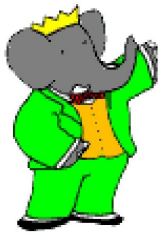
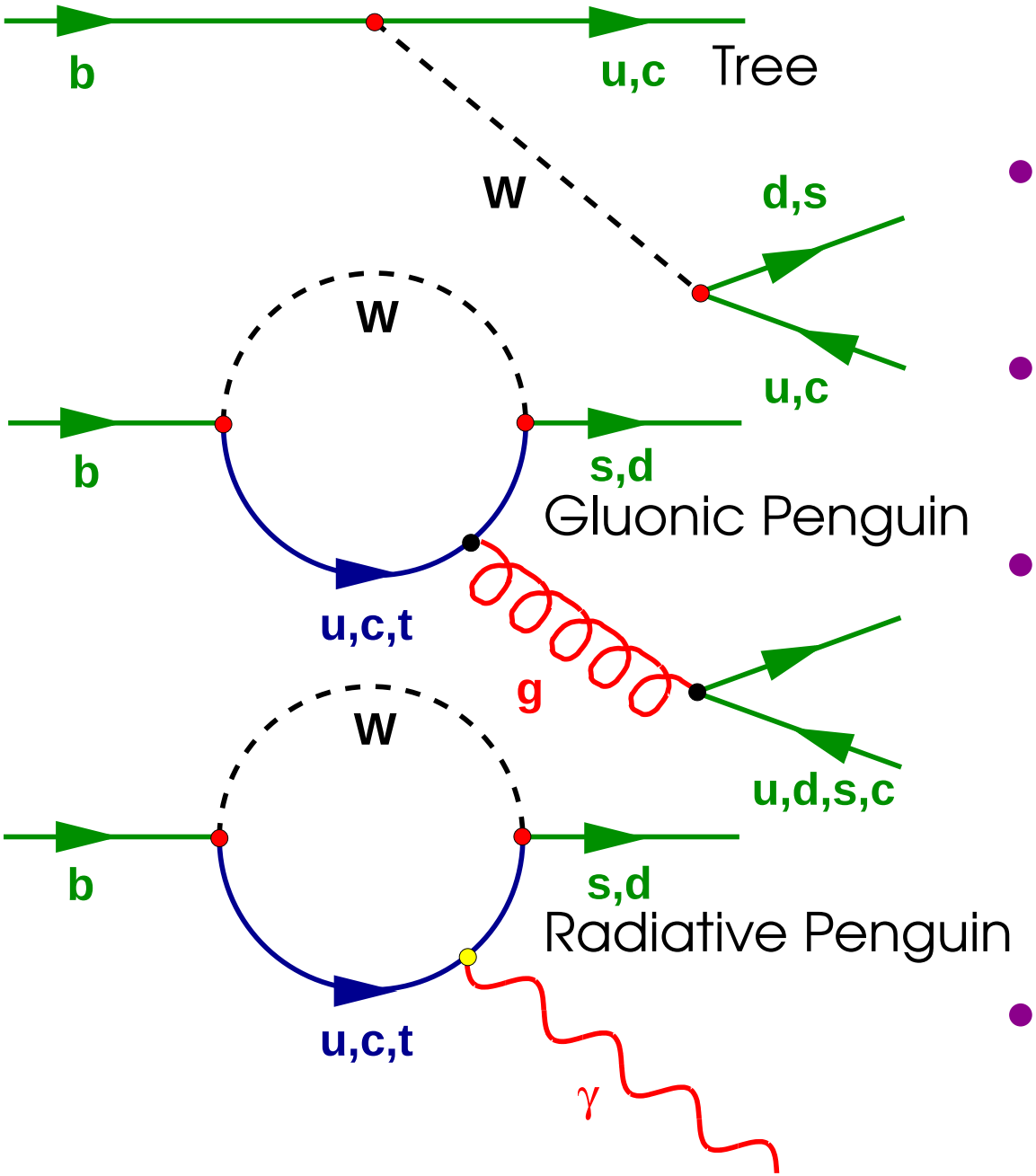
Search for Direct $\mathcal{CP}$ Violation in $B \to K\pi, \pi\pi, KK$, Quasi-2-Body Decays and $B \to K^*\gamma$ at *BABAR*

EPS-HEP 2001 — Sven Menke, SLAC for the *BABAR* Collaboration — 13. July 2001, Budapest

- Physics Motivation
- PEP II & The *BABAR* Detector
- Charmless Hadronic 2 Body Decays
  - $B^0 \to \pi^+\pi^-, K^+\pi^-, K^0\pi^0, K^+K^-, K^0\overline{K}^0$
  - $B^+ \to K^+\pi^0, \pi^+K^0, \pi^+\pi^0, K^+\overline{K}^0$
- Charmless Quasi-2-Body Decays
  - $B^+ \to \eta' K^+, \omega\pi^+, \phi K^+, \phi K^{*+}$, $B^0 \to \phi K^{*0}$
- Charmonium Quasi-2-Body Decays: $B^+ \to J/\psi K^+$
- Radiative Penguins
  - $B^{0(+)} \to K^{*0(+)}\gamma$ and $B^0 \to \gamma\gamma$
- Conclusions



Physics Motivation

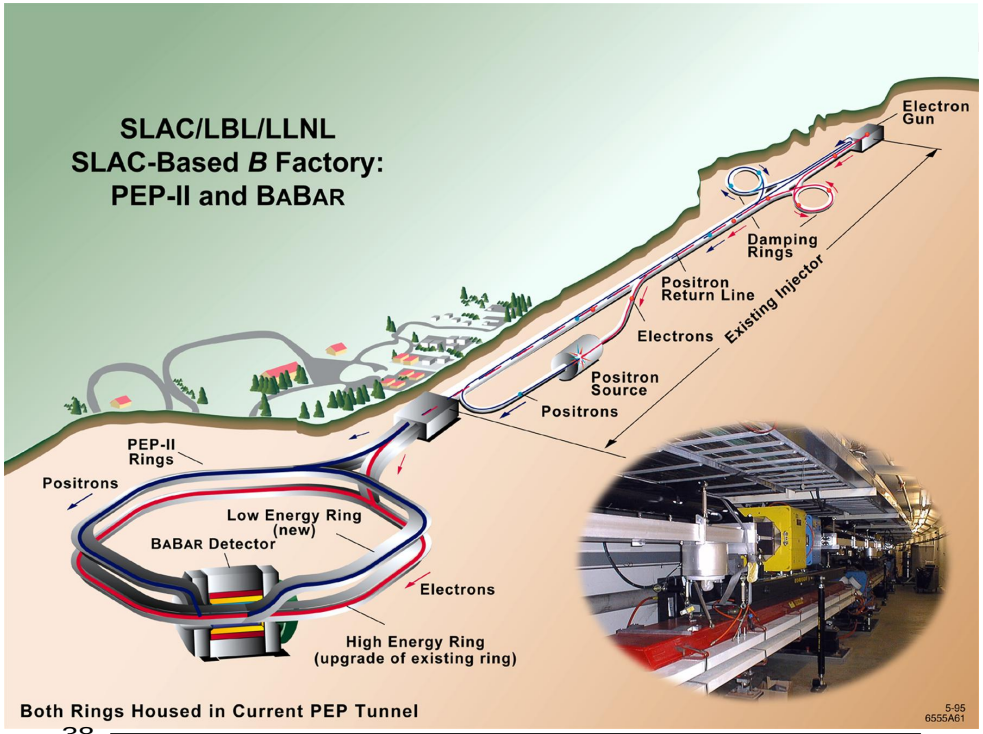


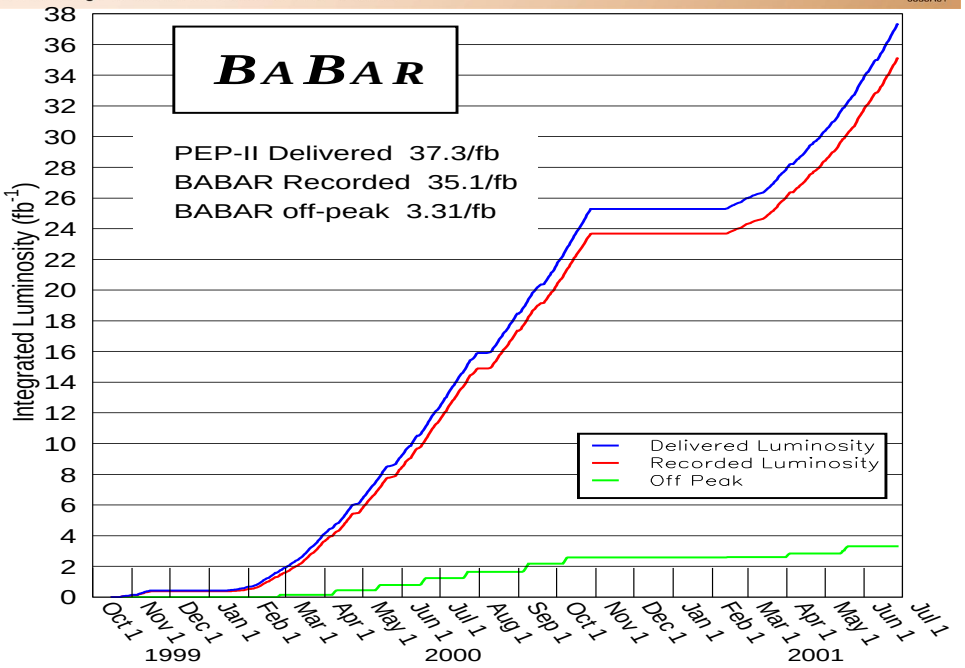
- Charge Asymmetry ⇨ Direct $\mathcal{CP}$ Violation
- P/T Ratio different in different modes
- Isospin Analysis ⇨ CKM angle α
- Sensitive to New Physics

PEP II B-Factory

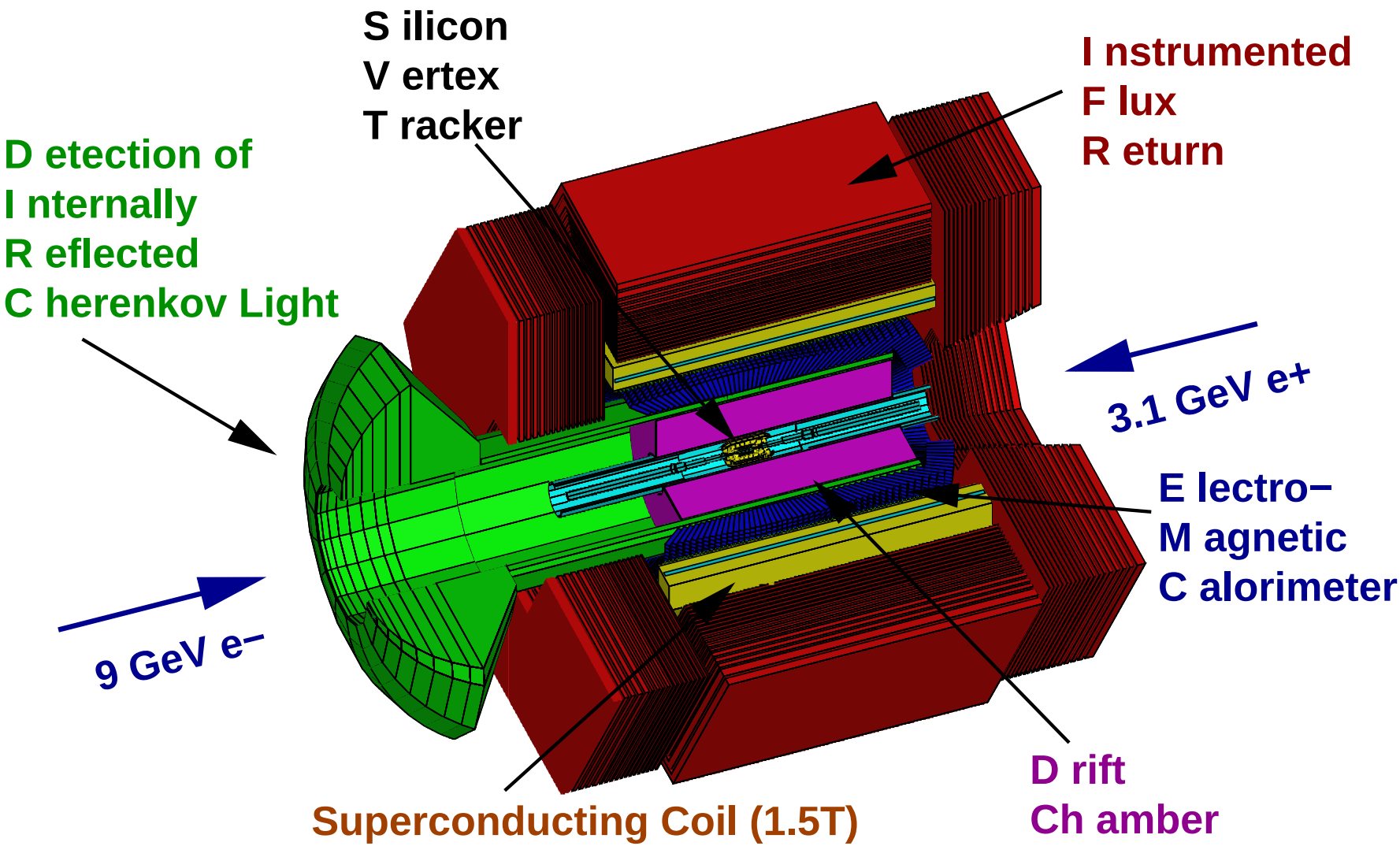
- Asymmetric e^+e^- machine (9 GeV on 3.1 GeV) at the $\Upsilon(4S)$ resonance

- 1999-2000 dataset:
  $20.7\,fb^{-1}$ on-peak
  (22.6 million $B\overline{B}$ events)
  $2.6\,fb^{-1}$ off-peak

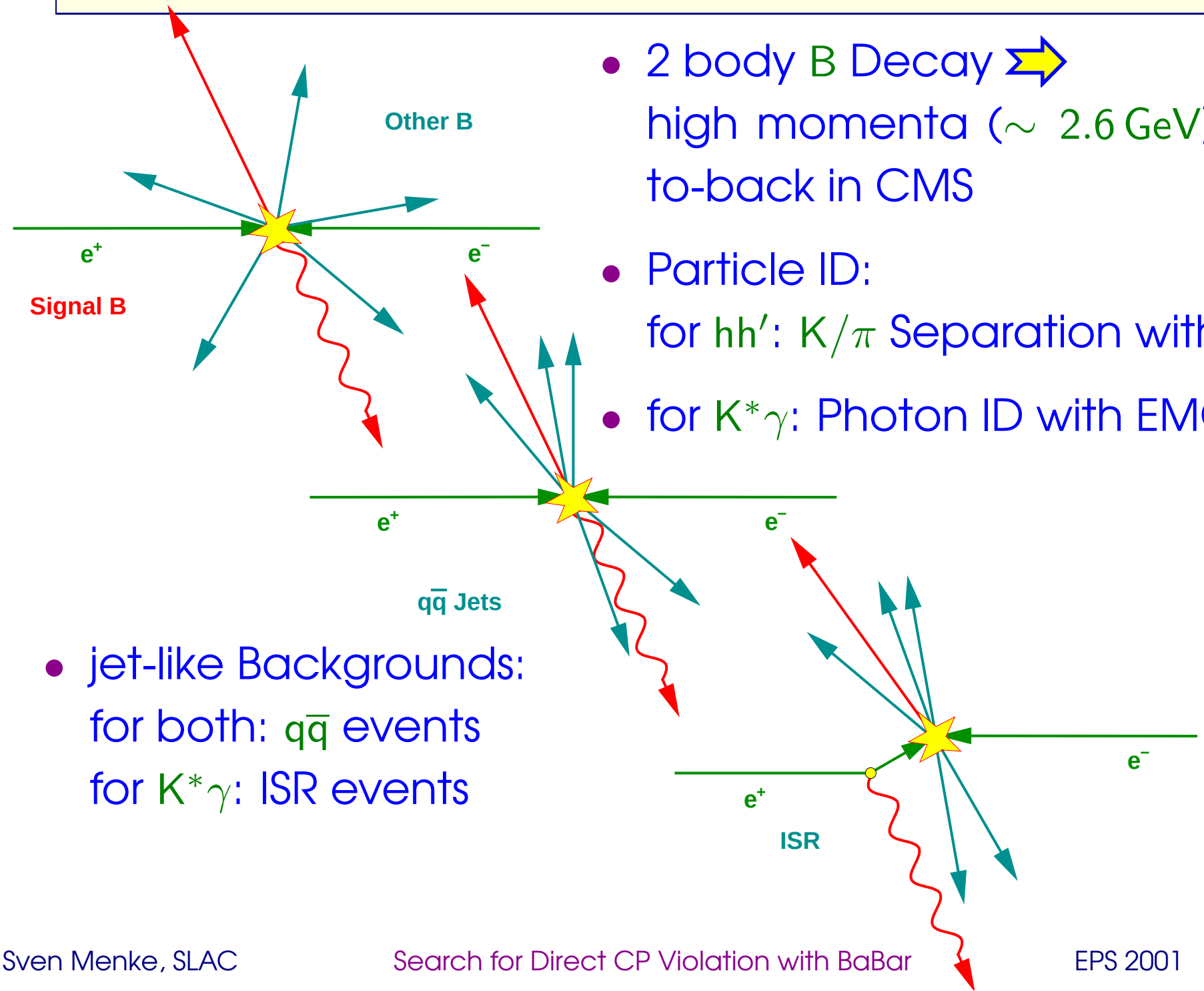




The *BABAR* Detector



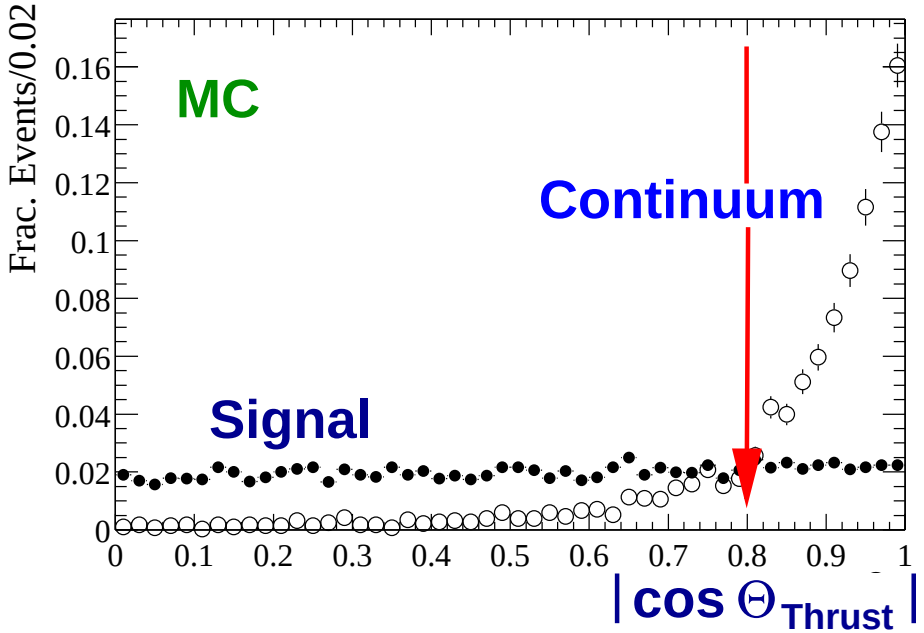
Signal and Background



- 2 body B Decay ⇨
  high momenta ($\sim$ 2.6 GeV) back-to-back in CMS
- Particle ID:
  for hh′: K/π Separation with DIRC
- for K*γ: Photon ID with EMC

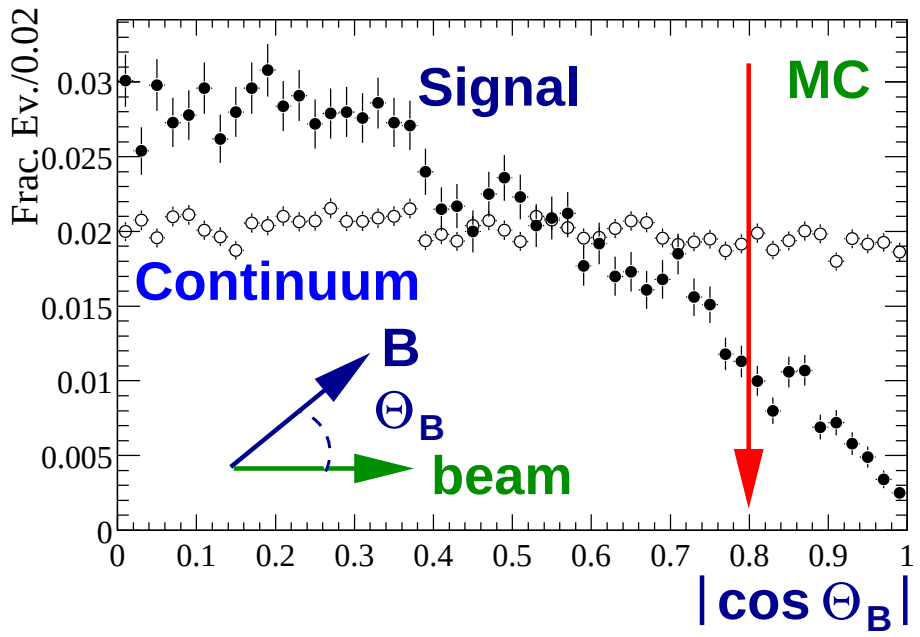
- jet-like Backgrounds:
  for both: $q\bar{q}$ events
  for K*γ: ISR events

Background Suppression I: Event Shape

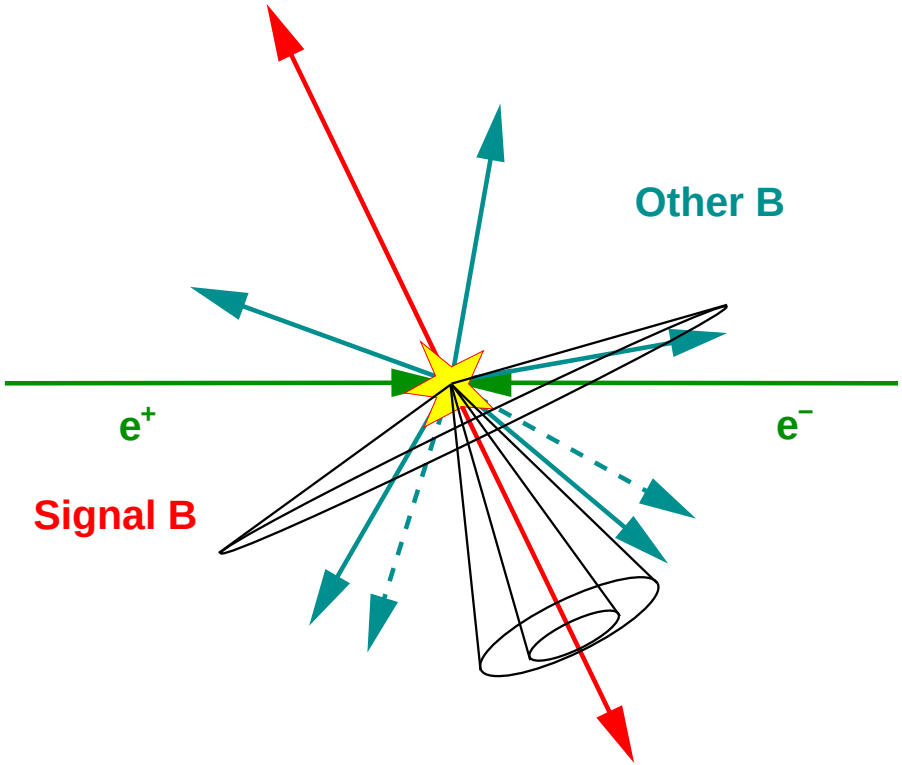


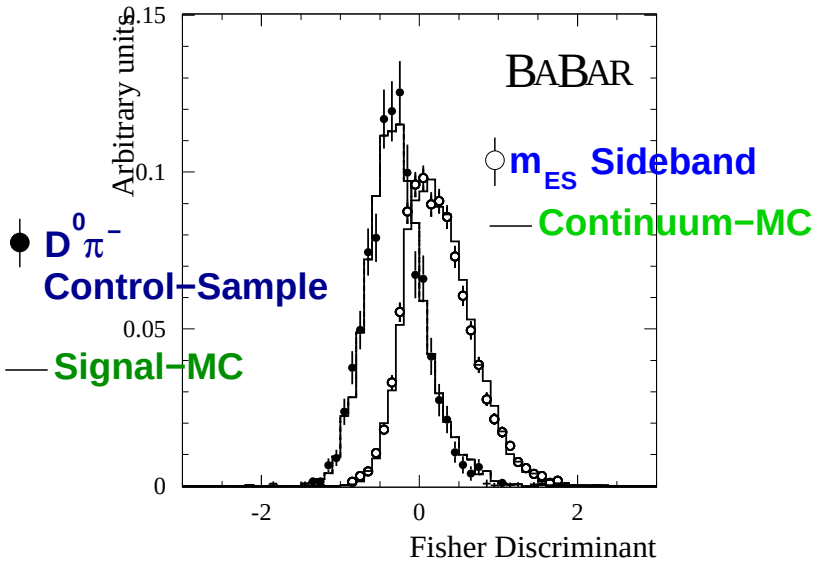
- $K^*\gamma$: cut on $|\cos\Theta_{Thrust}| < 0.8$
- hh': cut on $|\cos\Theta_{Sphericity}| < 0.9$

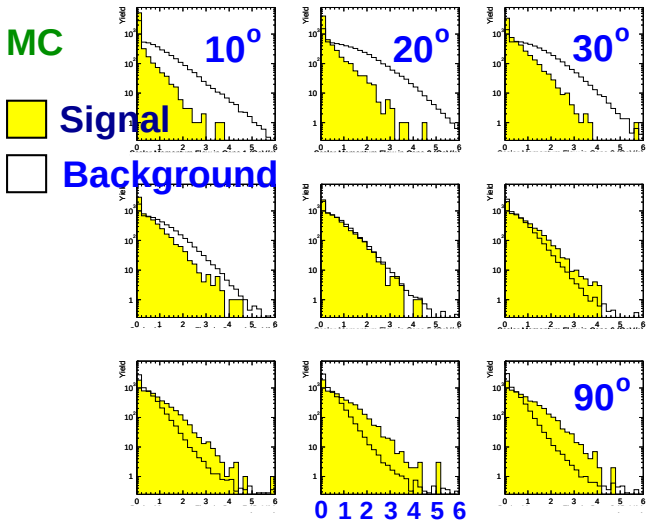
- $K^*\gamma$: cut on $|\cos\Theta_B| < 0.8$
- hh': cut on normalized 2nd Fox-Wolfram moment $H_2/H_0 < 0.95$ and Sphericity $S > 0.01$



Background Suppression II: Fisher Discriminant





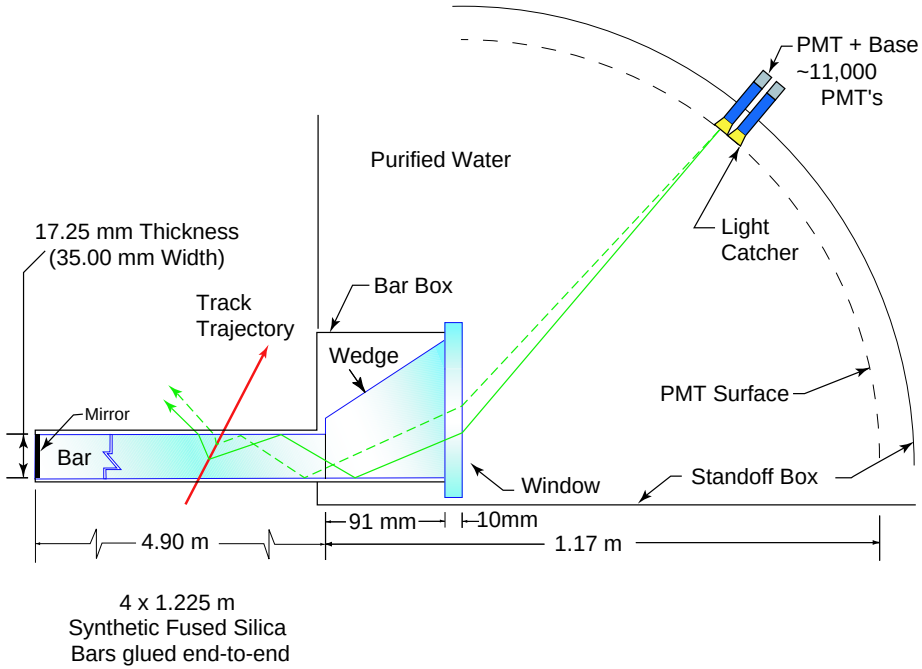


- hh′: Fisher Discriminant

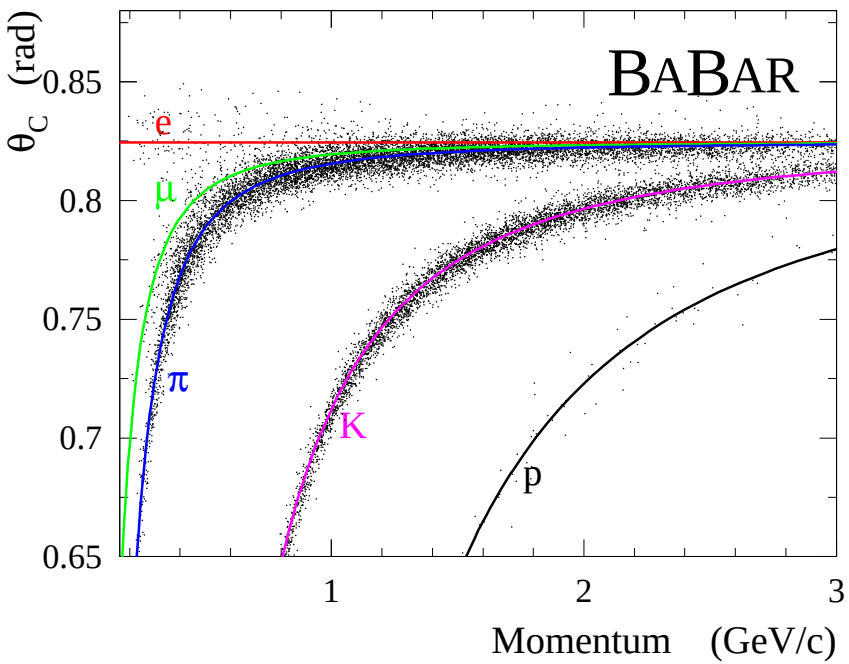
$$\mathcal{F} = \sum_{i=1}^{9} \alpha_i x_i$$

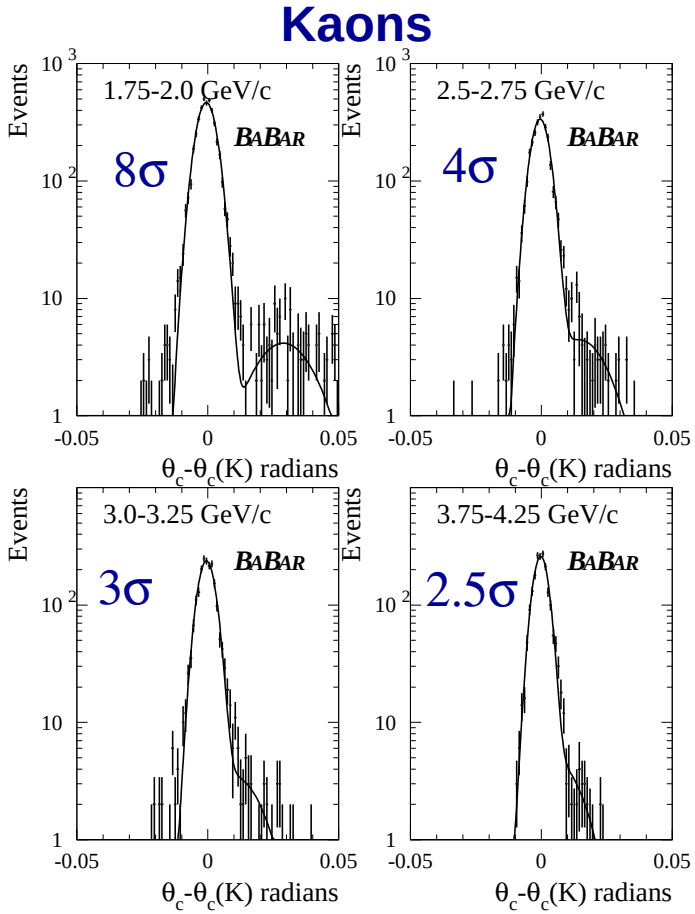
, with linear momentum flow x_i in nine 10° cones around B-Thrust and α_i trained to maximize discrimination power.

Particle ID I: π/K Separation with the DIRC



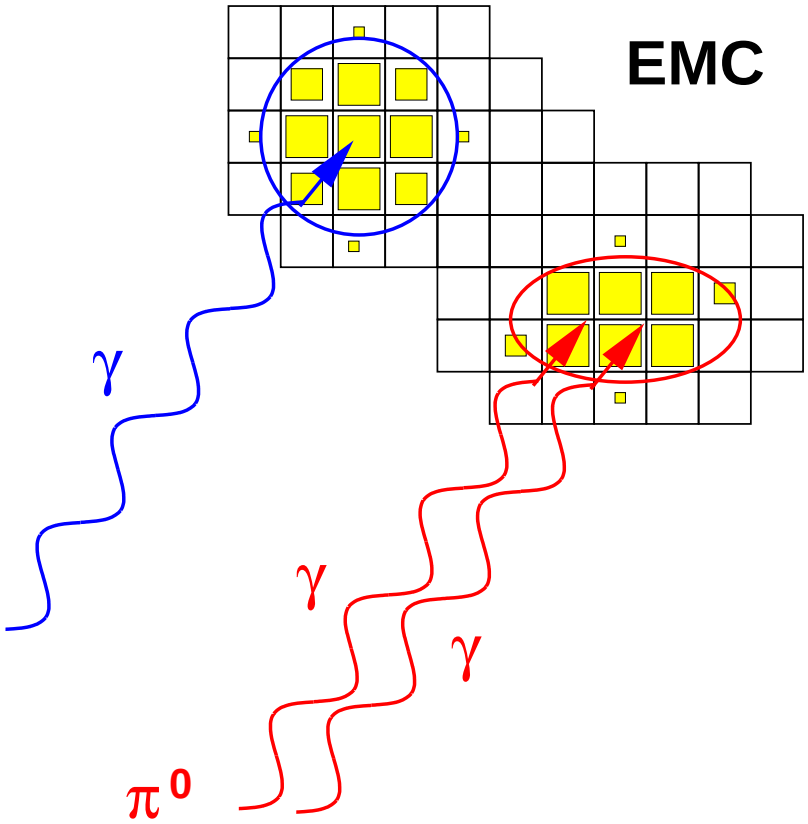
- Use DIRC for high momentum K/π Separation
- K efficiency $\sim 90\,\%$
- π mis-id $< 10\,\%$

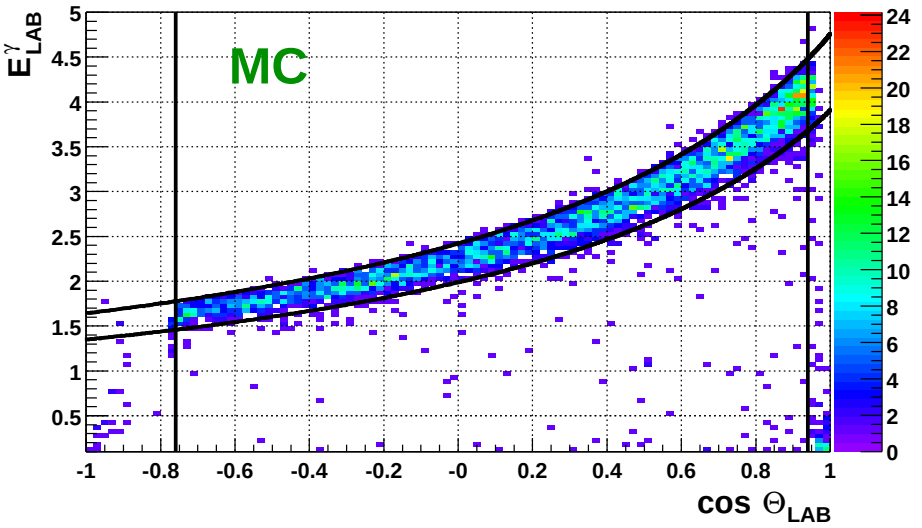




Particle ID II: γ Reconstruction with the EMC

- $K^*\gamma$: Accept photons with $2.3\,\text{GeV} < E_{CMS} < 2.8\,\text{GeV}$
- Polar Angle Cut: $-0.73 < \cos\Theta_{LAB} < 0.94$





- efficient "merged" π^0 rejection with second cluster moment
- reject hadronic splitoff: 25 cm isolation cut in EMC
- π^0, η veto: $|m_{\gamma\gamma} - m_{\pi^0,\eta}| > 2.5\,\sigma$
- Total γ efficiency: $\sim 60\,\%$

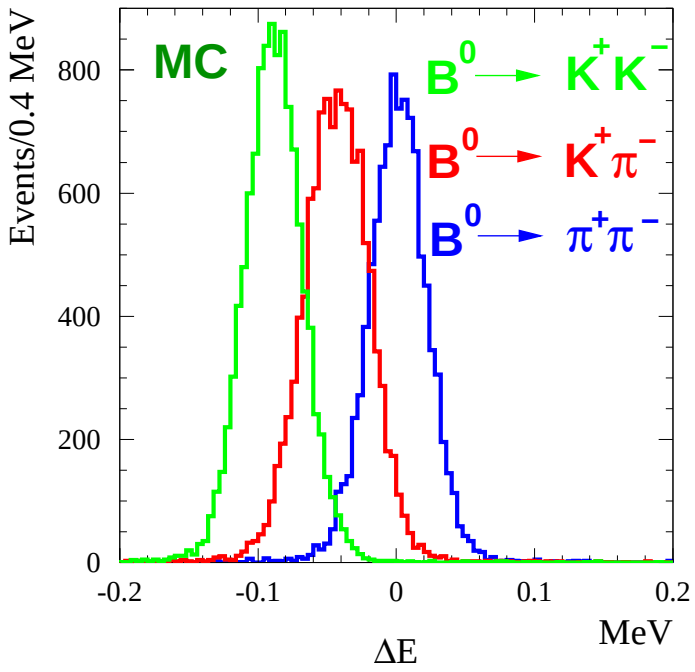
Kinematic Selection: ΔE and m_{ES}

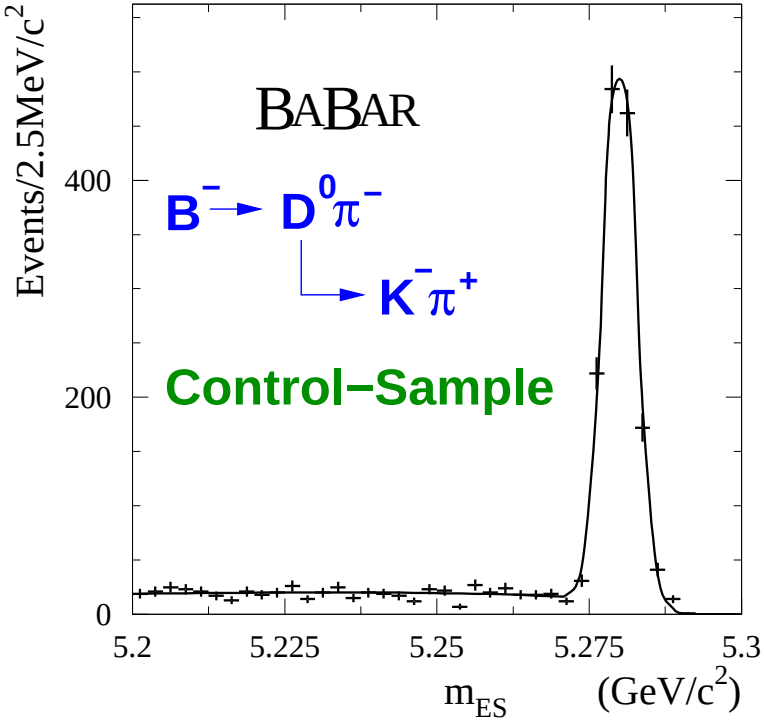
- Energy Difference between B candidate energy and beam Energy in the CMS:

$$\Delta E = E_B^{rec} - E_{beam},$$

assuming π-mass for all tracks

- Resolution $20 - 40$ MeV for hh′;
  $\sim 40 - 60$ MeV for $K^*\gamma$





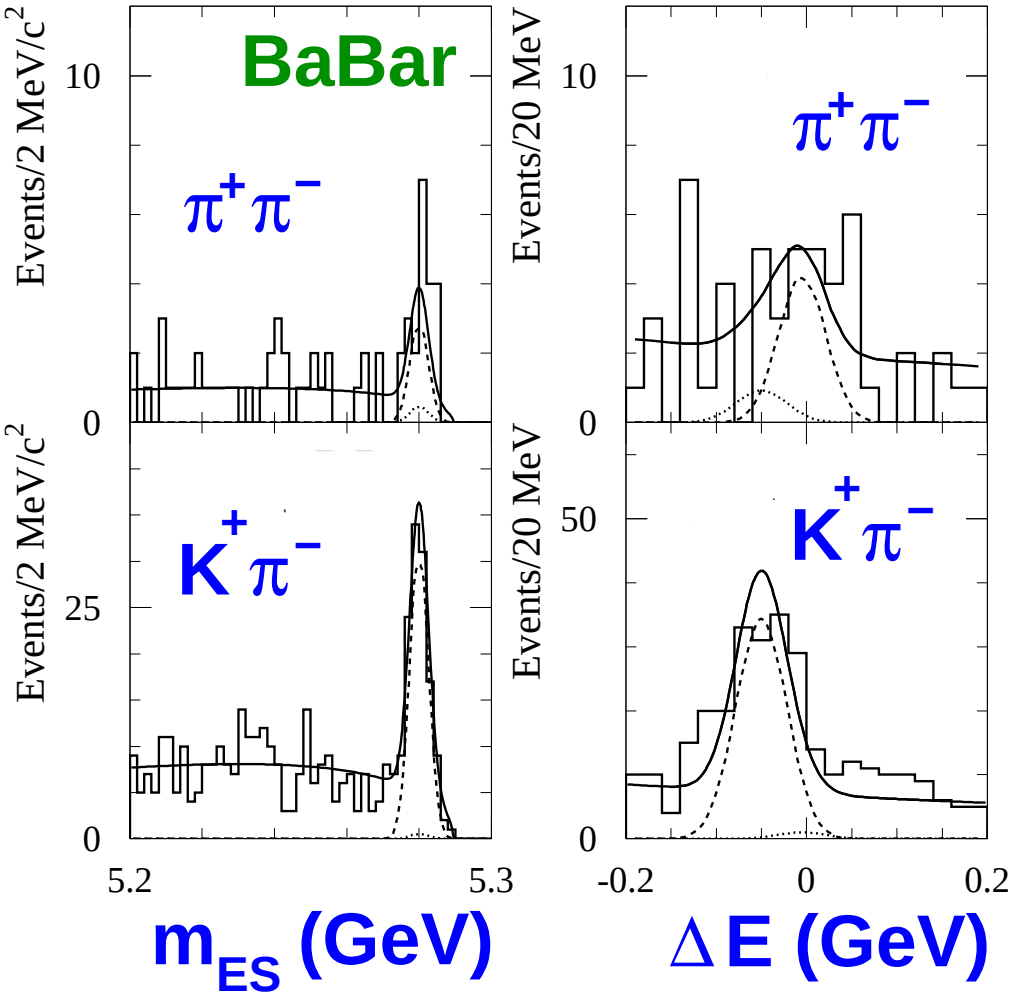
- "energy-substituted mass":

$$m_{ES} = \sqrt{E_{beam}^2 - \vec{p}_B^{\,2}}$$

- Unbinned Max. Likelihood Fit:

$$\mathcal{L} = \frac{e^{-\sum n_i}}{N!} \prod_{i=1}^{N} \sum_{j=1}^{m} n_j \mathcal{P}_j(\vec{x}_i; \vec{\alpha}_i)$$

Results for $B^0 \to h^+h'^-$

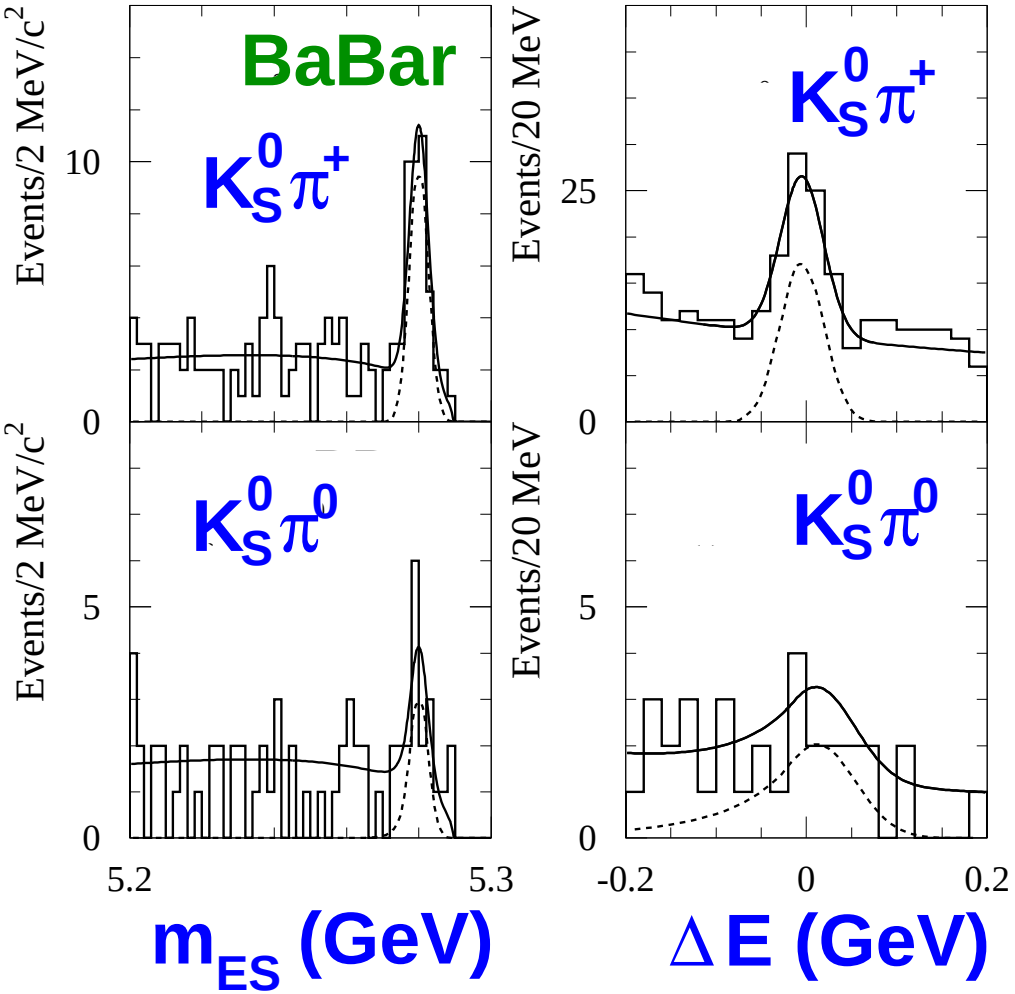


- systematic errors dominated by PDF shape and parameters
- Efficiency $\sim 45\,\%$ in all three modes
- $K\pi \gg \pi\pi$ ⇨ significant Penguin contribution

$$\begin{aligned}
\mathrm{Br}(B^0 \to \pi^+\pi^-) &= (4.1 \pm 1.0 \pm 0.7) \times 10^{-6} \\
\mathrm{Br}(B^0 \to K^+\pi^-) &= (16.7 \pm 1.6\,^{+1.2}_{-1.7}) \times 10^{-6} \\
\mathrm{Br}(B^0 \to K^+K^-) &< 2.5 \times 10^{-6} \text{ @ } 90\,\% \text{ CL}
\end{aligned}$$

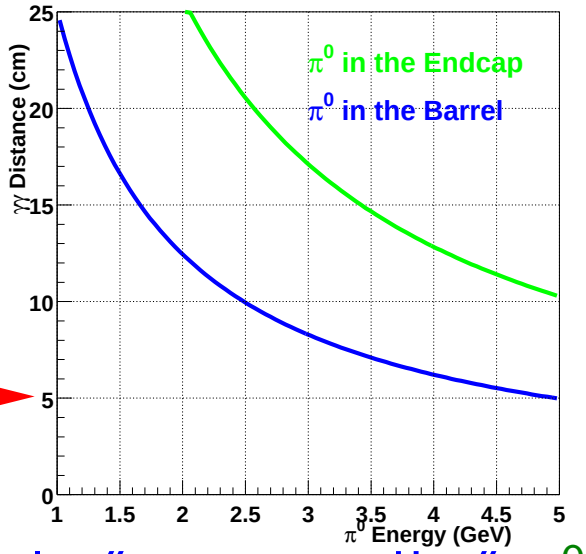
Results for $B^+ \to K^0 h^+$ and $B^0 \to K^0 \pi^0$

- $\sigma(K^0_S \to \pi^+\pi^-) = 4.3\,\text{MeV}$
- $|m_{\pi^+\pi^-} - m_{K^0_S}| < 3.5\sigma$
- Efficiency: $\sim 40\,\%$ in $(K^0_S \to \pi^+\pi^-)h^+$ modes and $\sim 32\,\%$ in the $K^0_S\pi^0$ mode

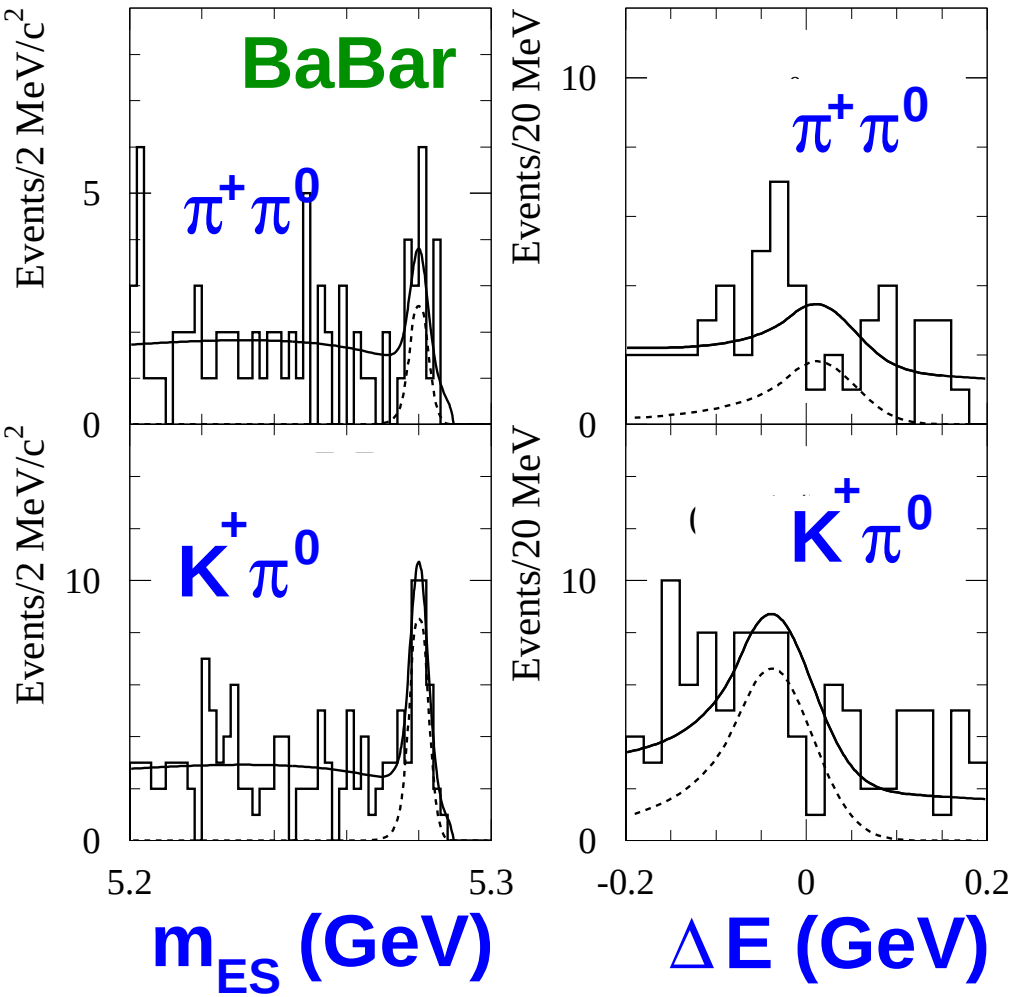


$$\begin{aligned} \text{Br}(B^+ \to K^0\pi^+) &= (18.2\,^{+3.3}_{-3.0} \pm 2.0) \times 10^{-6} \\ \text{Br}(B^0 \to K^0\pi^0) &= (8.2\,^{+3.1}_{-2.7} \pm 1.2) \times 10^{-6} \\ \text{Br}(B^+ \to K^+\overline{K}^0) &< 2.4 \times 10^{-6} \;@\; 90\,\%\;\text{CL} \end{aligned}$$

Results for $B^+ \to h^+\pi^0$



- use only "composite" π^0s
- $\sigma(\pi^0 \to \gamma\gamma) = 8.5$ MeV at high energies
- Total Efficiency: $\sim 31\,\%$
- Largest Systematic Error: $\pm 5\,\%$ on π^0 Efficiency



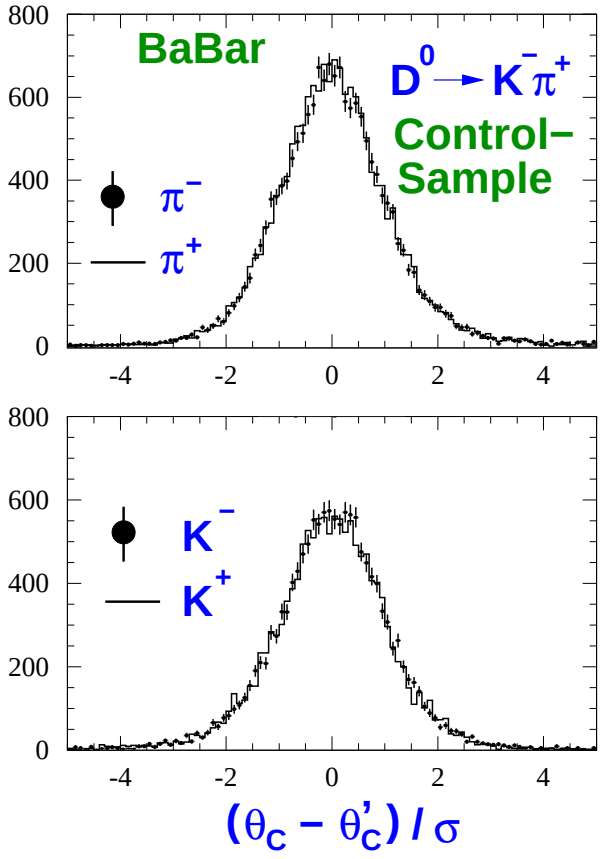
$$\begin{aligned} \mathrm{Br}(B^+ \to \pi^+\pi^0) &= (5.1\,^{+2.0}_{-1.8} \pm 0.8) \times 10^{-6} \\ &< 9.6 \times 10^{-6} \text{ @ } 90\,\% \text{ CL} \\ \mathrm{Br}(B^+ \to K^+\pi^0) &= (10.8\,^{+2.1}_{-1.9} \pm 1.0) \times 10^{-6} \end{aligned}$$

$\mathcal{CP}$-Violating Charge Asymmetries

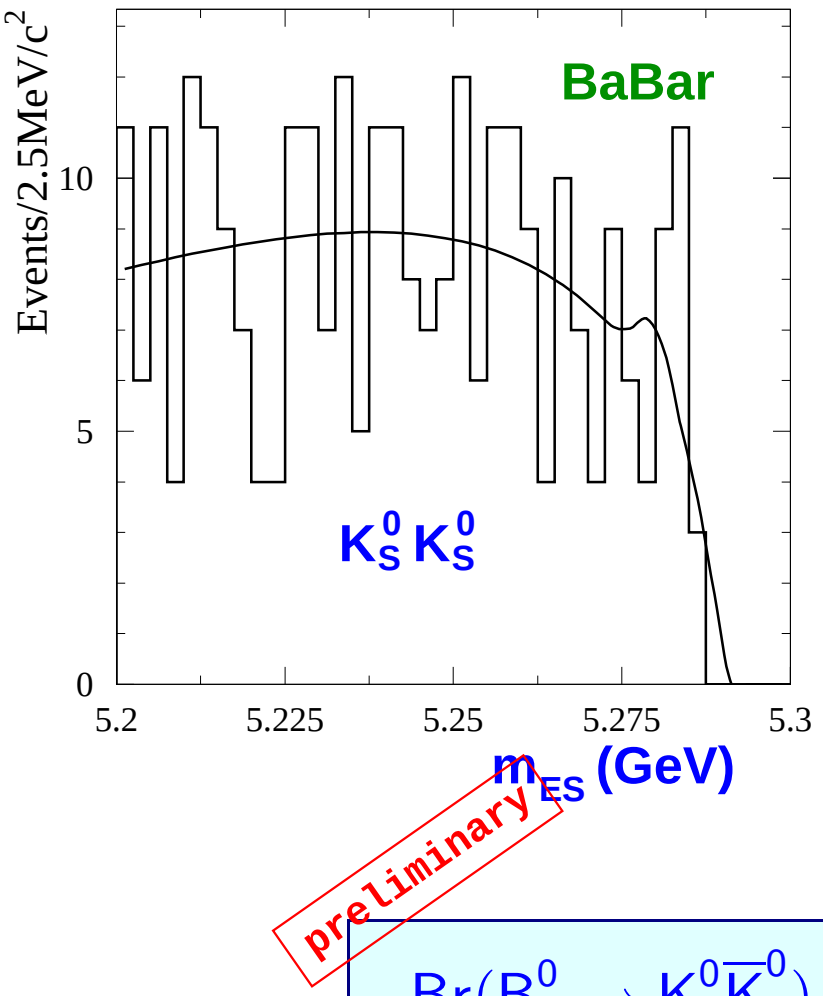
- Differences in the Decay width for $B \to f$ and its $\mathcal{CP}$ conjugate $\overline{B} \to \bar{f}$ indicate Direct $\mathcal{CP}$ Violation
- $$\mathcal{A}_{\mathcal{CP}} = \frac{Br(\overline{B} \to \bar{f}) - Br(B \to f)}{Br(\overline{B} \to \bar{f}) + Br(B \to f)} \sim |A_1||A_2| \sin\Delta\phi_W \sin\Delta\phi_S$$
- use "self-tagged"modes

$$\begin{aligned} \mathcal{A}_{\mathcal{CP}}(K^{\pm}\pi^{\mp}) &= -0.19 \pm 0.10 \pm 0.03 \\ \mathcal{A}_{\mathcal{CP}}(K^{0}\pi^{\pm}) &= -0.21 \pm 0.18 \pm 0.03 \\ \mathcal{A}_{\mathcal{CP}}(K^{\pm}\pi^{0}) &= 0.00 \pm 0.18 \pm 0.04 \end{aligned}$$

- No Evidence for Direct $\mathcal{CP}$ Violation so far



Search for $B^0 \to K^0_S K^0_S$

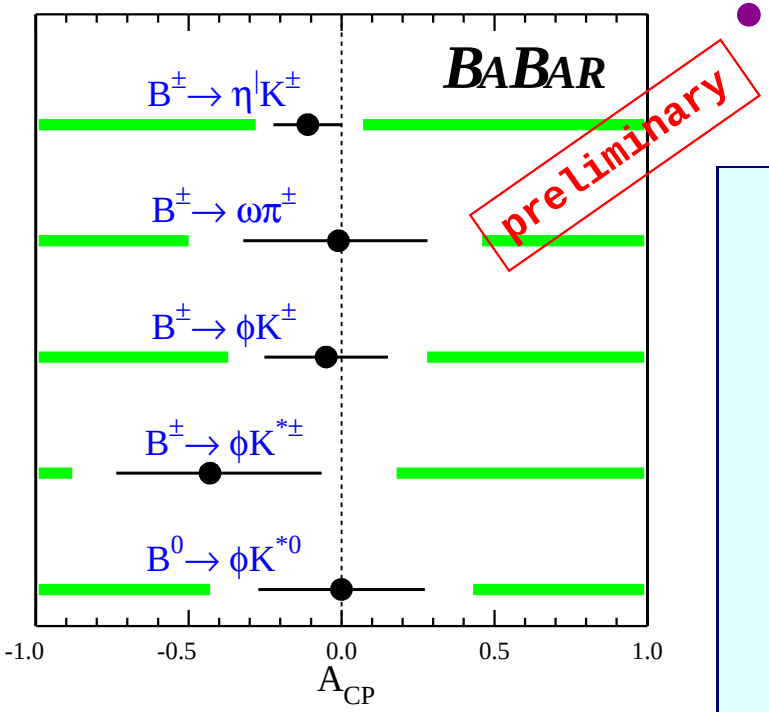


- Efficiency $\epsilon \sim 37\,\%$
- expected Background from m_{ES} Sideband: 1.7 ± 0.5 events
- found 3 events in the signal box after unblinding
- cross check Likelihood Analysis with Cut & Count Analysis

$$\mathrm{Br}(B^0 \to K^0 \overline{K}^0) \quad < \quad 10.6 \times 10^{-6} \ @ \ 90\,\% \ \mathrm{CL}$$

Search for Direct $\mathcal{CP}$ Violation in Quasi-2-Body B Decays

Mode	Systematics PDF	Sel.
$\eta' K^+$	± 0.018	± 0.01
$\omega\pi^+$	± 0.033	± 0.01
ϕK^+	± 0.033	± 0.01
ϕK^{*+}	± 0.061	± 0.02
ϕK^{*0}	± 0.022	± 0.02

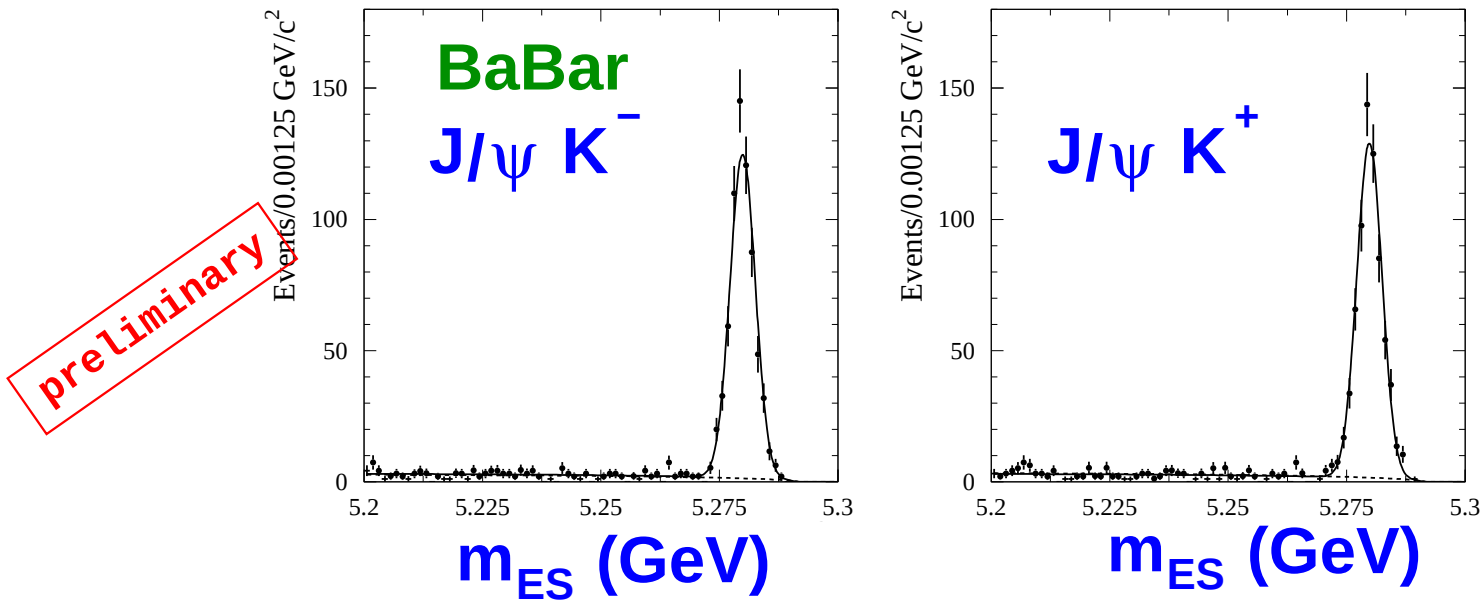


- ***BABAR*** measured Br in the Quasi-2-Body modes $B^+ \to \eta' K^+$, $B^+ \to \omega\pi^+$, $B^+ \to \phi K^+$, $B^+ \to \phi K^{*+}$, and $B^0 \to \phi K^{*0}$.

  see G. Mancinelli's talk this afternoon
- careful systematic studies of ~~$\mathcal{CP}$~~ faking (or removing) biases of the Detector ($\sim 1-2\,\%$)
- simultaneous fit of Br and Charge Asymmetries $\mathcal{A}_{\mathcal{CP}}$

$$
\begin{aligned}
\mathcal{A}_{\mathcal{CP}}(\eta' K^\pm) &= -0.11 \pm 0.11 \pm 0.02 \\
\mathcal{A}_{\mathcal{CP}}(\omega\pi^\pm) &= -0.01\,^{+0.29}_{-0.31} \pm 0.03 \\
\mathcal{A}_{\mathcal{CP}}(\phi K^\pm) &= -0.05 \pm 0.20 \pm 0.03 \\
\mathcal{A}_{\mathcal{CP}}(\phi K^{*\pm}) &= -0.43\,^{+0.36}_{-0.30} \pm 0.06 \\
\mathcal{A}_{\mathcal{CP}}(\phi K^{*0}/\overline{K}^{*0}) &= 0.00 \pm 0.27 \pm 0.03
\end{aligned}
$$

Search for Direct $\mathcal{CP}$ Violation in $B^+ \to J/\psi K^+$



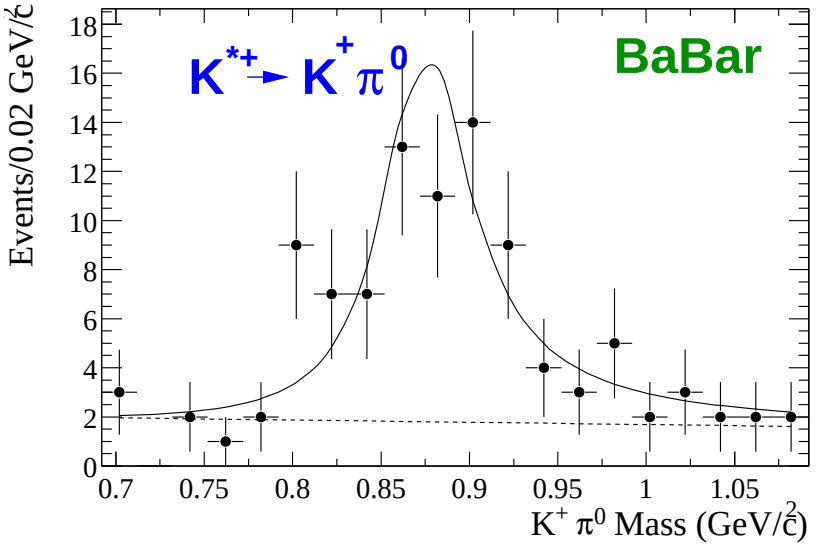
- good case study for $B^+ \to J/\psi\pi^+$
- evaluate charge separated: $\epsilon^{\pm}(p_\perp, \text{mult.}, \theta, \phi)$
- fit $1/\epsilon$ weighted m_{ES} distributions
- correct for (small) differences in $K^\pm$ nuclear interaction cross-sections

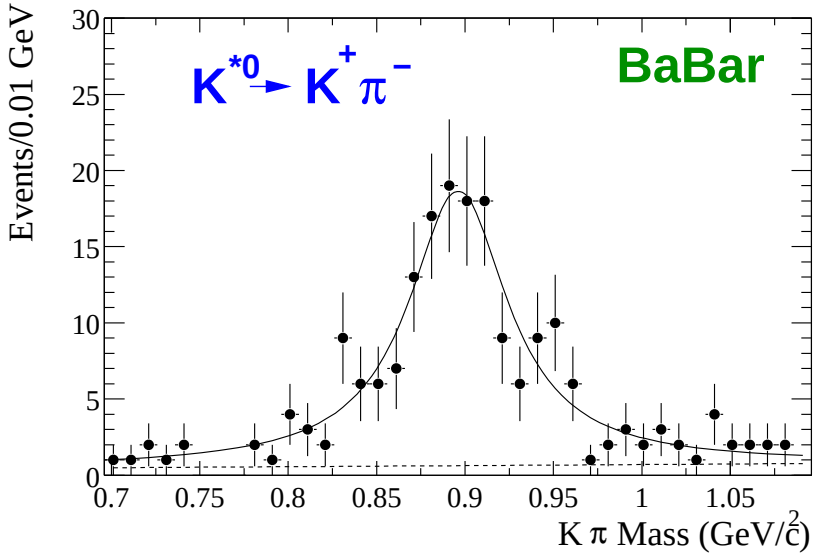
- We obtain the following yields:
  $N(J/\psi K^-) = 626 \pm 25$
  $N(J/\psi K^+) = 626 \pm 26$

$$\mathcal{A}_{\mathcal{CP}}(J/\psi K^\pm) = +0.004 \pm 0.029 \pm 0.004$$

K^* Reconstruction for $B \to K^*\gamma$

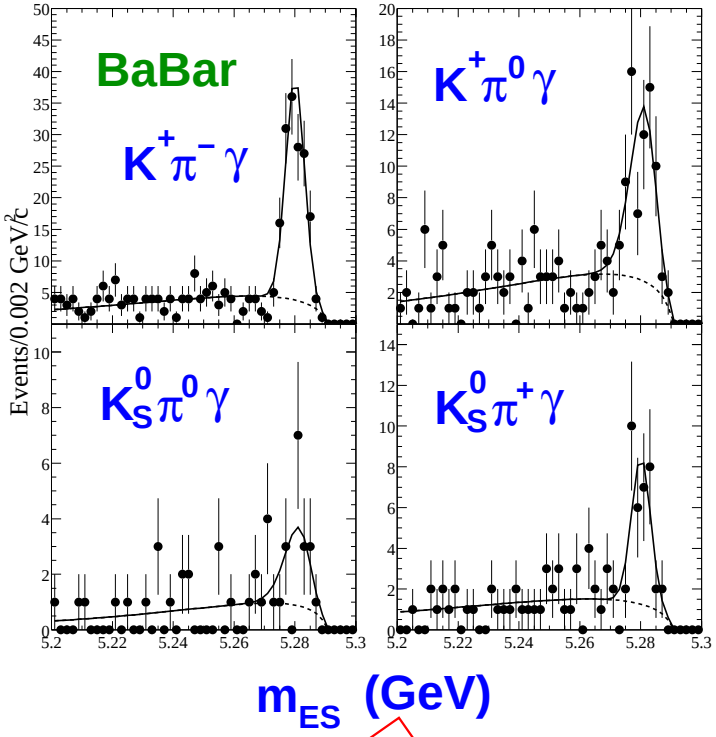
- require fully reconstructed K^* within ± 100 MeV of PDG mass in the modes $K^{*0} \to K^+\pi^-, K^0_S\pi^0$ and $K^{*+} \to K^+\pi^0, K^0_S\pi^+$
- K^* Helicity cut $|\cos\Theta_{K^*}| < 0.75$





- K^* resolution consistent with no non-resonnant contribution to $K\pi$
- Plots show Fits to relativistic p-Wave Breit-Wigner (not used in EML Fit)

Results for $B \to K^*\gamma$



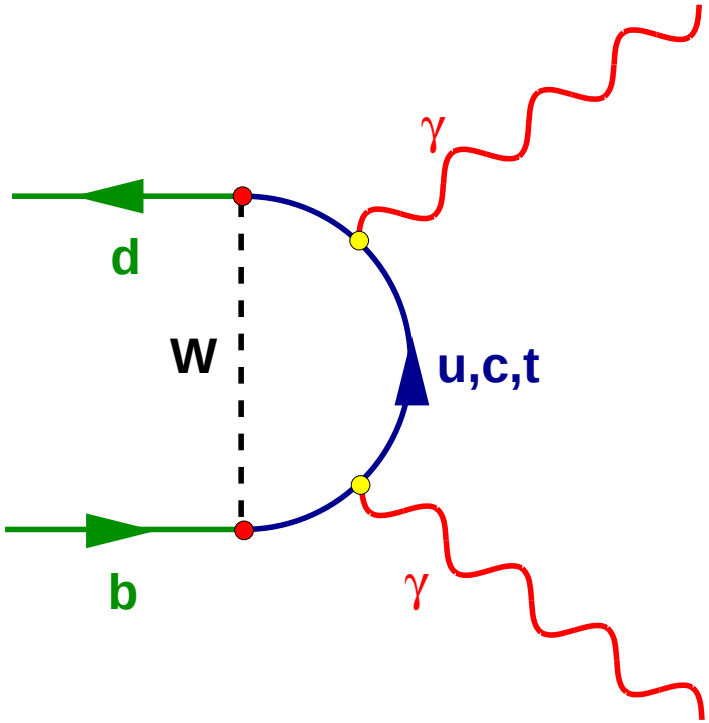
- require $-200\,\text{MeV} < \Delta E < 100\,\text{MeV}$ for $K^+\pi^-$ and $K^0_S\pi^+$
- require $-225\,\text{MeV} < \Delta E < 125\,\text{MeV}$ for $K^+\pi^0$ and $K^0_S\pi^0$

$$\begin{aligned}
\text{Br}(B^0 \to K^{*0}(K^+\pi^-)\gamma) &= (4.39 \pm 0.41 \pm 0.27) \times 10^{-5} \\
\text{Br}(B^0 \to K^{*0}(K^0_S\pi^0)\gamma) &= (4.10 \pm 1.71 \pm 0.42) \times 10^{-5} \\
\text{Br}(B^+ \to K^{*+}(K^0_S\pi^+)\gamma) &= (3.12 \pm 0.76 \pm 0.21) \times 10^{-5} \\
\text{Br}(B^+ \to K^{*+}(K^+\pi^0)\gamma) &= (5.52 \pm 1.07 \pm 0.33) \times 10^{-5}
\end{aligned}$$

preliminary

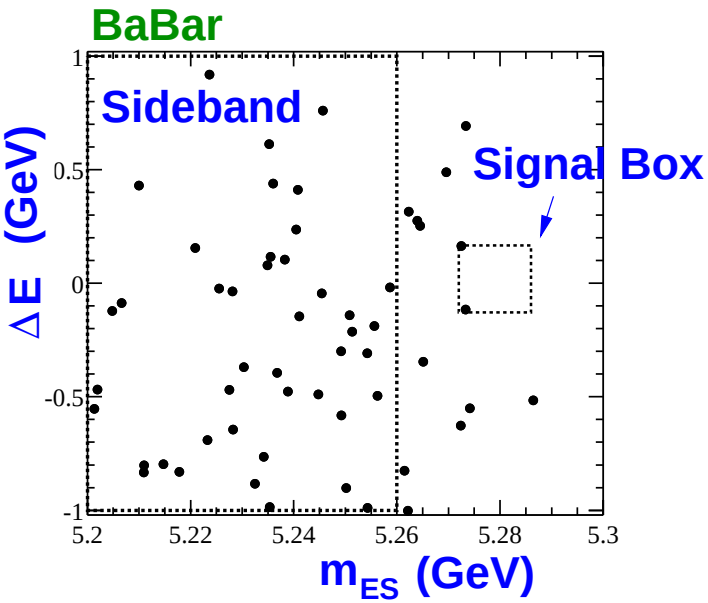
$$\begin{aligned}
\mathcal{A}_{\mathcal{CP}}(K^\pm\pi^\mp\gamma) &= -0.035 \pm 0.094 \pm 0.022 \\
\mathcal{A}_{\mathcal{CP}}(K^0_S\pi^\pm\gamma) &= -0.19 \pm 0.21 \pm 0.012 \\
\mathcal{A}_{\mathcal{CP}}(K^\pm\pi^0\gamma) &= 0.044 \pm 0.155 \pm 0.021 \\
\mathcal{A}_{\mathcal{CP}}(K^*\gamma) &= -0.035 \pm 0.076 \pm 0.012
\end{aligned}$$

Search for $B^0 \to \gamma\gamma$



preliminary

- Resolution:
  $\sigma(\Delta E) = 73\,\text{MeV}$,
  $\sigma(m_{ES}) = 3.9\,\text{MeV}$
- efficiency $(10.7 \pm 0.2)\,\%$
- found one event in Signal Box after unblinding
- expected Background 0.89 events



$$\text{Br}(B^0 \to \gamma\gamma) \quad < \quad 2.4 \times 10^{-6} \text{ @ } 90\,\% \text{ CL}$$

Conclusions

- No Evidence for Direct $\mathcal{CP}$ Violation yet
- Error on $\mathcal{A}_{\mathcal{CP}}(\mathrm{K}^{\pm}\pi^{\mp}) = -0.19 \pm 0.10 \pm 0.03$ soon interesting for theory comparison (see next talk by Matthias Neubert)
- $\mathrm{J}/\psi\mathrm{K}^{\pm}$ gives promising accuracy ($\mathcal{A}_{\mathcal{CP}}(\mathrm{J}/\psi\mathrm{K}^{\pm}) = 0.004 \pm 0.029 \pm 0.004$) ⇨ $\mathrm{J}/\psi\pi^{\pm}$ analysis
- Theoretical Branching Ratio Predictions for $\mathrm{B} \to \mathrm{K}^{*}\gamma$: 2 times larger than the measurement
- ***BABAR*** measurements for $\mathrm{B} \to \mathrm{X_s}\gamma, \rho\gamma, \omega\gamma$ soon
- ***BABAR*** recorded already $12\,\mathrm{fb}^{-1}$ in 2001

⇨ stay tuned for more Results