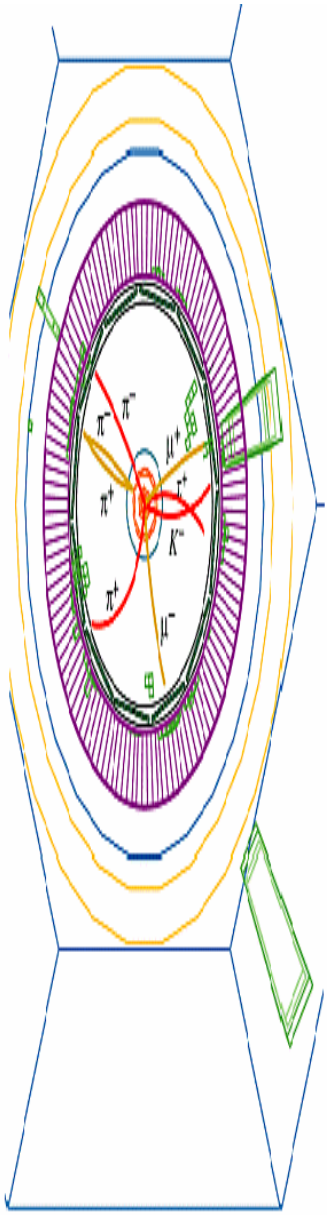
CHARM MIXING and lifetimes

at BABAR



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Search for lifetime differences in D^0 decays

New BaBar limits on D^0 mixing parameter y:

- **method and event selection**
- **lifetime extraction, systematics and results**

INTRODUCTION: x, y

Mass eigenstates: $|D^0_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$ ($|D^0\rangle, |\overline{D}^0\rangle$ flavour eigenstates)

→ **masses: M_1, M_2 & widths: Γ_1, Γ_2**

MIXING PARAMETERS: $x \equiv \frac{\Delta M}{\Gamma}, y \equiv \frac{\Delta\Gamma}{2\Gamma}$

- $\Delta\Gamma = \Gamma_1 - \Gamma_2$
- $\Gamma = (\Gamma_1 + \Gamma_2)/2$
- $\Delta M = M_1 - M_2$

In the SM : $|x|, |y| \leq 10^{-3}$ …**but** …

- New Physics can significantly enhance **x**
- FSI and SU(3) breaking can enhance **y**

Current sensitivy @ level of 10^{-2} (few 10^{-3} with 0.5ab^{-1} @ Belle & BaBar)

3 types of experiments are sensitive to a **combination of x & y** :

- **Wrong-sign searches :**
  - HADRONIC
  - Semileptonic
- **LIFETIME DIFFERENCE searches**

Lifetime difference search strategy

Rate asymmetry for neutral D decays into CP^+(even) and CP^- (odd) eigenstates :

$$y_{CP} \equiv \frac{\hat{\Gamma}(CP^+) - \hat{\Gamma}(CP^-)}{\hat{\Gamma}(CP^+) + \hat{\Gamma}(CP^-)} = \frac{\hat{\Gamma}(CP^+)}{\bar{\hat{\Gamma}}(CP^{\pm}\ \text{equal mix})} - 1 = \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+)} - 1$$

K^-K^+ ($\pi^-\pi^+$) is CP^+ eigenstate & $K^-\pi^+$ assumed an equal mixture of CP^+, CP^-

Extracting the rates by fitting to pure exp. the time-dependent rates:

$$y_{CP} \approx y\cos\varphi - \frac{1}{2}(|q/p|^2 - 1)\, x \sin\varphi$$

NO ~~CP~~ $\Rightarrow$ $y_{CP} \approx y$

$\sin\varphi \neq 0 \Rightarrow$ ~~CP~~ in interference mixing-decay

$|q/p| \neq 1 \Rightarrow$ ~~CP~~ in mixing

$$|D^0_{1,2}\rangle = \frac{1}{\sqrt{2}}\left[\, |D^0\rangle \pm |\bar{D}^0\rangle \,\right]$$

are $CP^{\pm}$ eigenstates

D^0 proper time reconstruction method

$e^+e^- \to c\bar{c} \to D^{*\pm}X$; $D^{*+} \to D^0\pi_s^+$; $D^0 \to K^-\pi^+, K^-K^+, \pi^-\pi^+$ **Reconstructed DECAY CHAIN**

TAG

3 independent samples

D* **is primary vertex : use BS – constraint**

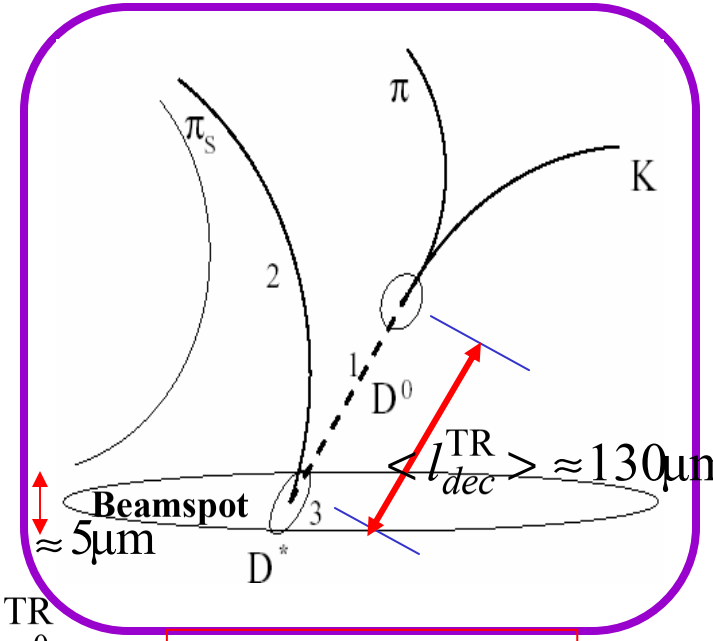
1) allows flavor-tagging
2) reduces BKG

$\delta m = m(h^+h^-\pi_s) - m(h^+h^-)$

Refitting technique with BS – constraint

1) $\vec{p}_{D^0}$ points back to BS to locate D^* decay point
2) slow pion π_s refitted to this point
3) D^* built vertexing the D^0 and the refitted π_s

improves δm resolution



BS: $\sigma_y \approx 5\mu m < \sigma_x \approx 120\mu m < \sigma_z \approx 9000\mu$ m

τ_D in xy

D^0 proper time: $t = m_{D^0} \dfrac{l_{dec}^{TR}}{cp_{D^0}^{TR}}$, $l_{dec}^{TR} = (\vec{d}_{D^0}^{TR} - \vec{d}_{D^*}^{TR}) \cdot \hat{p}_{D^0}^{TR}$

DECAY LENGTH

resolution $\approx$ 65μm

D^0 candidates selection criteria

This analysis uses 57.8 fb^{-1} (2000+2001 data) & selects events from $c\bar{c}$ continuum

It uses also simulated (G4) data : $\approx 30\, fb^{-1}$ generic $q\bar{q}$ & *signal* samples

Tracking [DCH+SVT], **vertexing** [SVT], **PID** [DIRC+(DCH+SVT)] are crucial

- **GOOD QUALITY TRACKS & VERTEXING RESOLUTION** (at least 6 SVT–hits for π_s)
- **GOOD VERTEX FIT** for **BOTH** D^0 and D^* vertices : $P(\chi^2_{FIT}) > 1\%$
- **REJECTION of D^* from B decays**: $p^{\Upsilon(4S)}_{D^0} \geq 2.5\ GeV/c$ **$c\bar{c}$ ONLY**
- **PARTICLE IDENTIFICATION applied on BOTH D^0 DAUGHTERS**
  - **K** : ***tight*** likelihood selection (***pion contamination***: <3% for p<3GeV/c)
  - π : likelihood selection **& muon veto**
- **REJECTION of combinatorial BKG due to low *p* pions** : ***helicity*-cut** on $\cos\theta^{D-CMS}_{\pi\text{-}D^0}$
- **δm-cut :** $\pm 2[3] MeV$ window around fit peak for π_s with[out]DCH–hits

Selected D^0 candidates

$\approx 158{,}000$

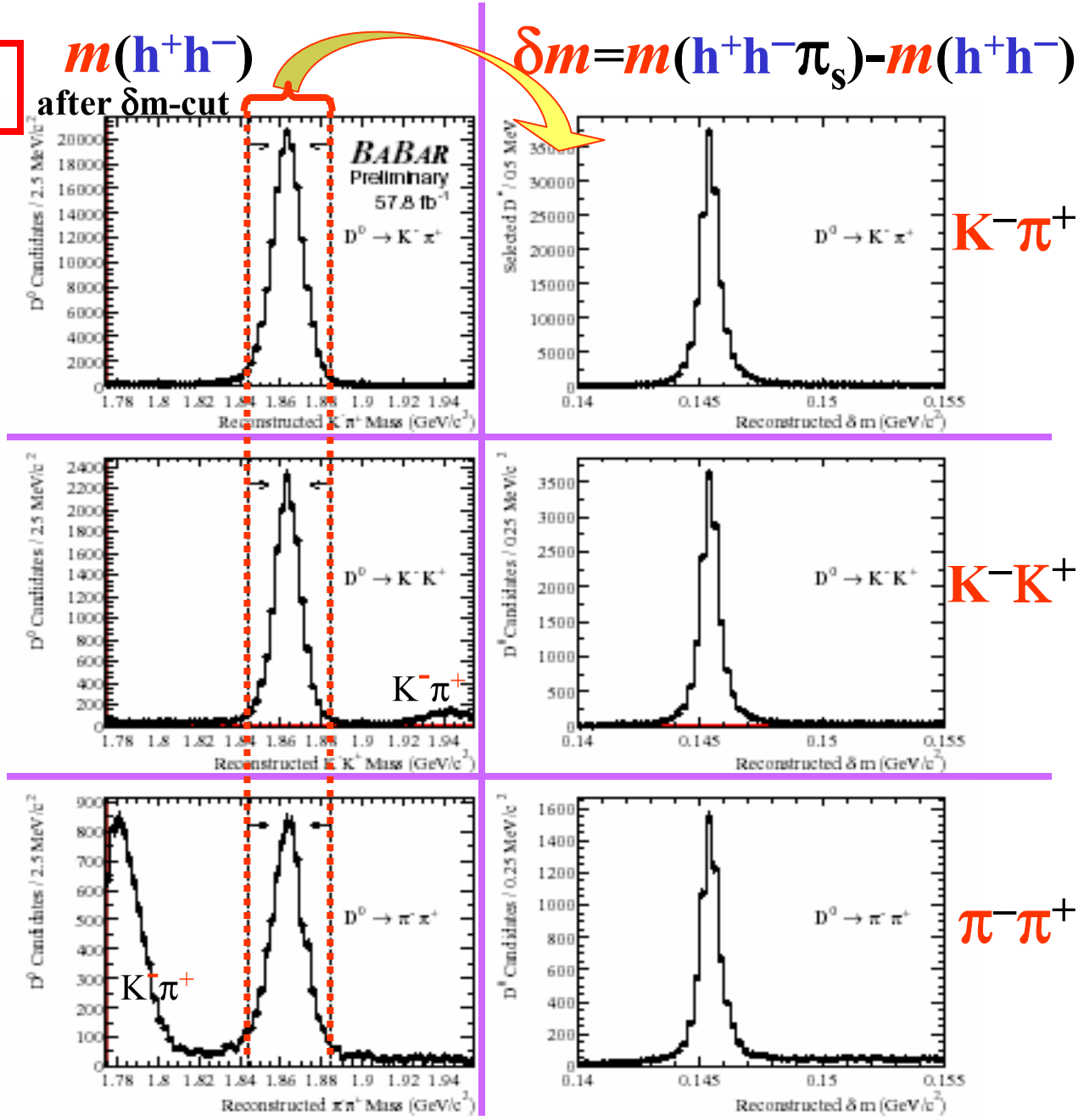
$\frac{S}{S+B} \approx 99.5\%$

$\approx 16{,}500$

$\frac{S}{S+B} \approx 97.1\%$

$\approx 8{,}350$

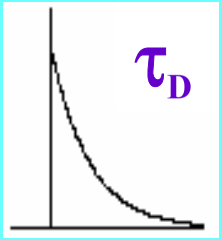
$\frac{S}{S+B} \approx 92.4\%$



Unbinned maximum likelihood fit

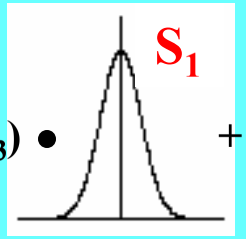
$\mathbf{L} = \Pi_i P_i$ where $P_i(m_i, t, \delta t;$ 11 parameters)=

$P_{sig}(m_i)$ • **SIGNAL**

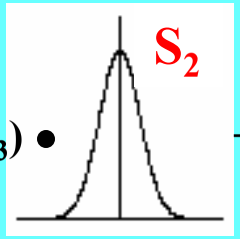


$\otimes$

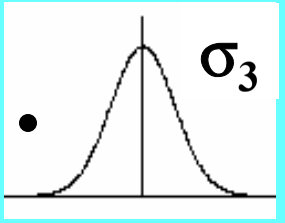
$(1-f_2)(1-f_3)$ •



$+ f_2(1-f_3)$ •



$+ f_3$ •



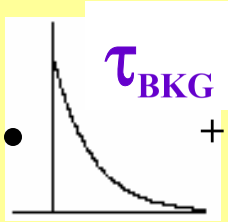
proper-time RESOLUTION

$+$

$+[1-P_{sig}(m_i)]$ •

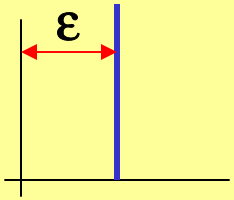
BKG

$(1-f_0)$ •



flying BKG

$+ f_0(1-f_4)$ •



NO-flying BKG

$\otimes$

BUT with ...

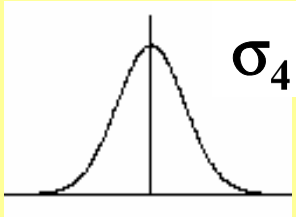
S_{BKG} S_1

S_{BKG} S_2

σ_3

$+$

$+$ $f_0 f_4$ •



for tails

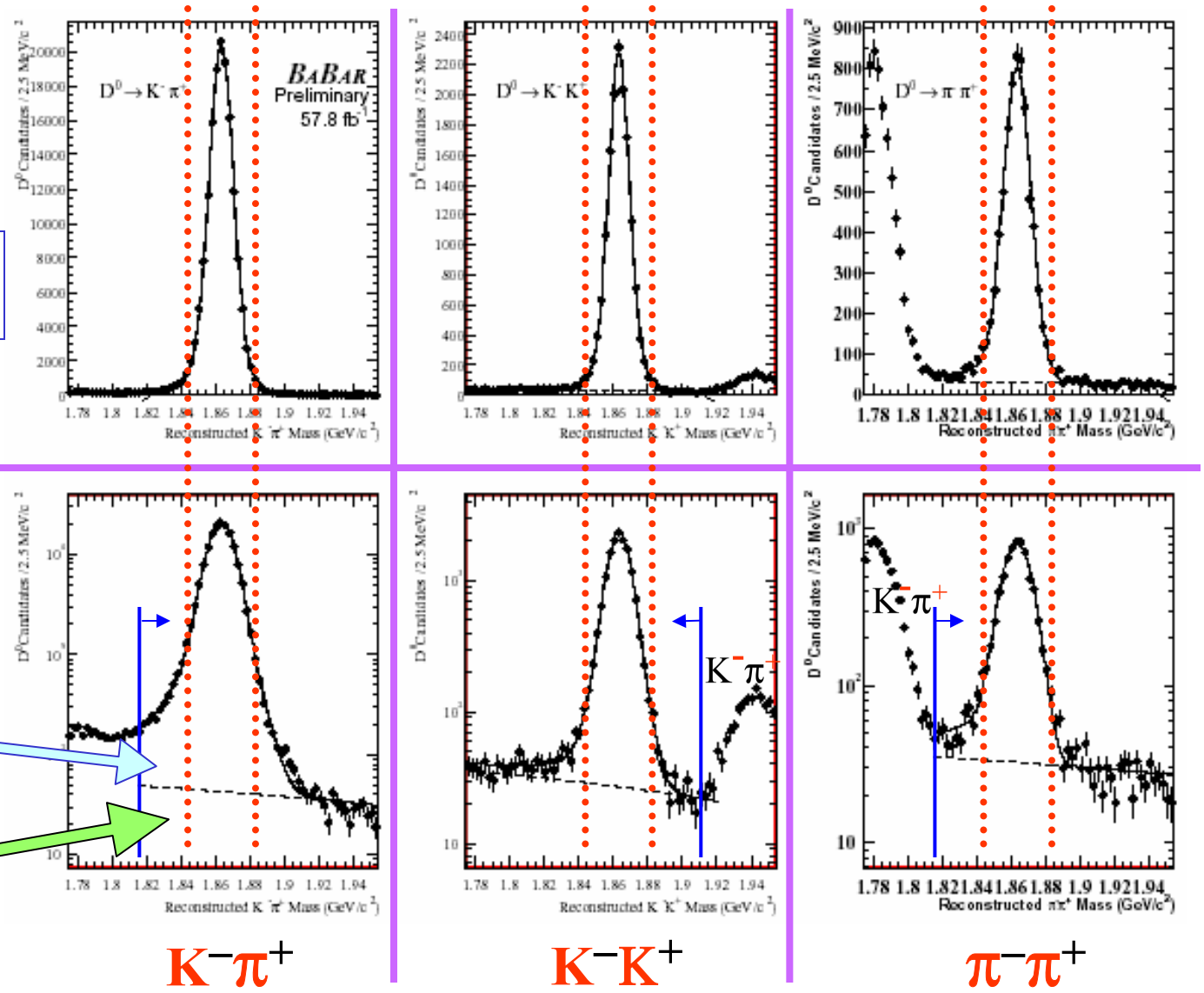
D^0 candidate signal probability in the lifetime fit

"sidebands" candidates as part of likelihood fit

BKG constrained in data

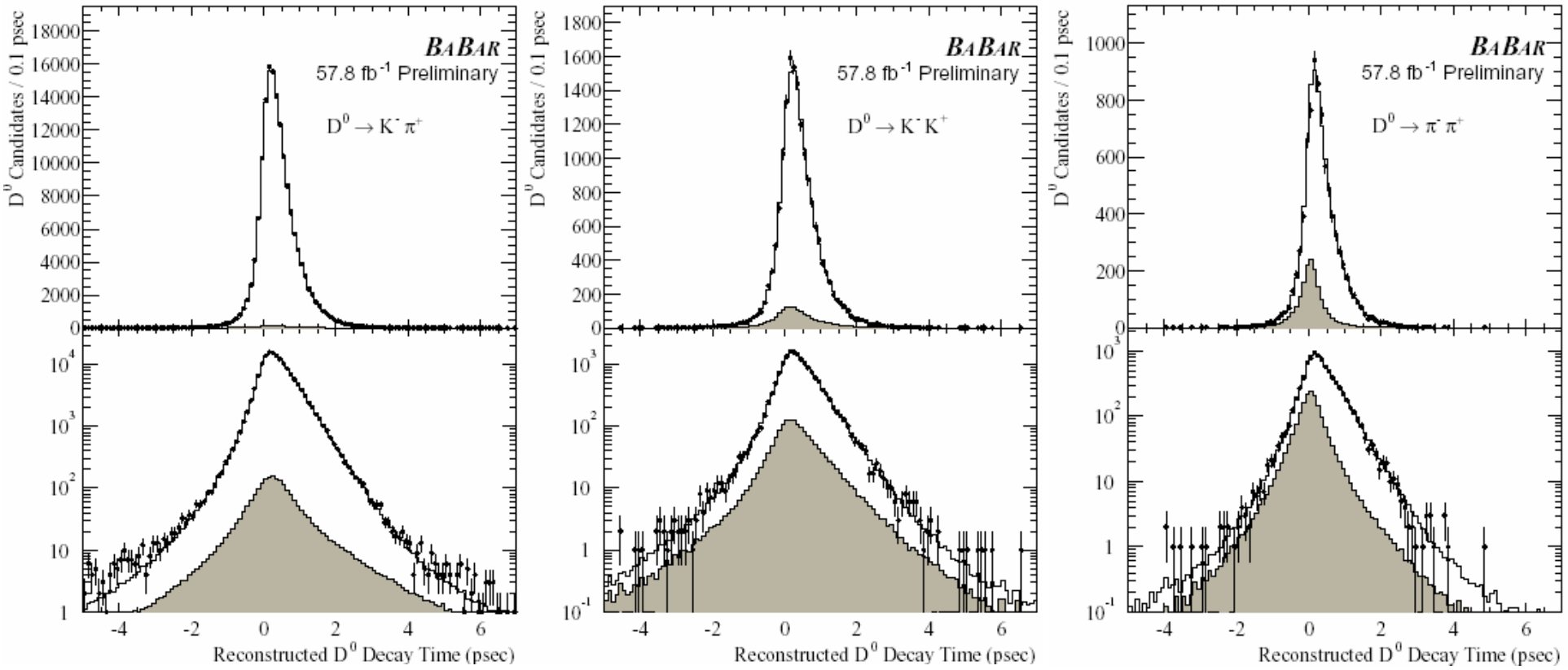
LOW MASS TAIL

Portion assigned to BKG



Proper time distributions and lifetime fit results

$K^-\pi^+$ K^-K^+ $\pi^-\pi^+$



Points : **DATA** |White histogram : **FIT RESULT** |Gray histogram : **BKG fit portion**

Lifetime ratio systematics - I

D^0 lifetime measurement is an HIGH PRECISION measurement
[statistical uncertainty for our data sample is about 1.3*fs* namely *3/1000*]

At this level of precision wide studies of systematics sources (tracking, vertexing, alignment) are needed.

Note: – 1.5μm average bias in vertex position translates in 3*fs* lifetime bias
– 1*MeV* mass shift due to momentum bias means 0.3*fs* lifetime bias

At this stage we do not present an absolute D^0 lifetime value because the overall systematic uncertainty (about 3–4*fs*) can be reduced with further work

We checked, on a limited sub-sample, the full compatibility of the **fit result** with both our HF2001 check $[412 \pm 2(\text{stat.})]\,fs$ and PDG value $[412.6 \pm 2.8]\,fs$

Many systematics effects on lifetime cancel in the lifetime RATIO

Lifetime ratio systematics - II

y systematics uncertainties calculated using large signal MC samples

- Simulated data has been modified by variation reflecting uncertainties in…
  - detector biases
  - event selection criteria
  - size and composition of BKG contribution
  - beamspot position and size

- SVT internal alignment systematic checks done using $e^+e^- \to \gamma\gamma \to 4$ *prongs*
  [zero lifetime control sample]

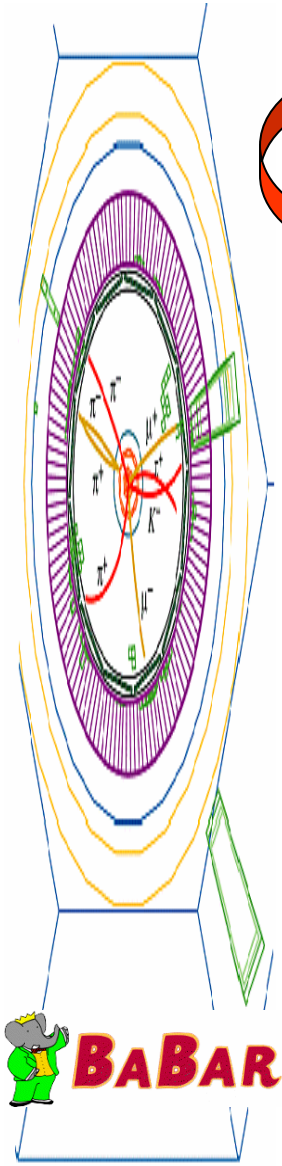
	y Uncertainty (%)	
Systematic Uncertainty	K^-K^+	$\pi^-\pi^+$
Monte Carlo Statistics	$^{+0.4}_{-0.6}$	$^{+0.4}_{-0.9}$
Tracking	0.2	0.9
Particle Identification	0.2	0.4
Background and Fragmentation	0.2	0.6
Alignment and Vertexing	$^{+0.2}_{-0.1}$	$^{+0.3}_{-0.1}$
Quadrature Sum	$^{+0.6}_{-0.7}$	$^{+1.2}_{-1.4}$

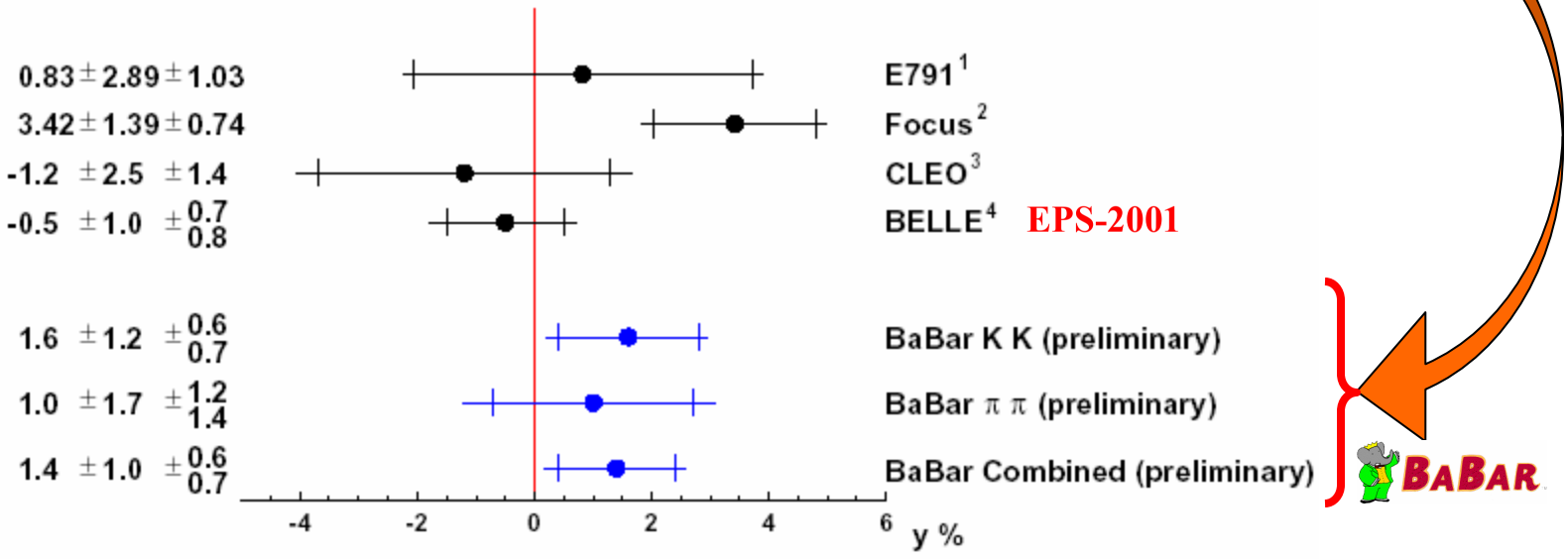
MC estimation shows about null bias within its statistical error which is taken as a further systematic uncertainty

RESULTS: limits on y

$$y = \begin{cases} 1.6 \pm 1.2\,(\text{stat.})^{+0.6}_{-0.7}\,(\text{syst.}) & (D^0 \to K^+K^-) \\ 1.0 \pm 1.7\,(\text{stat.})^{+1.2}_{-1.4}\,(\text{syst.}) & (D^0 \to \pi^+\pi^-) \end{cases}$$

$$y = \left[1.4 \pm 1.0\,(\text{stat.})^{+0.6}_{-0.7}\,(\text{syst.})\right]\%$$ **PRELIMINARY**





CONCLUSIONS AND NEAR TERM PROSPECTS

Our preliminary y measurement is consistent with zero but suggest a positive value not incompatible with FOCUS measurement

- **It is crucial to get a new measurement over LARGER DATA SAMPLES**
- **It is important to get a result from D*–untagged KK sample : the statistical uncertainty is <1% but still working on systematics**

Limits on x, y from hadronic wrong-sign analysis coming soon !

BACKUP TRANSPARENCIES (NOT SHOWN)

Wrong-sign hadronic search strategy

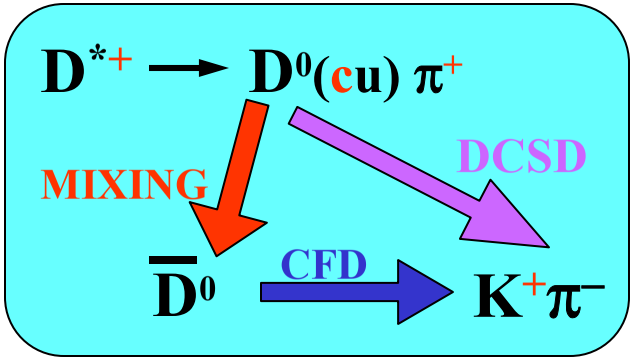
Type of experiment sensitive to $(x\cos\delta + y\sin\delta)\cos\phi$, $(y\cos\delta - x\sin\delta)\sin\phi$, $x^2 + y^2$

x' y'

δ : strong phase diff. between DCSD & CF

Look for deviation from exp in the time evolution of neutral D wrong-sign decay :

$$\Gamma_{D^0(t)\to K^+\pi^-} = \Gamma_{\overline{D}^0(t)\to K^-\pi^+} \approx e^{-t}\left[R_{DCS} + \sqrt{R_{DCS}}\, y' t + \frac{1}{4}(x'^2 + y'^2)\right]$$

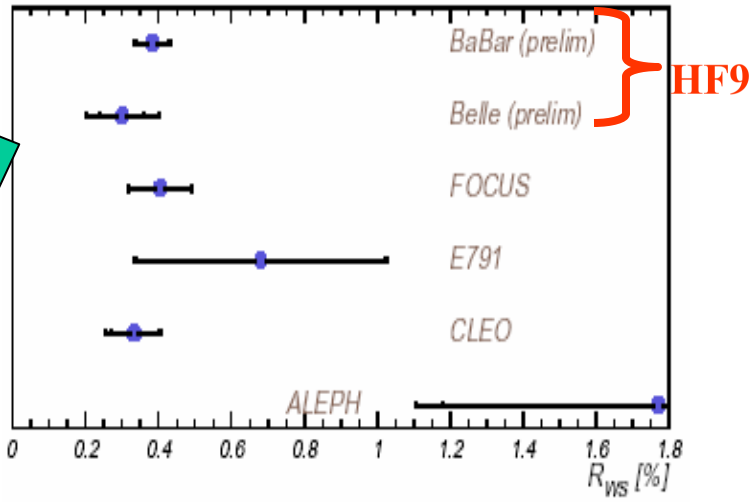


NO CP

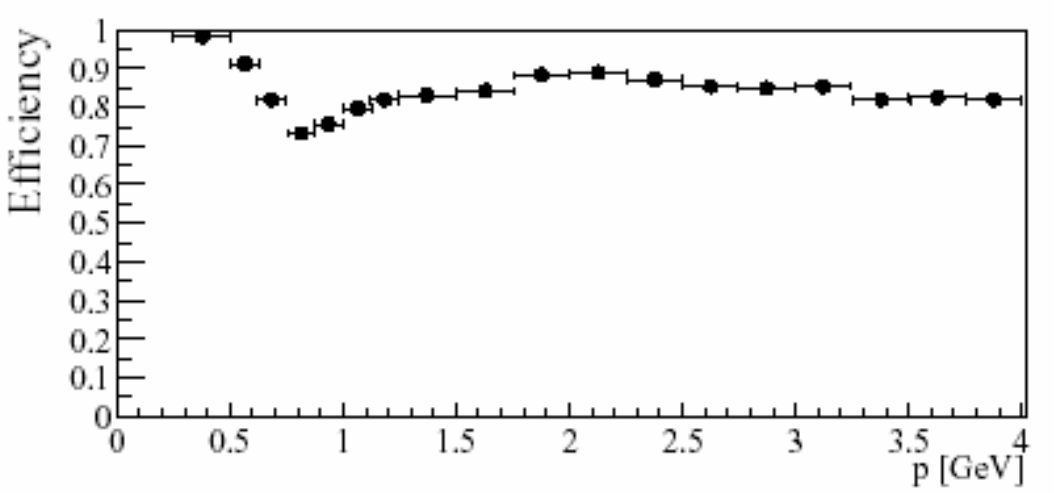
DCSD

INTERFERENCE

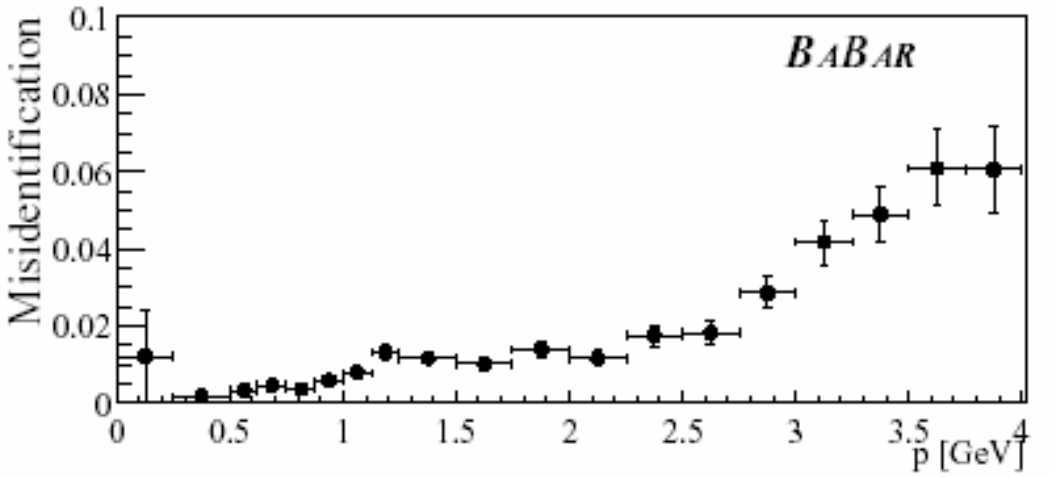
MIXING



Kaon ID performance



$$< \text{Efficiency} > \approx 85\%$$

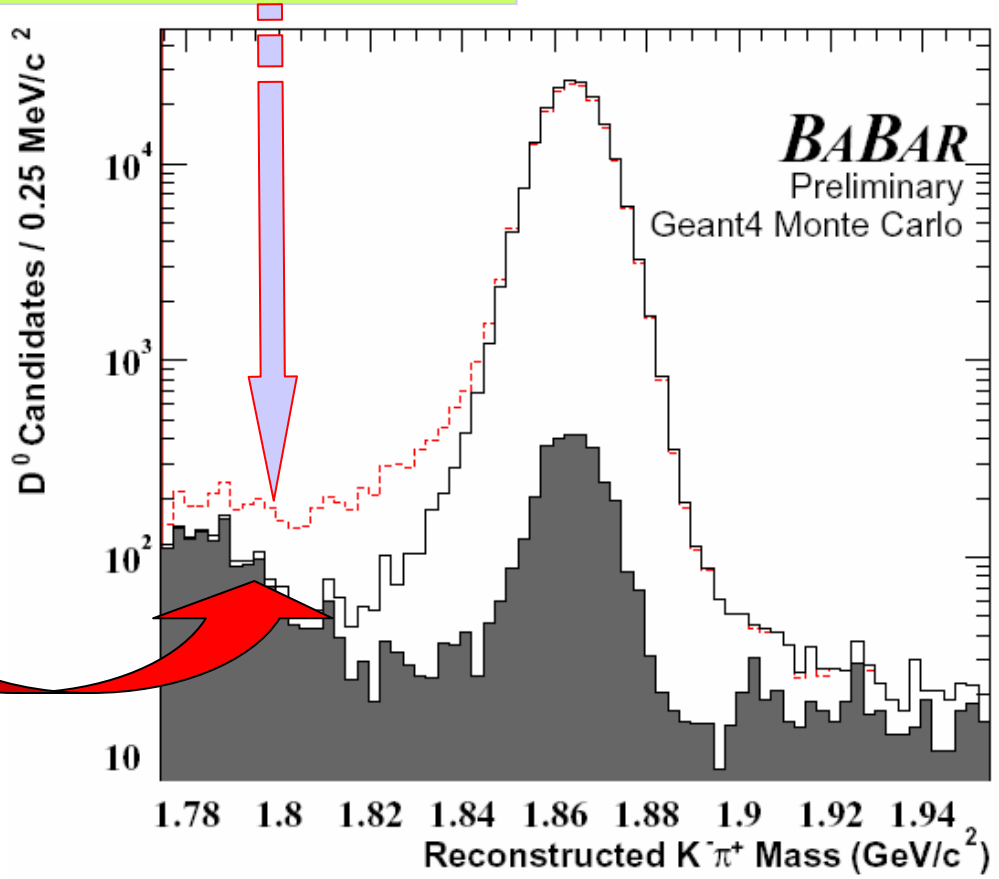


$$< \text{Mis-ID} > \begin{cases} < 2\%, & p < 2.5\,GeV/c \\ < 5\%, & p < 3.5\,GeV/c \end{cases}$$

Low mass tail

MC study: possible explanation is **internal bremsstrahlung**

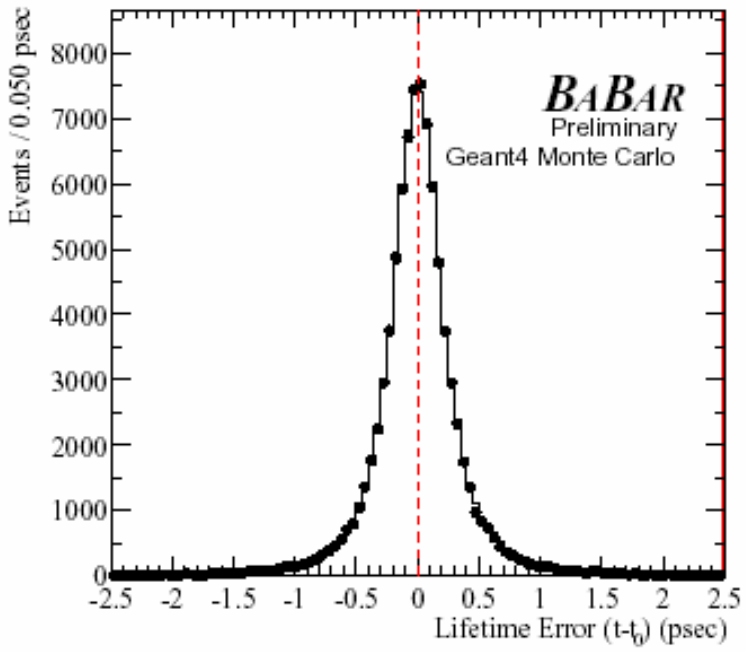
Simulation by randomly selecting 5% of D^0 candidates for which one daughter's momentum is **corrected** by the factor $[1-(E_\gamma/m_D)]$ where energy E_γ is properly randomly generated.

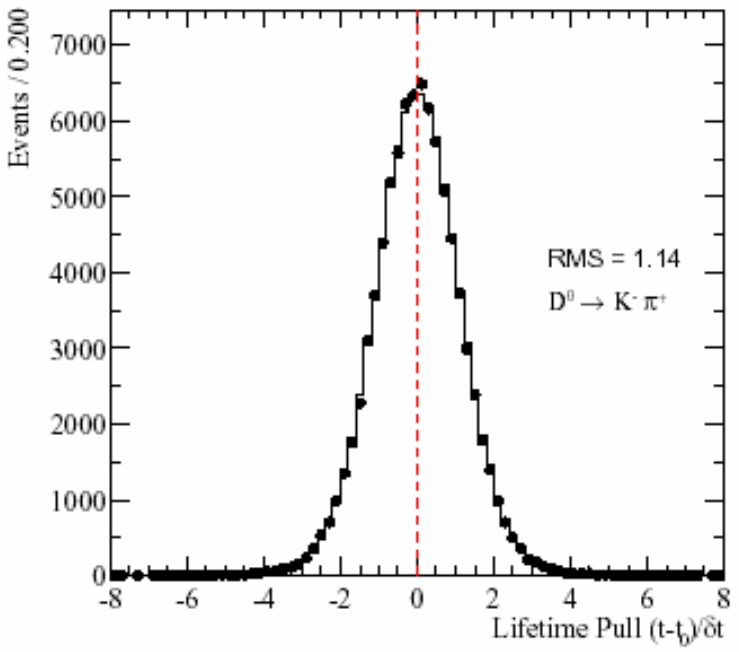


MC check : lifetime pull

MC indicates very little or null bias

The resolution model is found to fit reasonably well to the MC





(measured – true) proper time

(meas. – true) pr. time /pr. time error