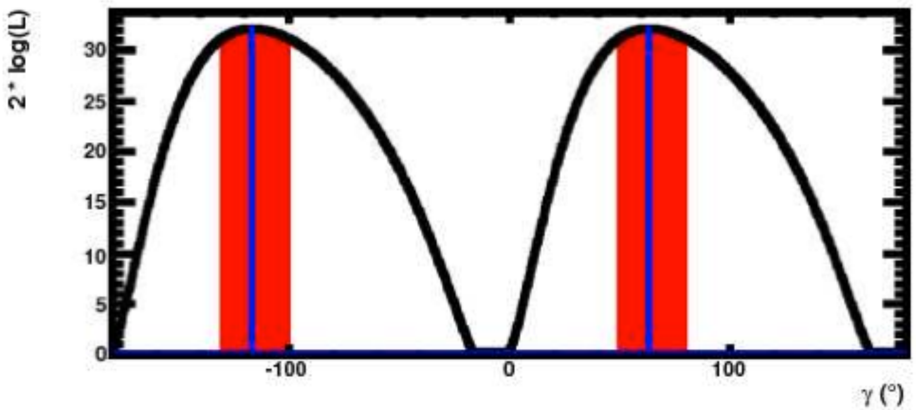
In the limit of low statistics, however, the eight ambiguous solutions are actually degenerate and quoting a central value for γ becomes meaningless

Expected sensitivity in 2011

With ~4k D_sK we would be at the limit of an unambiguous measurement. A lot will depend on how kind nature is with the branching ratios, how much we can improve selection and trigger efficiencies and so on.

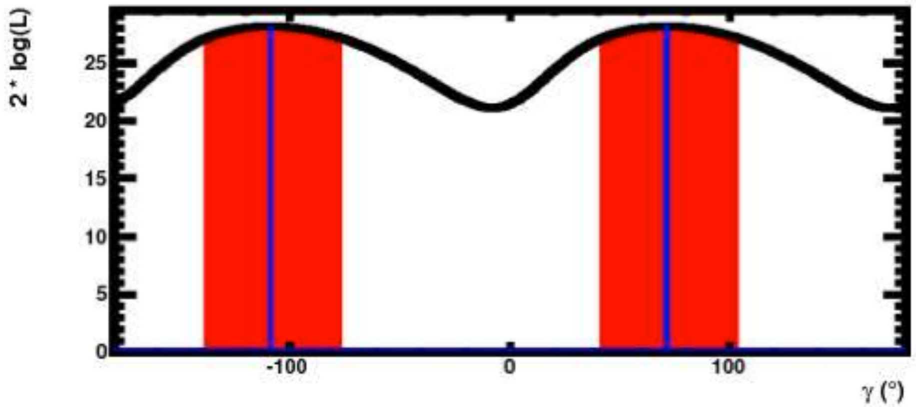
But for sure: we are in the game!

6k events



Ambiguous solutions **are** well resolved, central value has only a ~3° bias

1.5k events



Ambiguous solutions **not** well resolved, central value has an ~11° bias

ONE MORE THING

$B_s \rightarrow D_s K_1$

First six body final states reconstructed @LHCb

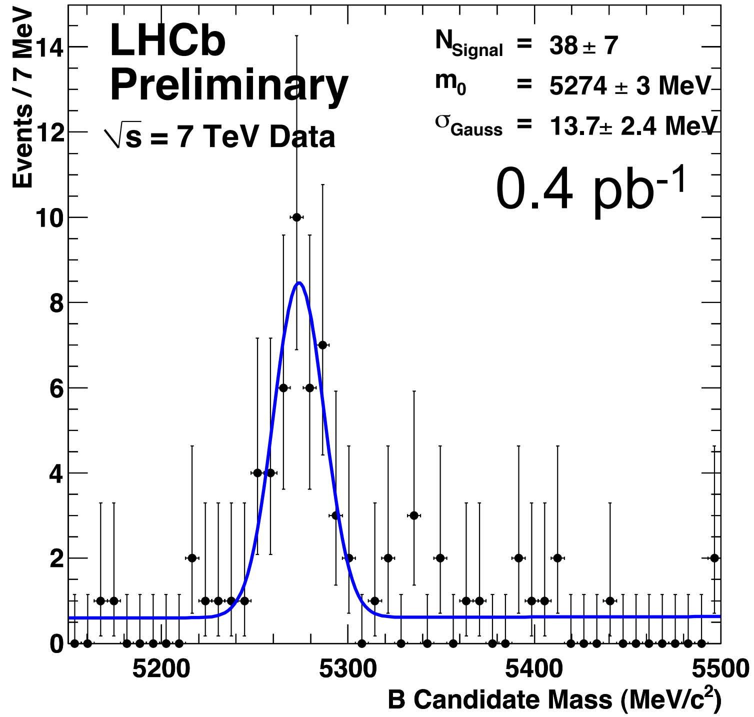
Current hadronic trigger is not optimized for these modes, next year's will be.

Estimating from MC

$B_s \rightarrow D_s K_1$ @LHCb^{2011} ~= 3.6 k

A potentially significant sample!

$B^{(0,+)} \rightarrow D^{(+,0)}\pi\pi\pi$



For $B_s^0 \rightarrow D_s^-(K^+\pi^-\pi^+)$: $\quad A_f \rightarrow A(\mathcal{D}), \quad \delta \rightarrow \delta(\mathcal{D}), \quad \lambda \rightarrow \lambda(\mathcal{D}) = \frac{p}{q}\frac{\bar{A}_f(\mathcal{D})}{A_f(\mathcal{D})}$

$$A_f(\mathcal{D}) = \left(a_{C_0} e^{i\delta_{C_0}} + \sum_{j=1}^{Nres} a_{C_j} \mathcal{A}_j(\mathcal{D}) e^{i\delta_{C_j}} \right) e^{i\delta_C(\mathcal{D})} \qquad \bar{A}_f(\mathcal{D}) = \left(a_{C_0} e^{i\delta_{U_0}} + \sum_{j=1}^{Nres} a_{U_j} \mathcal{A}_j(\mathcal{D}) e^{i\delta_{U_j}} \right) e^{i\delta_U(\mathcal{D})}$$

(Aleksan, Peterson & Soffer, hep-ph/0209194)

where:

"C" subscript is associated with $b \rightarrow c(\bar{u}s)$, with contributing resonant & non-resonant sources

"U" subscript is associated with $\bar{b} \rightarrow \bar{u}(c\bar{s})$, with contributing resonant & non-resonant sources

Thank you Warwick!

49 years since SU(2)xU(1) : let's see if the SM can make it 50 not out

BACKUPS

D_sK observables

- We can form two asymmetries, one for each final state $D_s^+K^-$ and $D_s^-K^+$
- There are then five observables
- **C**, which is common to the two asymmetries

$$S \propto \sin\left(\gamma + \delta_q + \phi_q\right)$$

$$\overline{S} \propto \sin\left(\gamma - \delta_q + \phi_q\right)$$

$$A_{\Delta\Gamma} \propto \cos\left(\gamma + \delta_q + \varphi_q\right)$$

$$\overline{A}_{\Delta\Gamma} \propto \cos\left(\gamma - \delta_q + \varphi_q\right)$$

$D_s K$ sensitivities

INPUT PARAMETERS

Toy MC input parameters	
Parameter	Input value
$\sigma(m_{B_s^0})$ (MeV/c^2)	14
$\Delta\Gamma_s/\Gamma_s$	0.1
Δm_s (ps^{-1})	17.5
mistag fraction ω	0.328
tagging efficiency ε_{tag}	0.5812
$\lvert\lambda_f\rvert$	0.37
$\gamma + \phi_s$ ($^\circ$)	60
$\Delta_{T1/T2}$ ($^\circ$)	0
$B_s^0 \to D_s^- \pi^+$ event yield (1 year)	140 k
$B_s^0 \to D_s^\mp K^\pm$ event yield (1 year)	6.2 k
$B_s^0 \to D_s^- \pi^+$ B/S ratio	0.2
$B_s^0 \to D_s^\mp K^\pm$ B/S ratio	0.7

I am lazy so this is cut-n-pasted from
LHCb-2007-41 (Marcel,Eduardo,Shirit)

$D_s K$ sensitivities

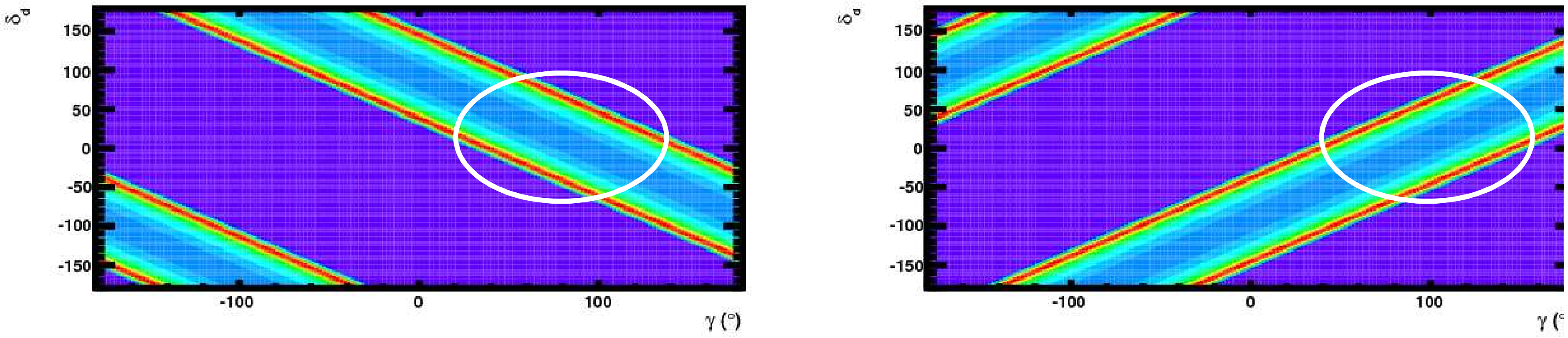
Sensitivity results from $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^\mp K^\pm$					
	$\Delta m_s\,(\mathrm{ps}^{-1})$	ω	$\lvert\lambda_f\rvert$	$\gamma + \phi_s\,(^\circ)$	$\Delta_{T1/T2}\,(^\circ)$
Input value	17.5	0.328	0.37	60	0
Fitted value	17.5	0.3279	0.373	60.3	0.5
σ (5y)	0.003	0.0013	0.029 ± 0.0011	5.7 ± 0.2	5.4 ± 0.2
σ (1y)	0.007	0.0030	0.066	12.7	12.1

Table 3: Sensitivity results from $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^\mp K^\pm$ tagged event samples.

Sensitivity results from $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^\mp K^\pm$ without constraint on asymmetry observables							
	$\Delta m_s\,(\mathrm{ps}^{-1})$	ω	C_f	S_f	D_f	$S_{\bar{f}}$	$D_{\bar{f}}$
Input value	17.5	0.328	0.759	–0.564	0.325	0.564	0.325
Fitted value	17.5	0.328	0.760	–0.568	0.328	0.559	0.335
σ (5y)	0.003	0.0013	0.046	0.063	0.119	0.065	0.126
σ (1y)	0.007	0.003	0.104	0.141	0.267	0.144	0.282

Table 9: Sensitivity results on the asymmetry observables from $B_s^0 \to D_s^- \pi^+$ and $B_s^0 \to D_s^\mp K^\pm$ tagged event samples.

Conventional extraction



With the “conventional” extraction, get four ambigiuous solutions for each intersection of these bands (there are two intersections)

x_d and x_s

The formulas for $x_{d,s}$ come from the decay amplitudes

$$R_b = \left(1-\frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right| \approx 0.4$$

a_d,a_s are hadronic parameters of order 1, λ is of course 0.22 (the Cabbibo angle)

$$x_s = R_b a_s \approx 0.4$$

$$x_d = -\left(\frac{\lambda^2 R_b}{1-\lambda^2}\right) a_d \approx 0.02$$

x_s is large enough to fit from data

BUT

x_d must be externally constrained!

Dπ and ambiguities

Two problems:

1) The uncertainty on $\mathbf{x_d}$ introduces correlations between the two asymmetries.

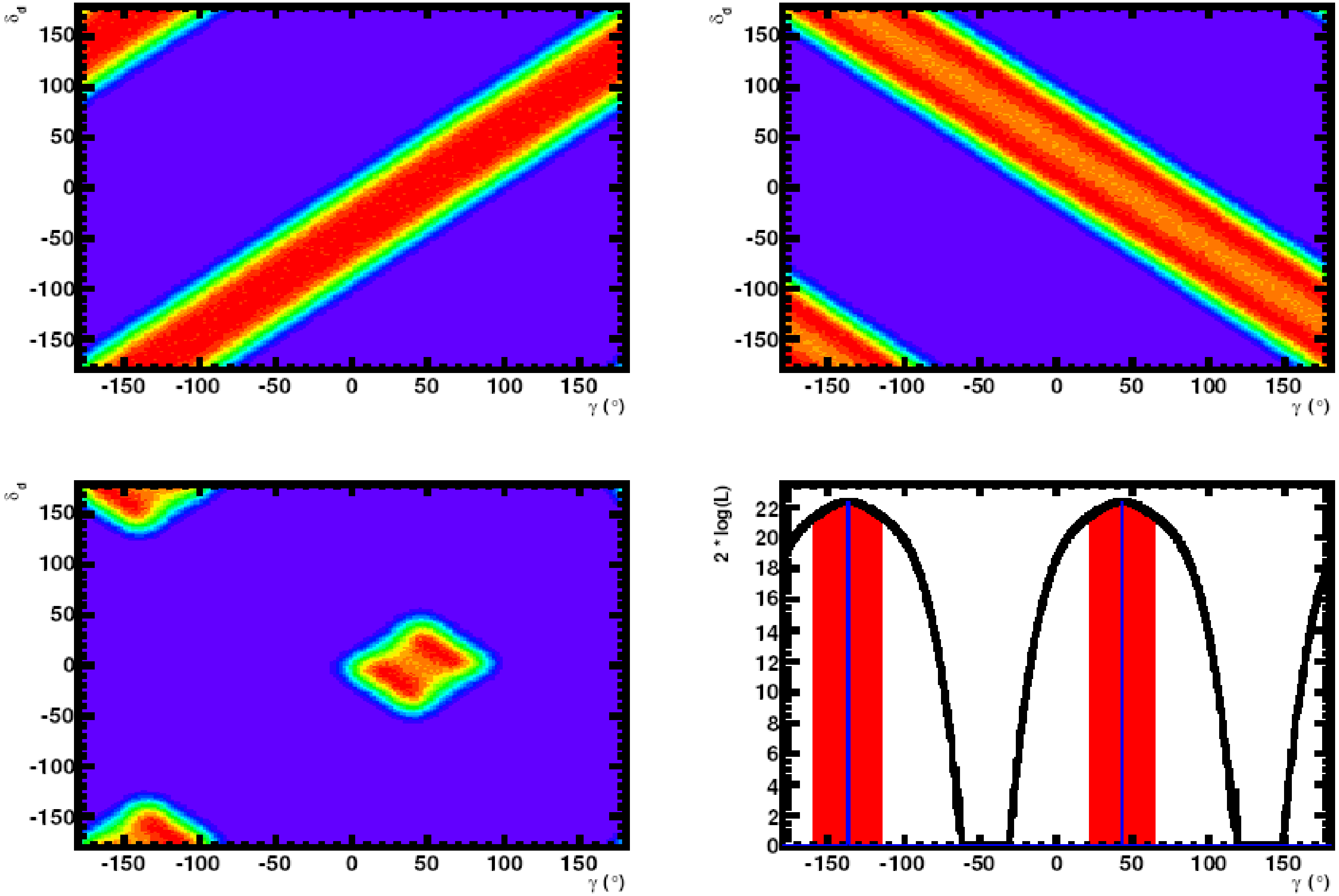
   - **The errors on each observable worsen, and after some time are saturated by the correlations.**

2) The negligible lifetime difference in the $\mathbf{B_d}$ system means $\mathbf{A}_{\Delta\Gamma}$ is not accesible

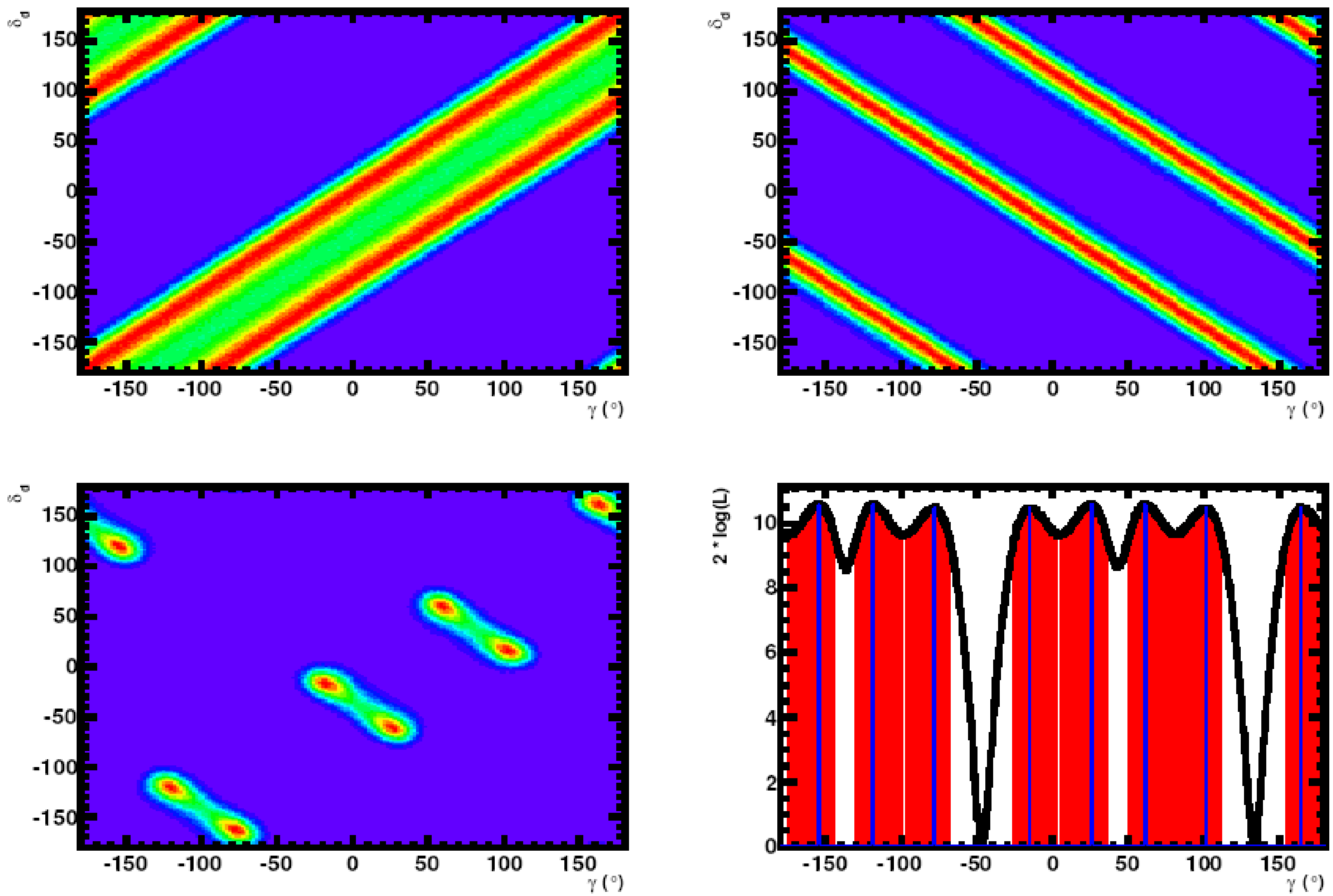
   - **The eight-fold ambiguity on γ remains. Also, the precisions vary with the value of the strong phases.**

Both will be resolved by using U-spin symmetry!

Dπ ambig, factorization limit



Dπ ambig, large strong phase



Using U–spin

U–spin is a subgroup of SU(3)

- QCD effects same if decays are related by interchange of **d** and **s** quarks

$$x_s = R_b a_s$$

$$x_d = -\left(\frac{\lambda^2 R_b}{1-\lambda^2}\right) a_d$$

QCD effects are parameterized by strong amplitudes ($\mathbf{a_{s,d}}$) and phases ($\delta_{\mathbf{s,d}}$)

$$S = \frac{2x_q \sin\left(\delta_q + \phi_q - \gamma\right)}{\left(x_q^2 + 1\right)}$$

Three different assumptions: equal phases and amplitudes, equal phases only, equal amplitudes only

Major advantage : no need to resolve $\mathbf{x_d}$

Ref: Fleischer, hep-ph/0304027

Using U–spin

Can make a "minimal" U-spin assumption

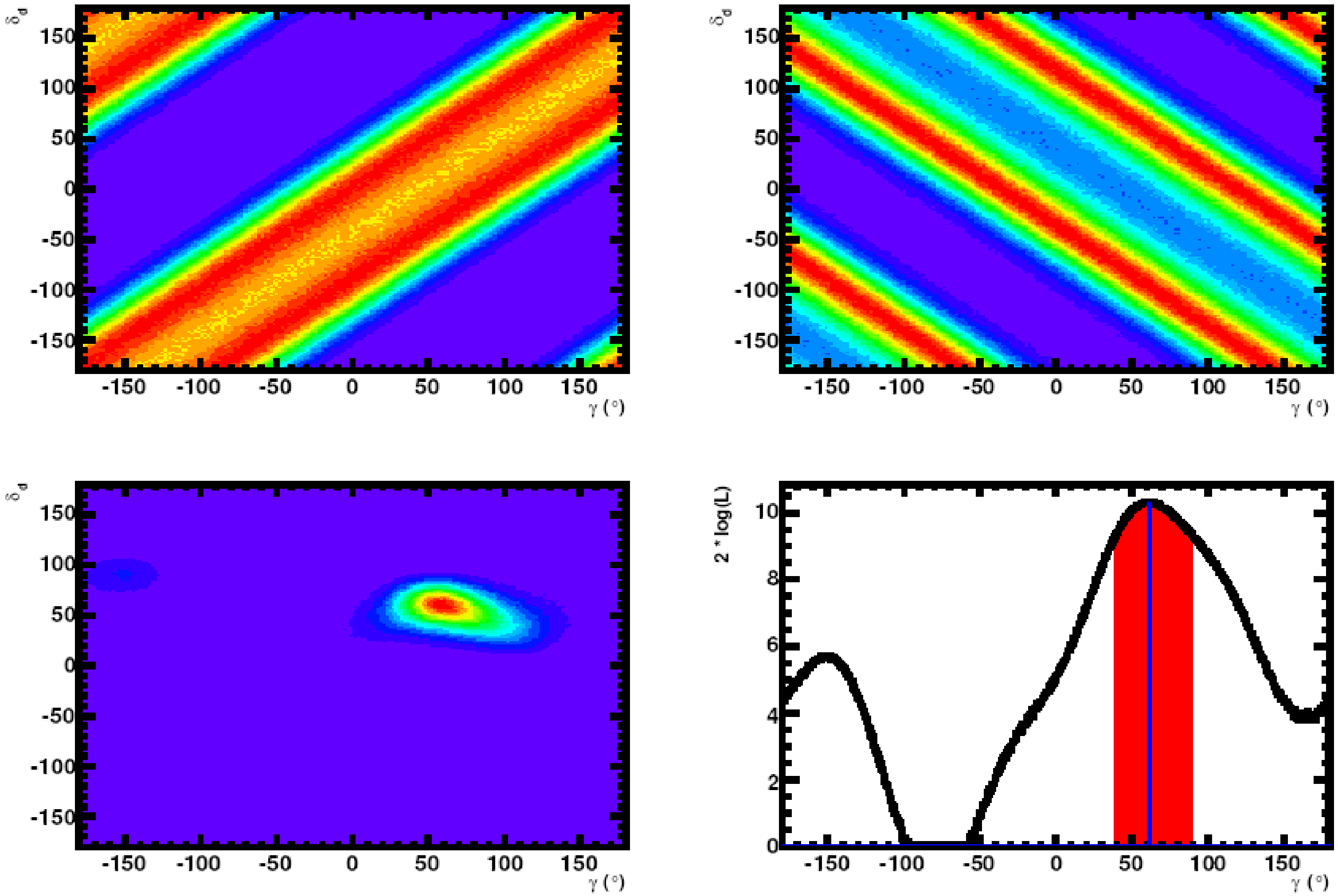
Strong phase in $B \rightarrow D\pi$ is the same as in $B_s \rightarrow D_s K$

Introduce this as a Gaussian constraint in the contour plots to resolve the ambiguities

- Assume strong phase known to 20° (theoretical and experimental error) after 1 year
- And 10° after 5 years

In this case, still need external kowledge of x_d

Using U-spin, large strong phase



More sophisticated U-spin

Introduce new "orthogonal" CP-observables

$$\langle S_q \rangle_+ = \frac{S_q + \bar{S}_q}{2} = \frac{2x_q \cos\delta_q}{1+x_q^2} \sin(\varphi_q + \gamma)$$

$$\langle S_q \rangle_- = \frac{S_q - \bar{S}_q}{2} = \frac{2x_q \sin\delta_q}{1+x_q^2} \cos(\varphi_q + \gamma)$$

Will now use B_s➔D_sK and B➔Dπ information at the same time to get a combined constraint on γ

Strong U-spin assumtion

Uses the relations

(1) $$\left[\frac{a_s \cos\delta_s}{a_d \cos\delta_d}\right] R = -\left[\frac{\sin(\phi_d+\gamma)}{\sin(\phi_s+\gamma)}\right]\left[\frac{\langle S_s\rangle_+}{\langle S_d\rangle_+}\right]$$

(2) $$\left[\frac{a_s \sin\delta_s}{a_d \sin\delta_d}\right] R = -\left[\frac{\cos(\phi_d+\gamma)}{\cos(\phi_s+\gamma)}\right]\left[\frac{\langle S_s\rangle_-}{\langle S_d\rangle_-}\right]$$

to extract γ under the assumptions $\delta_d=\delta_s$ and $\mathbf{a_d=a_s}$,

The parameter **R** can be determined from $B_s \rightarrow D_s K$ ➔ $$R = \left(\frac{1-\lambda^2}{\lambda^2}\right)\left[\frac{1+x_d^2}{1+x_s^2}\right]$$

- $\mathbf{x_d}$ is a negligable second order correction.

Phase U–spin assumtion

Uses the relation

$$\left[\frac{\tan(\phi_d+\gamma)}{\tan(\phi_s+\gamma)}\right]=\left[\frac{\tan\delta_s}{\tan\delta_d}\right]\left[\frac{\langle S_s\rangle_-}{\langle S_s\rangle_+}\right]\left[\frac{\langle S_d\rangle_+}{\langle S_d\rangle_-}\right]$$

to extract γ under the assumption **$\delta_d=\delta_s$**. It does not require any assumption about the value of **a_d** or **a_s.**

Amplitude U-spin assumtion

Uses the relation

$$\left(\frac{a_s}{a_d}\right)R = \sigma\left|\frac{\sin(2\phi_d + 2\gamma)}{\sin(2\phi_s + 2\gamma)}\right|\sqrt{\frac{\langle S_s\rangle_+^2 \cos^2(\phi_s+\gamma) + \langle S_s\rangle_-^2 \sin^2(\phi_s+\gamma)}{\langle S_d\rangle_+^2 \cos^2(\phi_d+\gamma) + \langle S_d\rangle_-^2 \sin^2(\phi_d+\gamma)}}$$

to extract γ under the assumption **$a_d = a_s$**. It does not require any assumption about the value of δ_d or δ_s, apart from an assumption about their relative signs

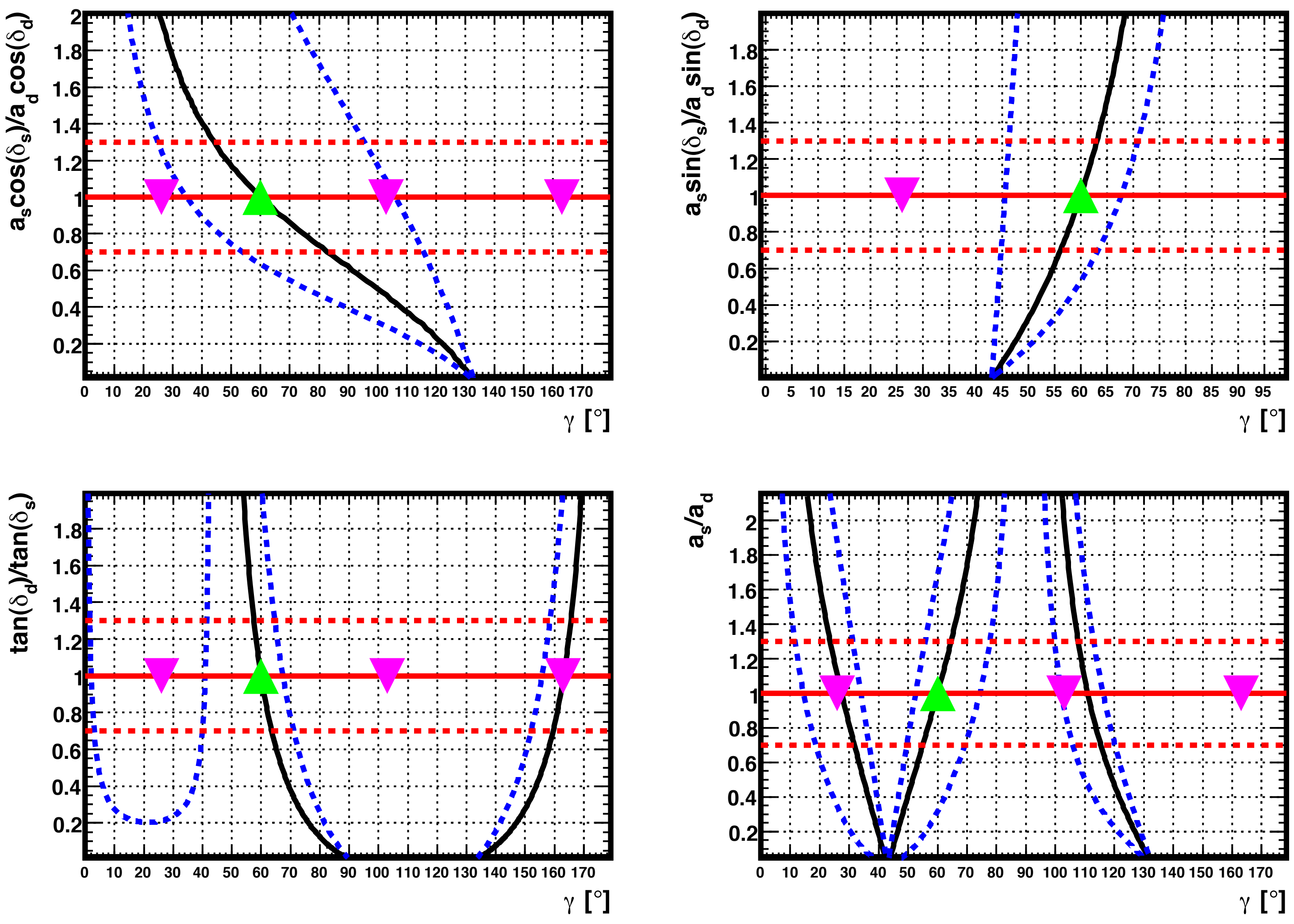
if $\cos(\delta_d)$ has the same sign as $\cos(\delta_s)$,

$$\sigma = -\mathrm{sgn}\left[\langle S_s\rangle_+ \langle S_d\rangle_+ \sin(\phi_d+\gamma)\sin(\phi_s+\gamma)\right]$$

if $\sin(\delta_d)$ has the same sign as $\sin(\delta_s)$,

$$\sigma = -\mathrm{sgn}\left[\langle S_s\rangle_- \langle S_d\rangle_- \cos(\phi_d+\gamma)\cos(\phi_s+\gamma)\right]$$

Example U-spin constraints



D_sK_1

With the substitution: $A \to A(\mathcal{D}),\ \lambda \to \lambda(\mathcal{D}),\ \delta \to \delta(\mathcal{D})$.

$$\Gamma(B_s^0 \to D_S^- K^+ \pi^- \pi^+) = \int \frac{|A(\mathcal{D})|^2}{2} e^{-t/\tau} [(1+|\lambda(\mathcal{D})|^2)\cosh(\Delta\Gamma_s t/2) + (1-|\lambda(\mathcal{D})|^2)\cos(\Delta m_s t)$$
$$-2|\lambda(\mathcal{D})|\cos(\delta(\mathcal{D})+(\gamma+\phi_s))\sinh(\Delta\Gamma_s t/2) - 2|\lambda(\mathcal{D})|\sin(\delta(\mathcal{D})+(\gamma+\phi_s))\sin(\Delta m_s t)] d\mathcal{D}$$

After integration over the Dalitz plot, we get :

$$\Gamma(B_s^0 \to D_S^- K^+ \pi^- \pi^+) = \frac{|A_{eff}|^2}{2} e^{-t/\tau} [(1+|\lambda_{eff}|^2)\cosh(\Delta\Gamma_s t/2) + (1-|\lambda_{eff}|^2)\cos(\Delta m_s t)$$
$$-2|\lambda'|\cos(\delta_{eff}+(\gamma+\phi_s))\sinh(\Delta\Gamma_s t/2) - 2|\lambda'|\sin(\delta_{eff}+(\gamma+\phi_s))\sin(\Delta m_s t)]$$

where:

$$\left|A_{eff}\right|^2 = \int \left|A_f(\mathcal{D})\right|^2 d\mathcal{D}$$

$$\left|\lambda_{eff}(\mathcal{D})\right|^2 = \frac{\int \left|\lambda(\mathcal{D})\right|^2 \left|A_f(\mathcal{D})\right|^2 d\mathcal{D}}{\int \left|A_f(\mathcal{D})\right|^2 d\mathcal{D}}$$

$$\cos\delta_{eff} = \frac{a}{c}, \quad \sin\delta_{eff} = \frac{b}{c}, \quad \lambda' = \frac{c}{\left|A_{eff}\right|^2}$$

where:

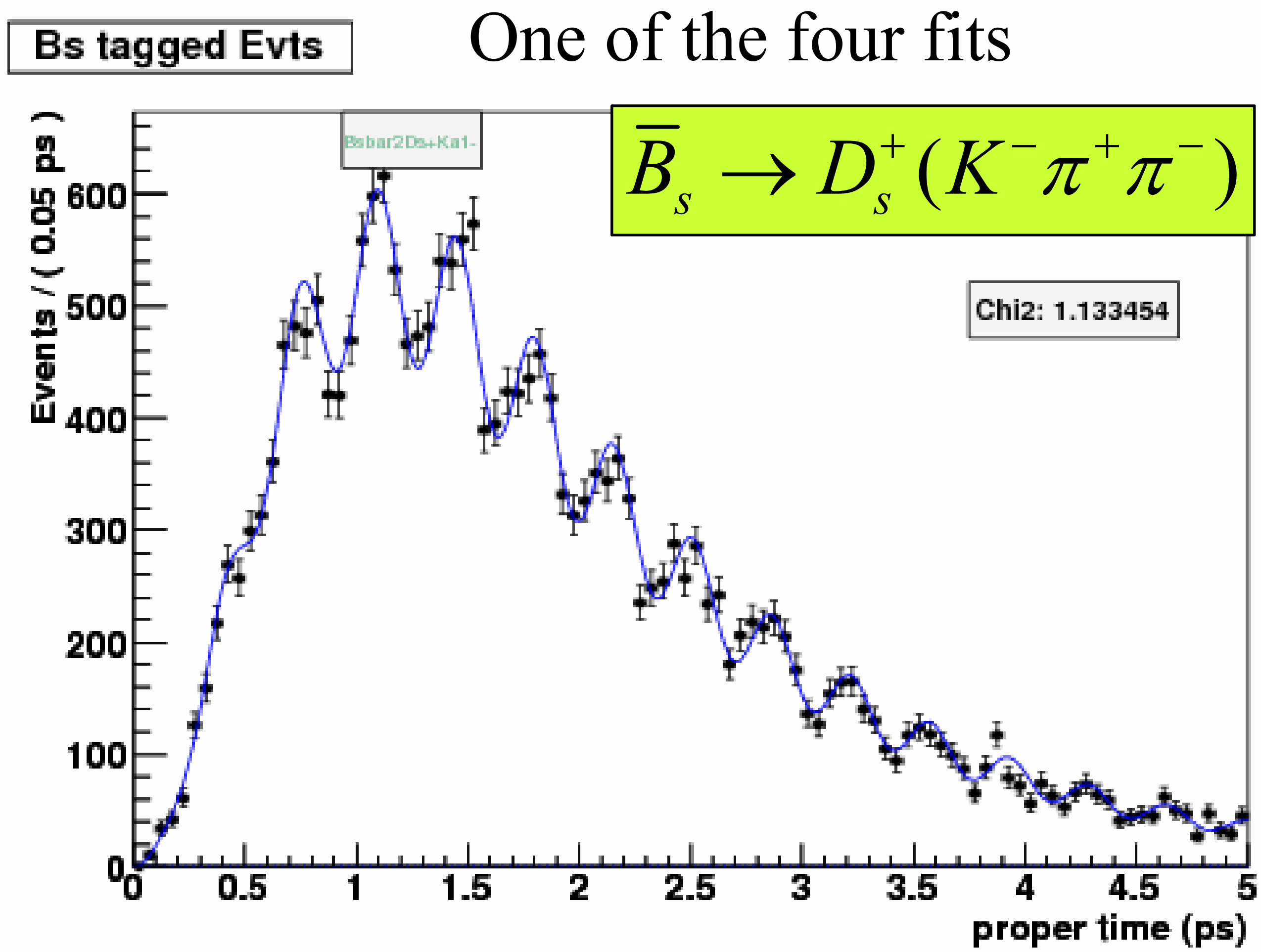
$$a \equiv \int \left|A_f(\mathcal{D})\right|^2 \left|\lambda(\mathcal{D})\right| \cos\delta(\mathcal{D}) d\mathcal{D}$$

$$b \equiv \int \left|A_f(\mathcal{D})\right|^2 \left|\lambda(\mathcal{D})\right| \sin\delta(\mathcal{D}) d\mathcal{D}$$

$$c \equiv \sqrt{a^2+b^2}$$

"Penalty": One more free parameter (now 4) in the fit to the 4 TD rates.

D_sK_1


Bs tagged Evts
One of the four fits
Bsbar2Ds+Ka1-
$\bar{B}_s \to D_s^+(K^-\pi^+\pi^-)$
Chi2: 1.133454
Events / (0.05 ps)
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
proper time (ps)