Experimental issues for measurements of the time-dependent CPV in $\boldsymbol{b \longrightarrow s\gamma}$ decays

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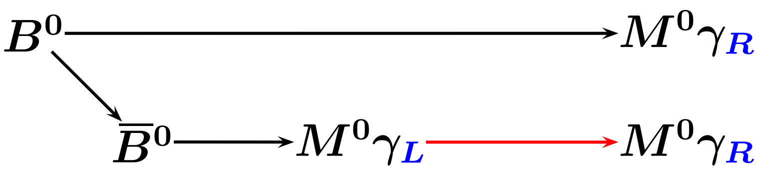
Outline

- motivation for studying TDCPV in $\boldsymbol{b \longrightarrow s\gamma}$
- experimentally accessible modes
- main experimental issues
- expected sensitivity in a super $\boldsymbol{B}$ factory

Motivation

- standard model: photon in $b \longrightarrow q\gamma$ is predominantly left-handed
- Atwood, Gronau, Soni (1997): time-dependent CPV in $B^0 \longrightarrow M^0_{CP}\gamma$ decays is probe for photon polarization



interference suppressed by $\frac{2m_q}{m_b}$

- in the standard model, neglecting final state effects

$\beta_s \equiv \arg\left[-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right] =$ small

$$
\begin{aligned}
S(B^0 \rightarrow K^{*0}(\rightarrow K^0_S\pi^0)\gamma) &= \eta_{CP} \times \sin(2\beta + 2\beta_s) \times 2m_s/m_b \\
S(B^0 \rightarrow \rho^0\gamma) &= \eta_{CP} \times \text{'0'} \times 2m_d/m_b
\end{aligned}
$$

- Atwood, Gershon, Hazumi, Soni (2004):
  value of S independent of resonance structure in $B^0 \longrightarrow P_1P_2\gamma$
  $\longrightarrow$ can extend analysis to inclusive $B^0 \longrightarrow K^0_S\pi^0\gamma$
- Grinstein, Grossman, Ligeti, Pirjol (2004):
  $b \longrightarrow q\gamma g$ contribution not negligible
  - contribution from opposite helicity photon of order 0.1
  - contribution depends on $m_{P_1P_2}$

Which modes do we consider?

The most accessible modes are

mode	$\mathcal{B} \times 10^6$	typical efficiency	typical S/B	Ref.
$B^0 \to K^*(890)^0\gamma \to K^0\pi^0\gamma$	13.4	0.055	1.5	[1,2]
$B^0 \to K_2^*(1430)^0\gamma \to K^0\pi^0\gamma$	2.1	0.05	0.5	
other $B^0 \to K^0\pi^0\gamma$	$0 - 4?$	0.05	$0.5?$	
$B^0 \to K^0\eta\gamma$	9 ± 3	$0.01?$	0.8	[3]
$B^0 \to K^0\eta'\gamma$	$\sim 10?$	$0.01?$	$0.5?$	
$B^0 \to K^0\phi\gamma$	~ 3	0.013	3	[4]
$B^0 \to \rho^0\gamma$	~ 1	0.15	$0.2?$	[5,6]
$B^0 \to \omega\gamma$	$\sim 1?$	0.09	$0.3?$	[5,6]

[1] Belle hep-ex/0503008, [2] Babar hep-ex/0405082, [3] Belle hep-ex/0411065, [4] Belle hep-ex/0309006,
[5] Babar hep-ex/0408034, [6] Belle hep-ex/0408137

Note:

- not all these modes have been seen yet
- efficiencies and S/B not necessarily optimal for CPV measurement

What are the experimental issues?

- small branching fractions
  $\longrightarrow$ need large data samples

- large backgrounds
  - physics background: continuum, other $B \longrightarrow X\gamma$ decays, other B decays
  - machine background? $\longrightarrow$ not in this talk

- for the most prominent $b \longrightarrow s\gamma$ modes: Δt reconstruction

This talk: concentrate on $B^0 \longrightarrow K_s^0\pi^0\gamma$, since that is where we have experience

What do we know about $B^0 \to K\pi\gamma$?

- branching fraction and direct CP asymmetry well measured in the self-tagging decays (charged kaon)

- contributions to $B^0 \to K\pi\gamma$ from

	$\mathcal{B}$ to $K\pi$	$\mathcal{B} \times 10^6$	$\mathcal{A}$
$K^*(890)^0$	1	40.1 ± 2.0	-0.03 ± 0.03
$K_2^*(1430)^0$	0.5	12.4 ± 2.4	-0.08 ± 0.15
$K^*(1410)^0$	> 0.4	< 130	
N.R. $(1.25 < m_X < 1.6)$		< 2.6	

- note I: results for $K^*(1410)^0$ and N.R. obtained by BELLE on only 29.4/fb

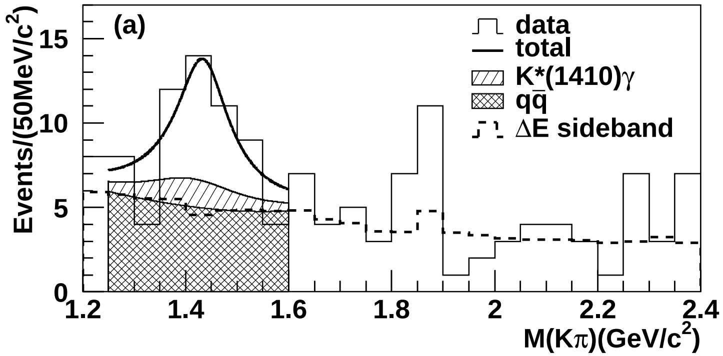
  $\longrightarrow$ more experimental input will help to understand how much statistics there actually is

- note II: signal-to-background-ratio depends on $m_{K\pi}$

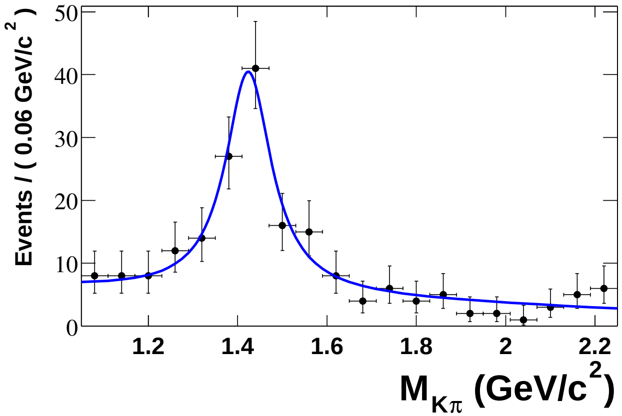
  $\longrightarrow$ this is of some relevance for systematic uncertainties

$K\pi$ invariant mass distribution

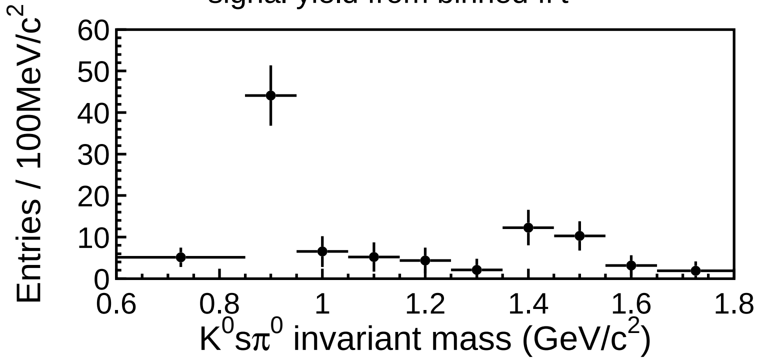
. $K^+\pi^-\gamma$ in 29/fb
BELLE hep-ex/0205025



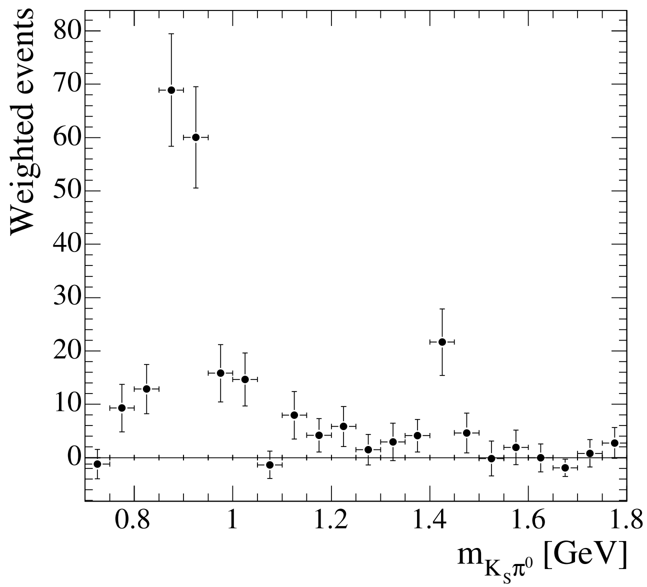
$K^+\pi^-\gamma$ in 81/fb
BABAR hep-ex/0409035
background subtracted



. $K_s^0\pi^0\gamma$ in 253/fb
BELLE hep-ex/0503008
signal yield from binned fi t



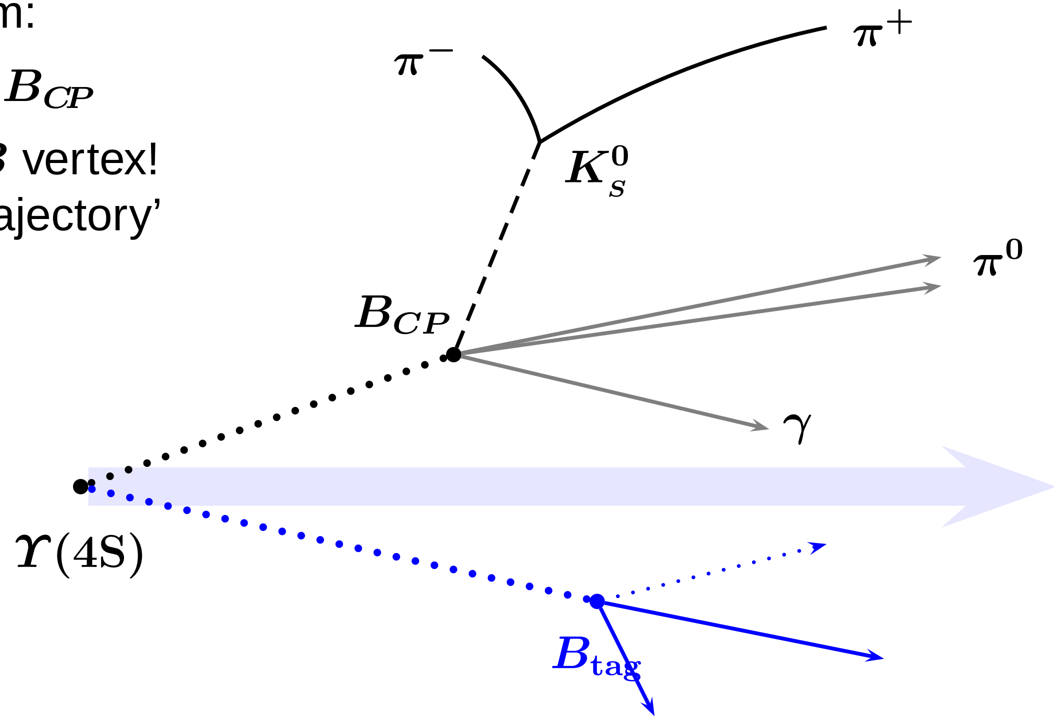
$K_s^0\pi^0\gamma$ in 210/fb
BABAR Moriond 2005
background subtracted



Δt reconstruction for $B^0 \to K_S^0 \pi^0 \gamma$

Challenging vertexing problem:

- Δt requires z position of B_{CP}
- no charged tracks from B vertex!
  $\rightarrow K_S^0$ provides single 'trajectory'



Can we reconstruct the B vertex with only one trajectory?

Δt reconstruction for $B^0 \to K^0_S \pi^0 \gamma$

Challenging vertexing problem:

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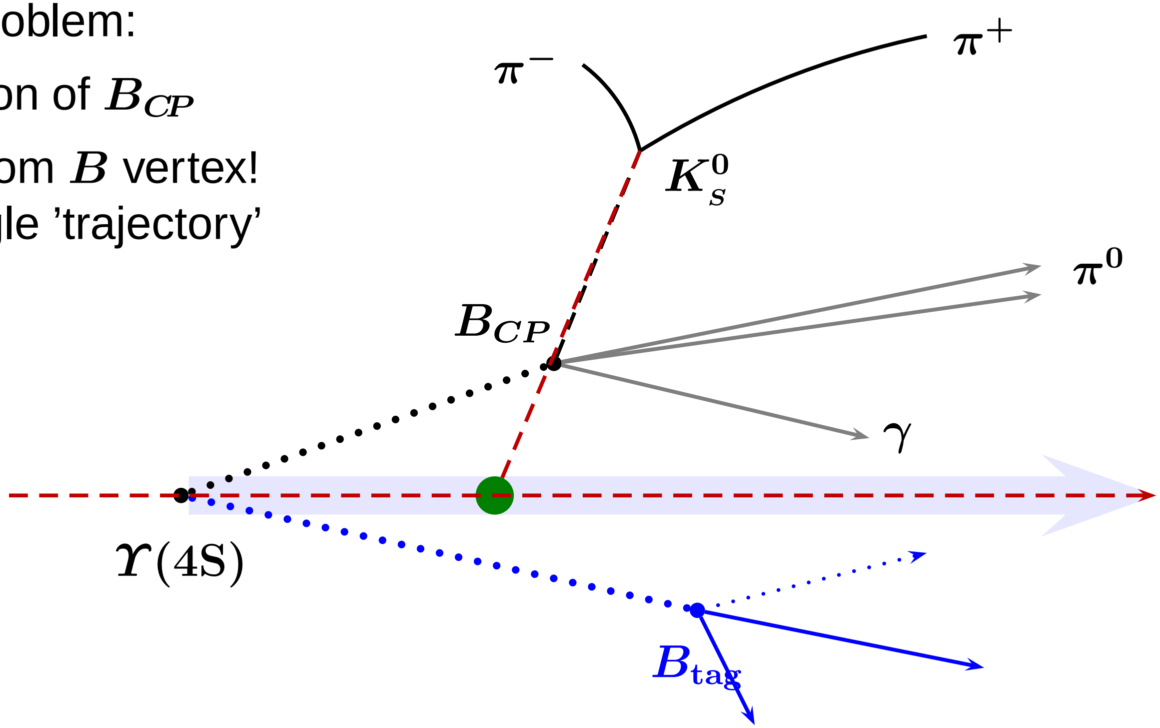
- no charged tracks from B vertex!
  $\rightarrow$ K^0_S provides single 'trajectory'



Solution (*BABAR* 2003)

- exploit small B lifetime + large boost
  $\rightarrow$ small transverse motion
- intersect K^0_S with beam trajectory
  - size and position of interaction region (IR) known
  - increase size to account for transverse motion of B_{CP}
  - intersect K^0_S trajectory and IR in transverse plane
- resolution not much worse than for 'normal' decays, because tagvertex 'dominates' uncertainty

Δt reconstruction for $B^0 \to K_S^0 \pi^0 \gamma$

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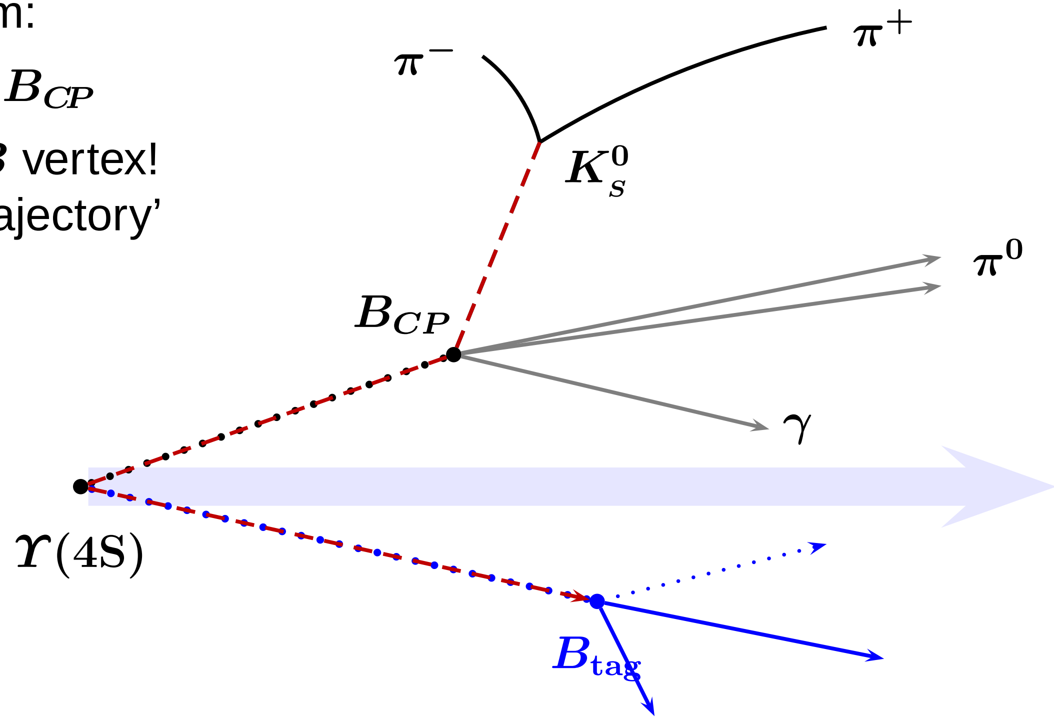
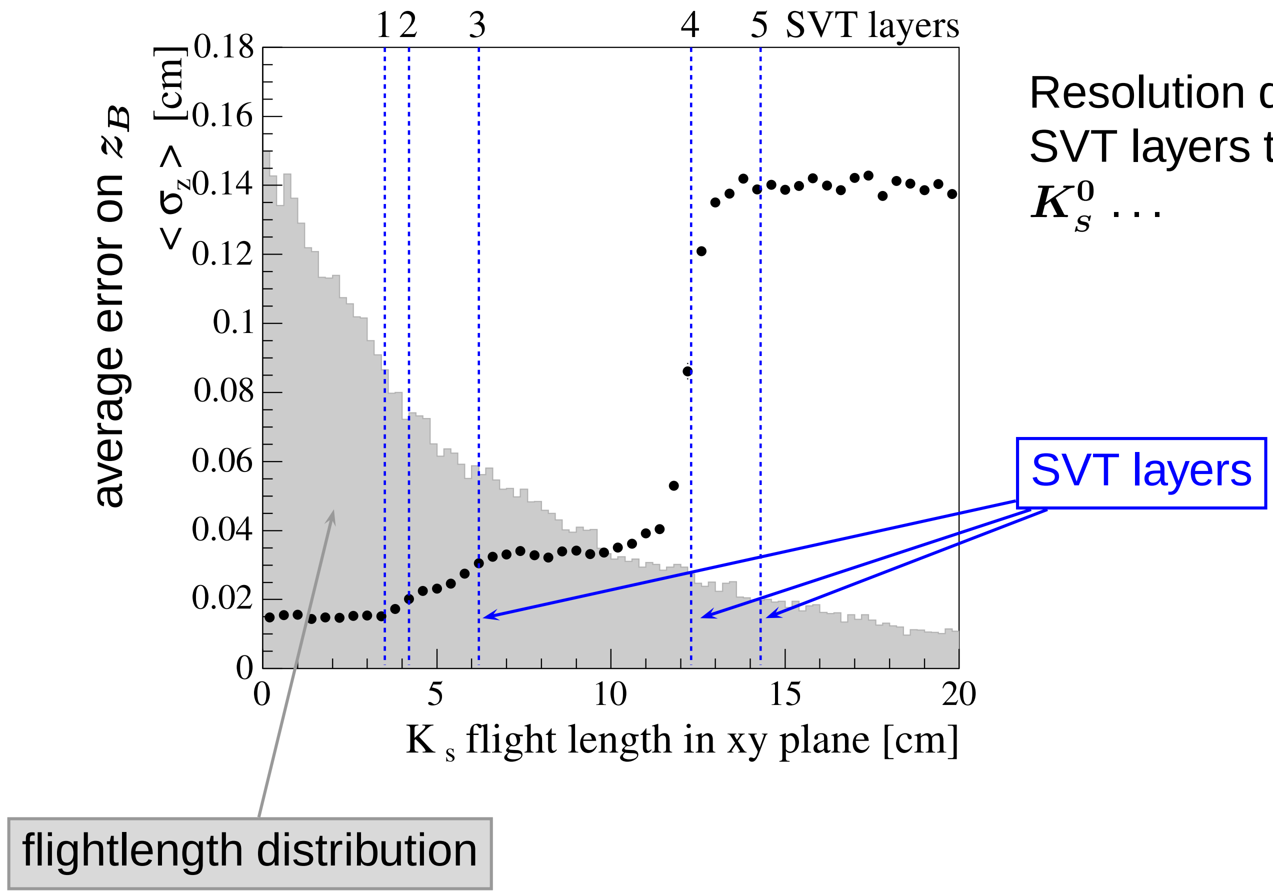


New development in 2004

- 'beam-constraint' on B *decay* vertex does not really account from transverse motion $\rightarrow$ leads to small bias in Δt scale
- used new vertexing algorithm (arxiv:physics/0503091) to apply constraint to B *production* vertex instead
- Δt now extracted from vertex fit to complete $\Upsilon(4S) \to B^0\overline{B}^0$ decay tree
  $\rightarrow$ requires sum-of-B-lifetime constraint to retain accuracy of old method

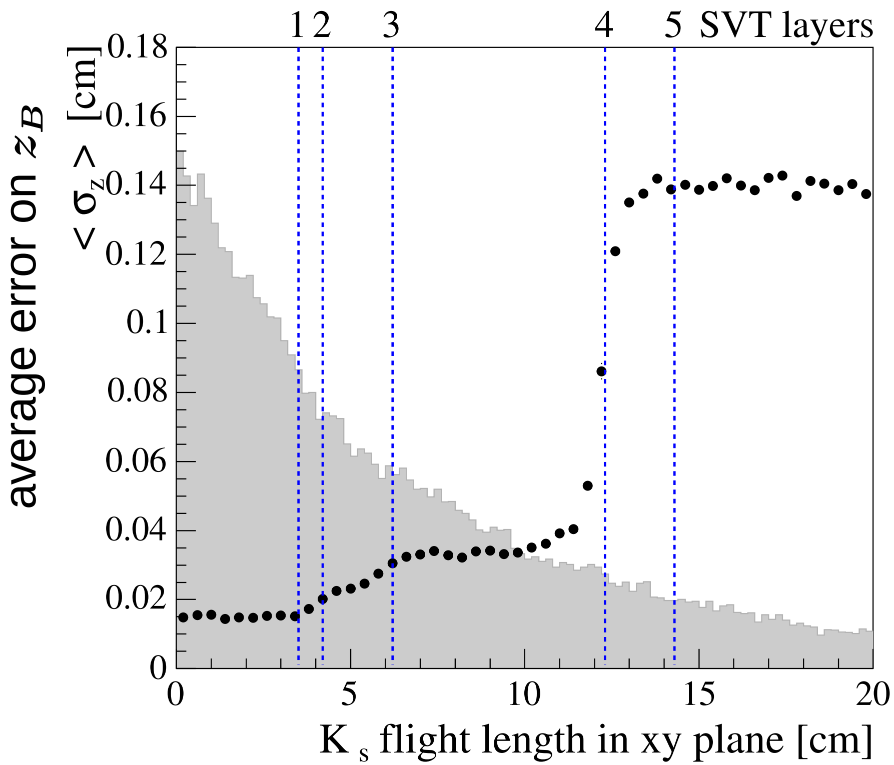
Remaining systematic uncertainty from vertex technique is small

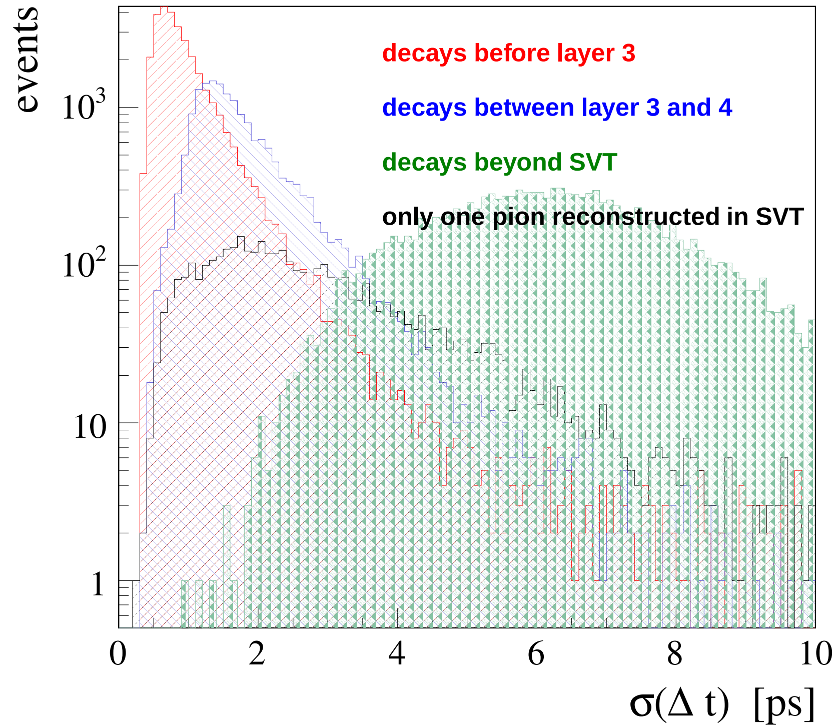
Vertexing inefficiency



Resolution depends on number of SVT layers traversed by pions from K_s^0 . . .

Vertexing inefficiency





Events with $\sigma(\Delta t) > 2.5$ ps are not used for time-dependent fits

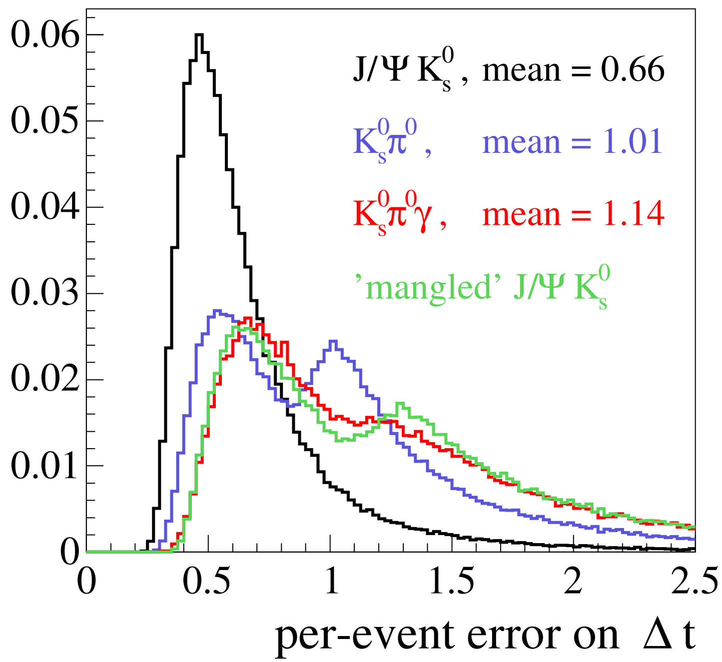
Fraction of usable events depends on K_s^0 momentum spectrum:

$$B^0 \to K_s^0 \pi^0 \quad \epsilon_{\mathrm{vtx}} \approx 0.61$$

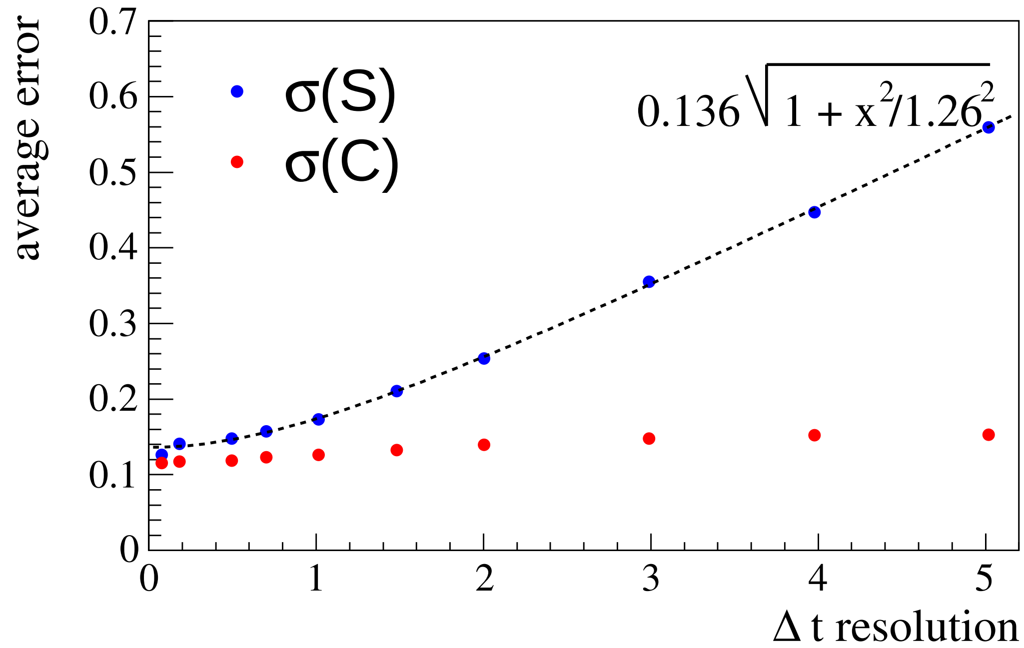
$$B^0 \to K^{*0} \gamma \quad \epsilon_{\mathrm{vtx}} \approx 0.72$$

Δt resolution

$\sigma(\Delta t)$ for different samples



error on S from 100 perfectly tagged events



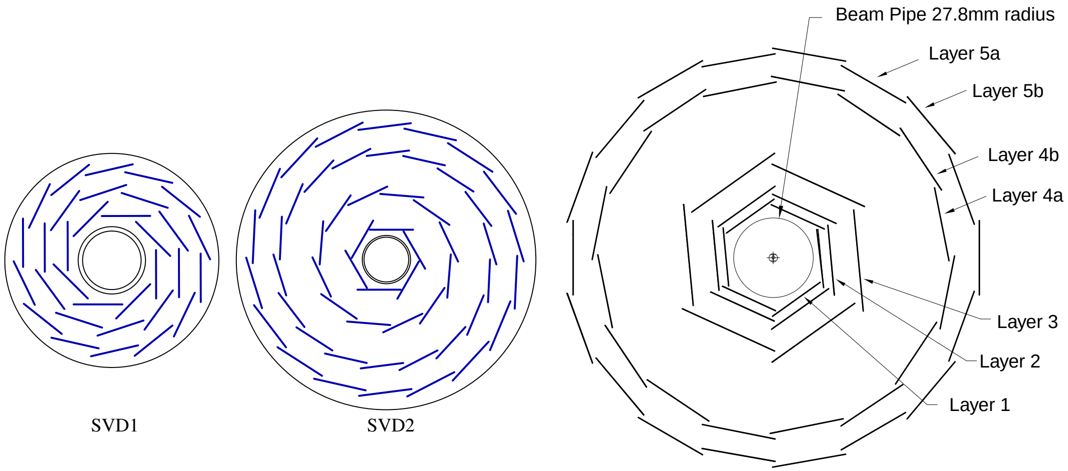
	$\langle\sigma(\Delta t)\rangle$	$\sigma(S)$
$J/\psi K_S^0$	0.66	~ 0.15
$K_S^0\pi^0\gamma$	1.14	~ 0.18

Loss in sensitivity due to loss in vertexing resolution:

- ~ 15 % from 'vertexing efficiency'
- ~ 20 % from resolution effect

SVT geometry

Babar and Belle vertex detectors



	BELLE SVD1	BELLE SVD2	*BABAR* SVT
outer radius [cm]	6.0	8.8	14.2
inner radius [cm]	3.0	2.0	3.2
beam pipe [cm]	2.0	1.5	2.8
'vertexing efficiency'	0.41	0.55	0.72

Size matters!

⇒ need precision tracking up to large distances

Backgrounds

Background sources

- combinatorial background from the continuum
- $B \to X\gamma$ background, for example $B^+ \to K_S^0\pi^+\gamma$
  $\longrightarrow$ real photon, but soft/fake π^0 from the other B
- 'generic' B background, for example $B \to XK_S^0\pi^0$, $B \to XK_S^0\eta$
  $\longrightarrow$ photon background from hard π^0 or η
  $\longrightarrow$ partially removed with explicit π^0/η vetoes

Estimated composition of data sample per 1/ab, using current *BABAR* selection:

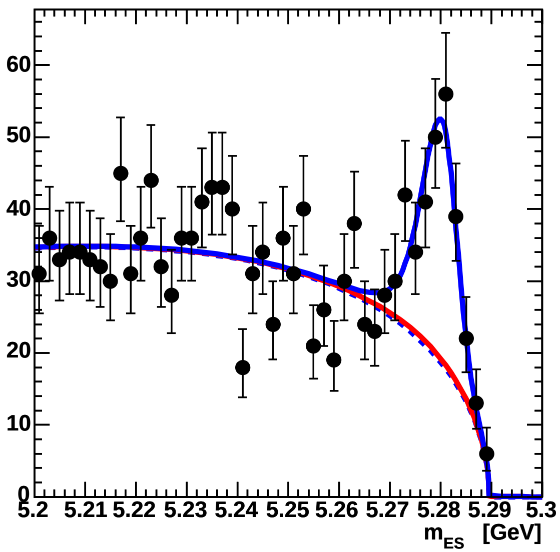
	$0.8 < m_{K\pi} < 1.0$		$1.1 < m_{K\pi} < 1.8$	
	fit region	signal region	fit region	signal region
signal	840	650	300 (?)	190
continuum	6200	230	12000	420
$B\overline{B}$ background	200	40	800	120

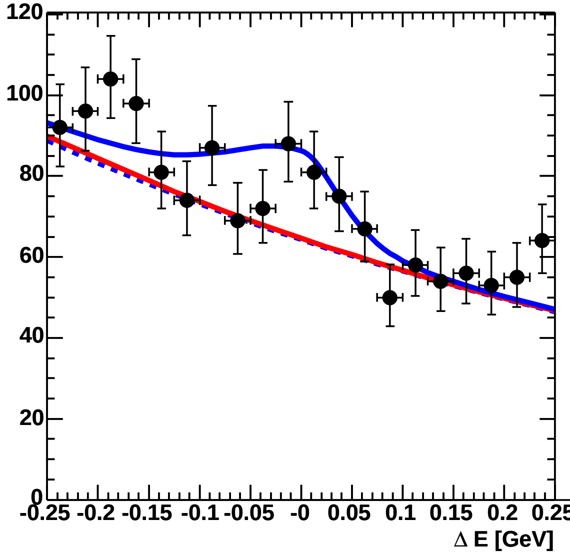
Fit region: $m_{\mathrm{ES}} > 5.2$, $-0.25 < \Delta E < 0.25$. Signal box: $m_{\mathrm{ES}} > 5.27$, $-0.2 < \Delta E < 0.1$, $L_2/L_0 < 0.4$

⇨ There is a substantial background from other B decays

Fitting for background composition

BABAR data + fi t for $B^0 \to K^{*0}\gamma$





Compare fi tted $B\overline{B}$ yield to expectation (*BABAR*, Moriond 2005):

	$K^*(890)$ region $0.8 < m_{K^0_S\pi^0} < 1.0$	above the $K^*(890)$ $1.1 < m_{K^0_S\pi^0} < 1.8$
MC expectation	~ 44	~ 170
fi t	8 ± 9	125 ± 40

Can we really fi t for this? How do we deal with background *asymmetries*?

Systematic uncertainties due to background

- continuum background is not a real problem
  - expect no correlation between asymmetry and main B selection variables
  - extract average asymmetry from 'sidebands'

- background from B decays is *much larger problem*
  - different decays contribute with different (unknown) asymmetries:
    $\longrightarrow$ asymmetry depends on ΔE and m_{ES}
    $\longrightarrow$ cannot extract meaningful asymmetry from fi t
  - current approach (babar)
    - use MC to estimate $B\overline{B}$ background yield
    - vary asymmetry within suitable range

Current uncertainty from $B\overline{B}$ background from *BABAR*:

	$0.8 < m_{K^0_S\pi^0} < 1.0$	$1.1 < m_{K^0_S\pi^0} < 1.8$
$\sigma^{syst}_{B\overline{B}}(S)$	0.04	0.24

- resonant/non-resonant differ due to ratio of signal to $B\overline{B}$ yield
- errors will decrease with better understanding of $B\overline{B}$ background composition and/or tighter cuts

Total systematic uncertainty for $S(K^*\gamma)$

From most recent measurements:

	BABAR (Moriond)	BELLE (hep-ex/0503008)
resolution function	0.01	0.05
vertexing technique	0.02	0.06
svt misalignment	0.02	
background fraction		0.02
signal/background pdfs	0.02	
$B\overline{B}$ background asymmetry	0.04	
tag side interference, Δm_B, τ_B	0.01	0.01
total	0.05	0.10

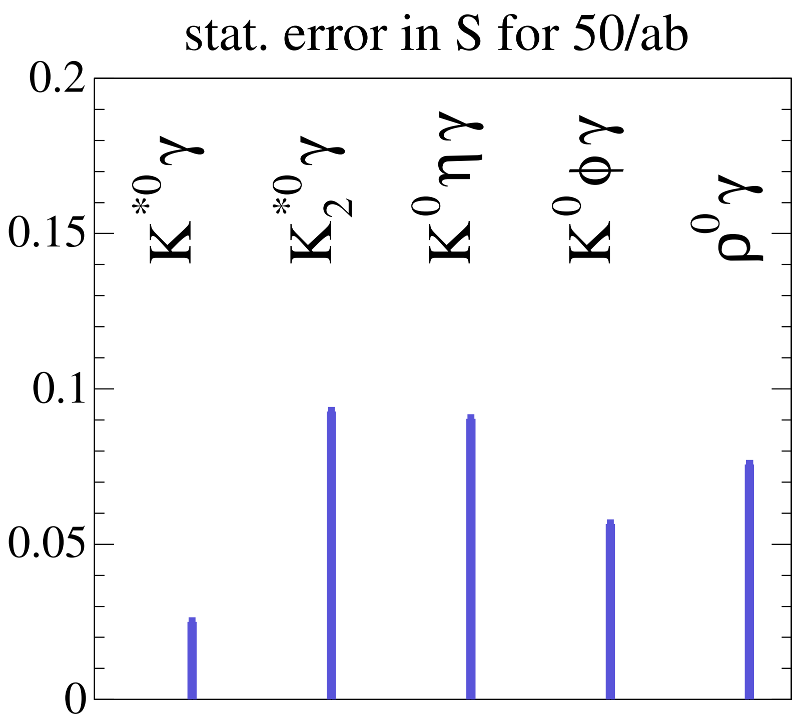
Experience/outlook from *BABAR*:

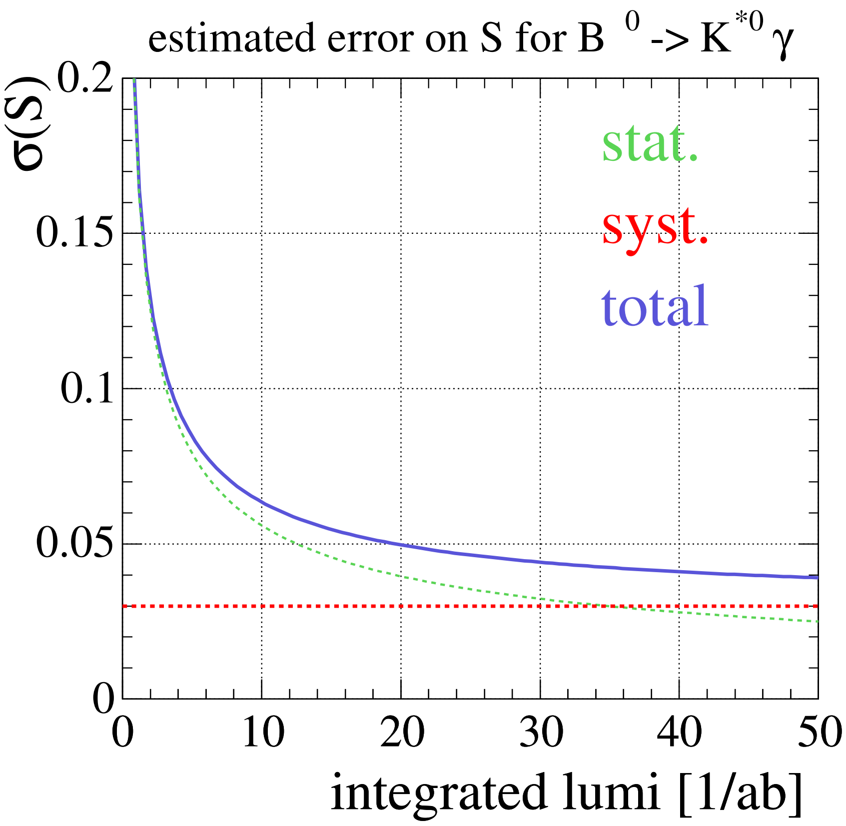
- current $B\overline{B}$ background asymmetry is ‘conservative’: just needs more work
- ’vertexing/resolution function’ systematics limited by control sample size
- other contributions will become as small as for other CP measurements, like $\sin 2\beta_{\psi K^0_S}$

⇒ systematic uncertainty of $\lesssim 0.03$ not unrealistic

Expected errors for some modes

Expected uncertainties for various modes,
using effi ciencies and S/B from slide 3:





Large uncertainties in some of these numbers: branching fractions, effi ciencies, background rates

At ~ 50/ab, "*systematic uncertainty* $\approx$ *statistical uncertainty*" for $B^0 \to K^{*0}\gamma$

Summary

- measuring photon polarization in $B^0 \to X\gamma$ decays via time-dependent CPV feasible for a handful of modes

- systematic uncertainty on S is

$$\sigma('\psi K_s^0{}') \oplus \sigma(\text{vertexing}) \oplus \sigma(B\overline{B}\text{background}) \lesssim 0.03$$

- for $B^0 \to K^{*0}\gamma$ statistical uncertainty matches systematic at about 50 ab^{-1}

⇨ **at 50 ab^{-1}, $\sigma(S) \lesssim 0.04$**

- for other modes, statistical errors dominate even at 50 ab^{-1}

⇨ uncertainty on S typically between 0.05 and 0.1

Backup Slides

How to estimate the error for other modes?

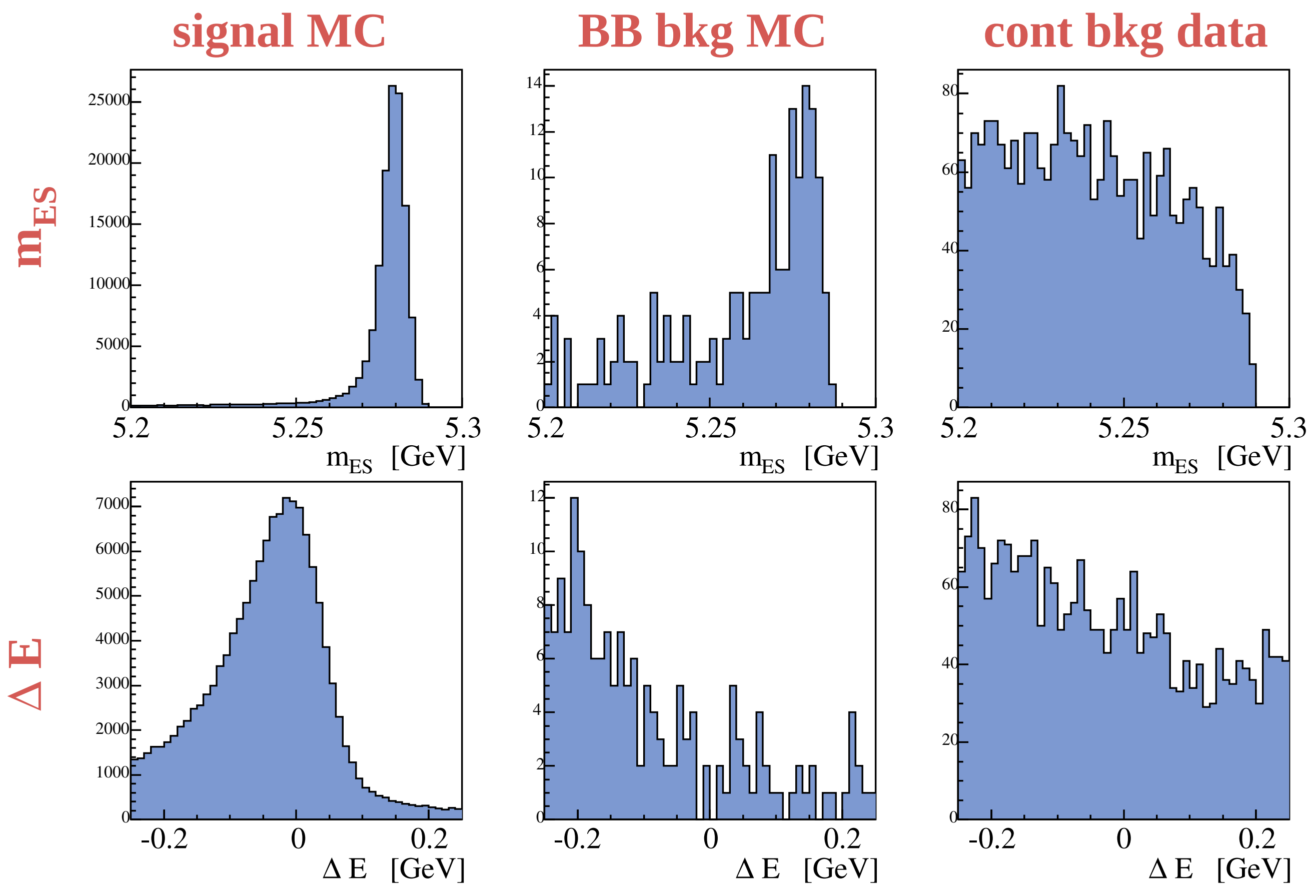
Used following expressions to estimate error in measured asymmetry:

$$\sigma(\mathcal{A}) = \frac{1}{\sqrt{N_S}} \times \sqrt{\frac{N_S + N_B}{N_S}} \times \sqrt{\frac{1}{\epsilon_{\rm tag}}} \times f(\sigma(\Delta t))$$

$$\begin{aligned}
\epsilon_{\rm tag} &= 0.30 \\
\langle f_S \rangle &\approx 1.4\sqrt{1 + \langle \sigma(\Delta t)/1.26 \rangle^2}/\sqrt{\epsilon_{\rm vtx}} \\
\langle f_C \rangle &\approx 1.3
\end{aligned}$$

- parameters tuned to match toy MC expectations for $K_S^0\pi^0$
- expression within $\sim 5\%$ accurate for $K_S^0\pi^0$, $K_S^0\pi^0\gamma$ and $J/\psi K_S^0$

Separating background in $m_{ES}/\Delta E$

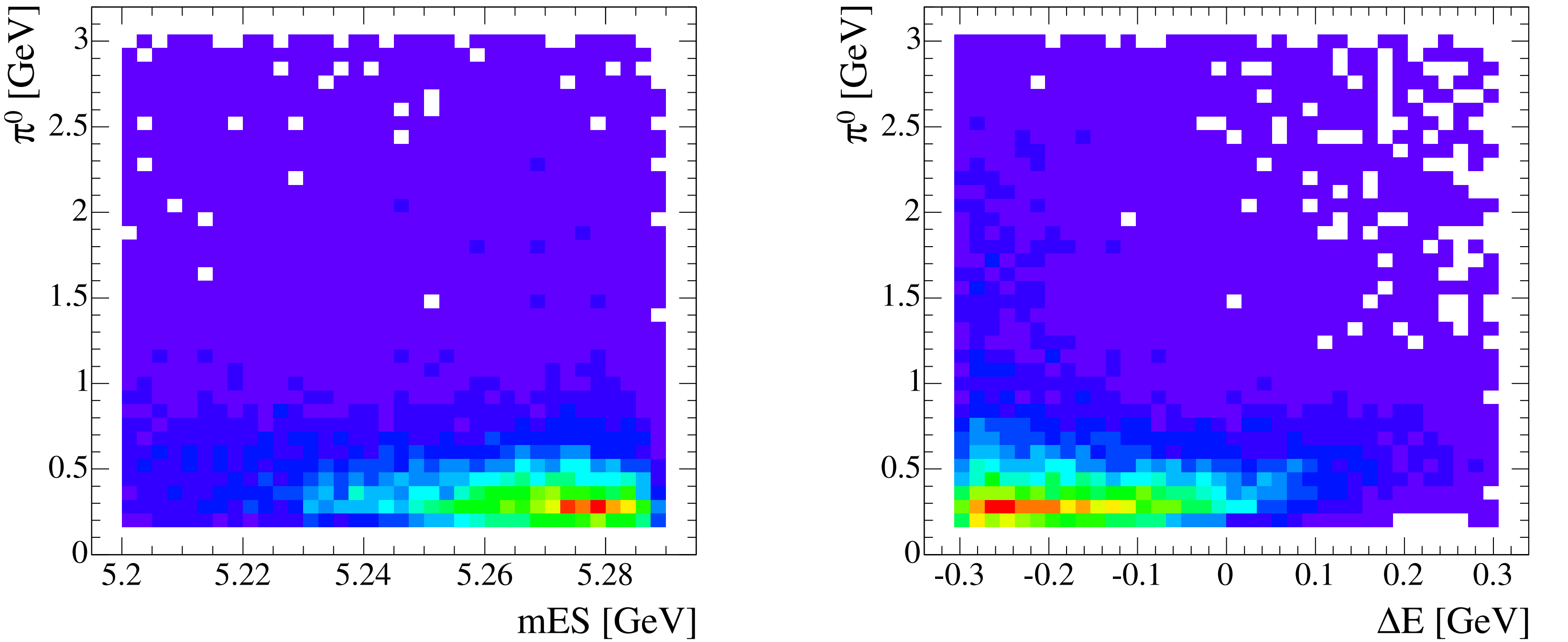


Typical for $B\overline{B}$ background:

- (sort of) peaks in m_{ES}
- occupies low sideband in ΔE

B background and low momentum π^0

Most $B\overline{B}$ background associated with low momentum π^0 candidates:



⇨ use hard cuts on π^0 energy