$D_s^+ \to K^+ \pi^0$ and $D_s^+ \to \pi^+ \pi^0$ at *BaBar*

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Overview

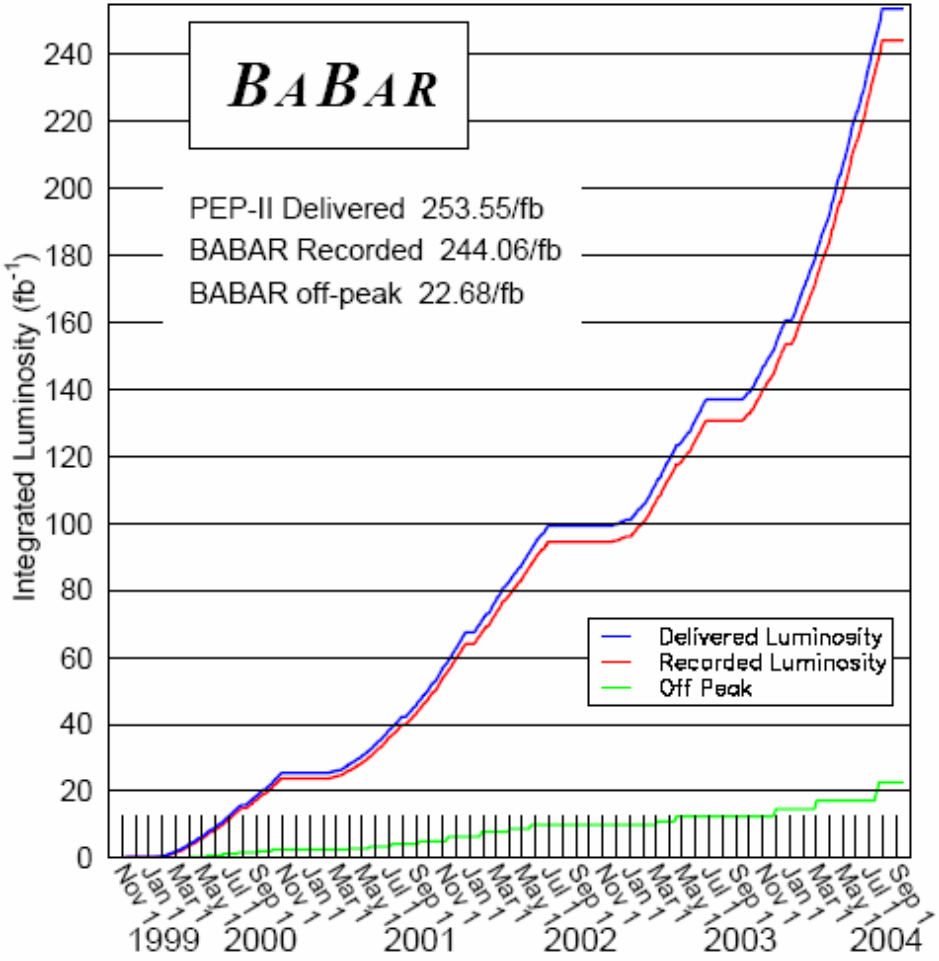
- PEP-II and the *BaBar* detector at SLAC.
- Motivation.
- Decay Reconstruction.
- Feasibility Study on MC:
  - Decay kinematics.
  - Expected significance.
- Summary:
  - Conclusions.
  - Current analysis status.
  - Future work.

PEP-II b-factory

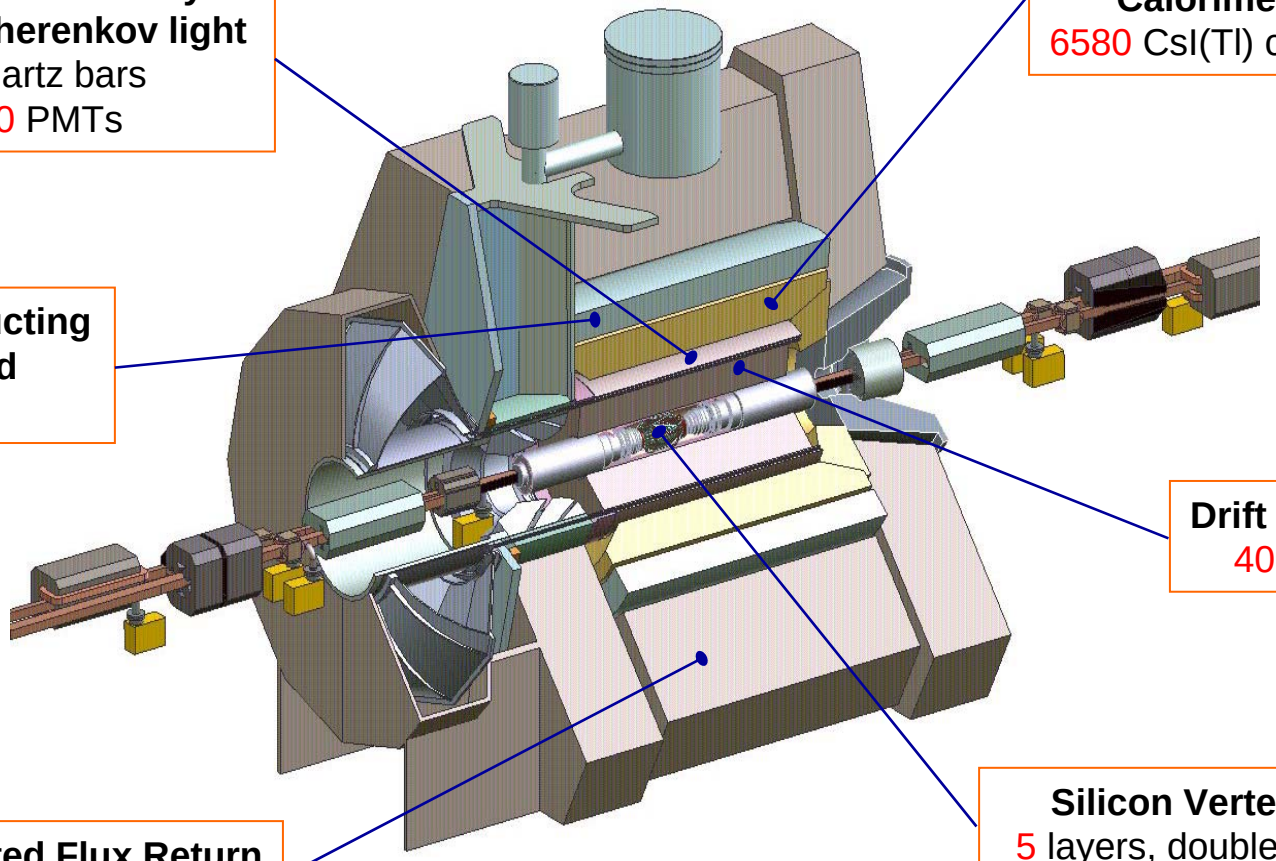
- **PEP-II Storage Rings**
  - Asymmetric energy e^+e^- collider – 9GeV electrons with 3.1GeV positrons
  - Boost $\beta\gamma = 0.56$
  - Centre of Mass energy:

$$\sqrt{s} = M(\Upsilon(4s)) = 10.58\,\mathrm{GeV}$$

  - Now have a large data sample:
    - **209** fb^{-1} on peak.
    - 21.5 fb^{-1} off peak.



The *BaBar* Detector



Detector of Internally Reflected Cherenkov light
144 quartz bars
11000 PMTs

Electromagnetic Calorimeter
6580 CsI(Tl) crystals

$3.1\,\mathrm{GeV}\ e^+$

Superconducting Solenoid
1.5T

Drift Chamber
40 layers

$9.0\,\mathrm{GeV}\ e^-$

Silicon Vertex Tracker
5 layers, double sided strips

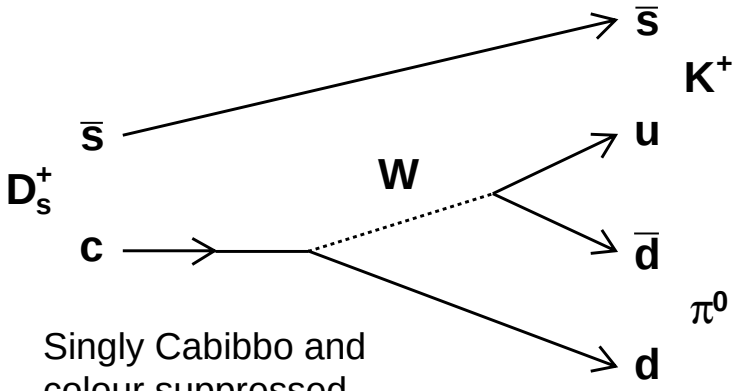
Instrumented Flux Return
iron / RPCs / LSTs

Motivation

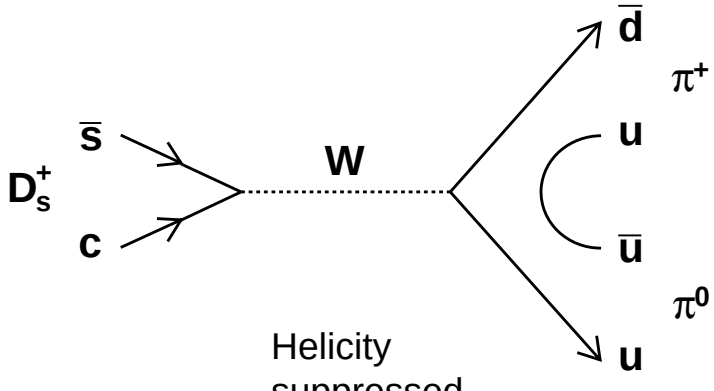
- Although *BaBar* is a b-factory it is also a c-factory; a lot of charm is produced:

$$\sigma(e^+e^- \to b\bar{b}) = 1.05\,\text{nb}$$
$$\sigma(e^+e^- \to c\bar{c}) = 1.30\,\text{nb}$$

- The decay modes $D_s^+ \to K^+\pi^0$ and $\pi^+\pi^0$ have not been observed.
- $D_s^+ \to K^+\pi^0$ is a singly Cabibbo suppressed decay which could be measureable with the large data sample at *BaBar*.
- $D_s^+ \to \pi^+\pi^0$ is helicity suppressed but the only difference here is the PID on the track so the mode will be measured in parallel with $K^+\pi^0$.



Singly Cabibbo and colour suppressed



Helicity suppressed

Feasibility Study

- **Goal:**
  - Investigate the *feasibility* of measuring $D_s^+ \rightarrow K^+\pi^0$ and $\pi^+\pi^0$ at *BaBar*.
- **Procedure:**
  - Write reconstruction software.
  - Identify useful quantities to select on.
  - Basic cut based analysis with a simple cut optimisation routine.
  - Perform this on a MC sample to determine an expected statistical significance.

Reconstructing the Decay

- D_s^+ mesons are reconstructed from one track and a π^0 candidate.
- D_s^+ candidates are required to come from a D_s^{*+} decaying radiatively to provide a cleaner signal.
  - $BR(D_s^{*+} \rightarrow D_s^+\gamma) = 95\%$.
- Building D_s^+ candidates:
  - There is only one track in the decay so can't vertex the D_s^+.
  - Simple 4-vector addition gives adequate reconstruction.
- Building D_s^{*+} candidates:
  - Production and decay point is assumed to be the beamspot.
- Concentrating on $K^+\pi^0$ mode for initial studies.
  - $\pi^+\pi^0$ mode will be investigated at a later stage by simply changing the PID requirements on the charged track.

MC and Decay Kinematics

- **MC samples**
  - Generated 10^5 $D_s^{*+} \rightarrow D_s^{+}\gamma$, $D_s^{+} \rightarrow K^{+}\pi^0$ signal MC events.
  - Reconstructed these plus 3×10^6 generic MC events each of the following modes:

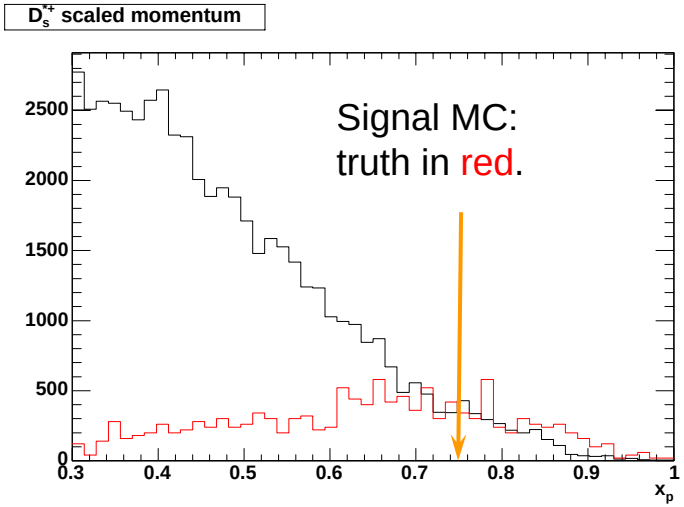
$$e^+e^- \rightarrow c\bar{c}, uds, B\bar{B}, B^0\bar{B}^0, \tau^+\tau^-$$

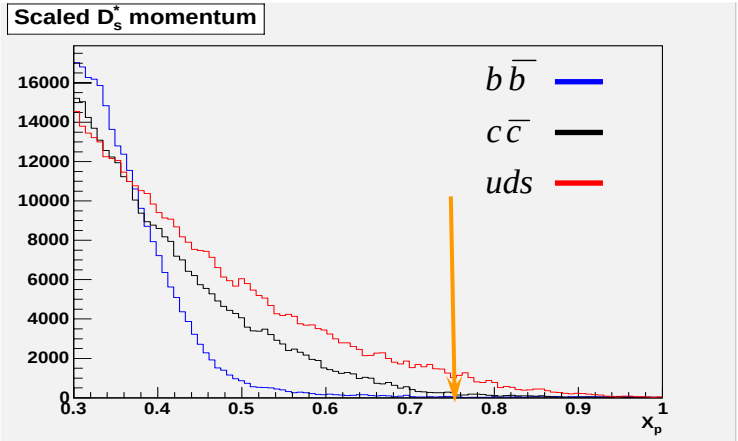
- **Decay Kinematics and Useful Variables**
  - D_s^* from $c\bar{c}$ are fast compared with $b\bar{b}$ decays, this provides a very good characteristic of the signal mode.
    - $\mathbf{X_p}$ = Ds^{*+} momentum normalised to the maximum kinematically allowed.
  - Photon from radiative D_s^* decay is soft $\Rightarrow$ increases combinatorics by picking up a lot of low energy photons.
    - γ lab and CM energies and lateral moment.
  - Reconstructed masses can be combined to form uncorrelated variables – good for a simultaneous fit.
    - ΔM $M(D_s^{*+}) - M(D_s^{+})$
    - ΣM $M(D_s^{*+}) + M(D_s^{+})$

Rejecting *b* Background

- Momentum is normalised to the beam momentum in CM frame. MC truth signal is in red.
- Optimised Cut: $x_p > 0.75$
- Almost the same as cutting on the D_s^* CM momentum.
- This is good because D_s^* carries most of the momentum in this mode.

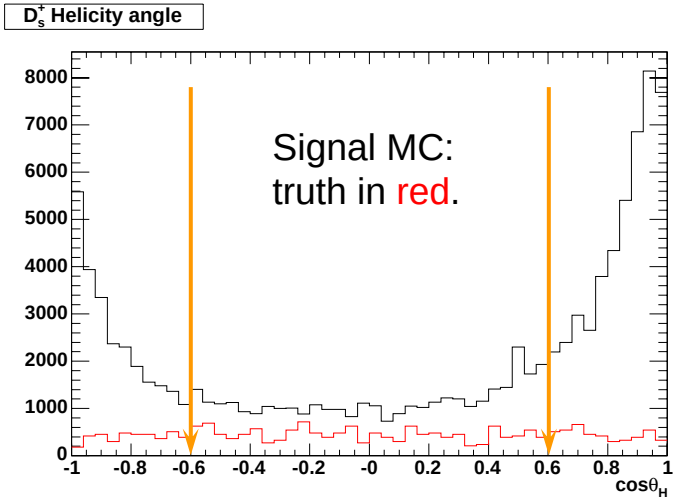
$$x_P = p^*_{D_s^{*+}} / \sqrt{E^{*\,2}_{beam} - m^2_{D_s^{*+}}}$$

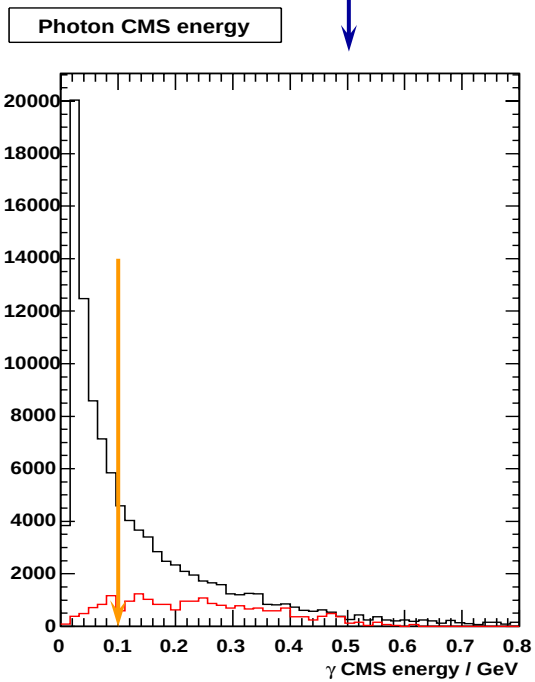


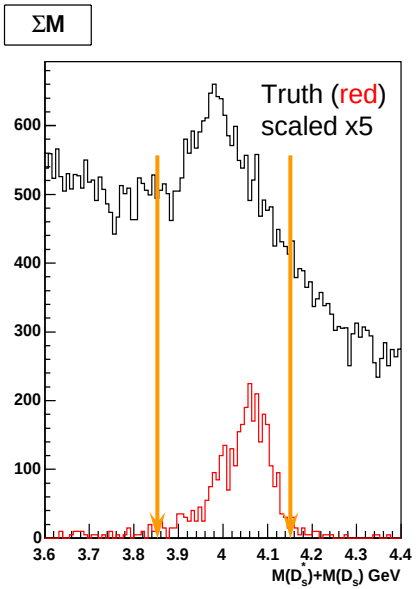


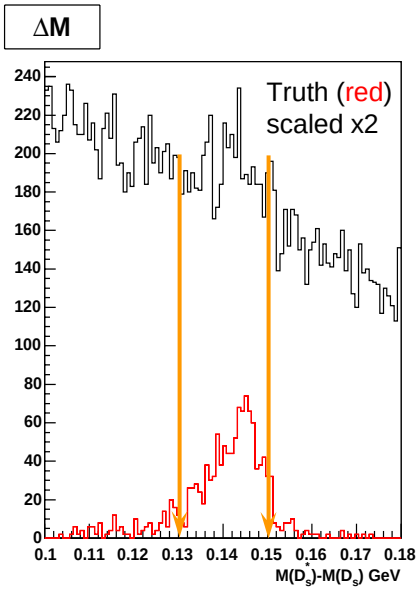
Further Useful Cuts

- D_s^+ decay angle, θ_H
- Sum and difference of D_s^* and D_s masses; ΣM, ΔM
- Radiative γ E_{cms}









Determining Significance

- Cuts optimised simultaneously.
- The number of D_s^* mesons from ccbar is estimated:
  - ~10% of ccbar events will contain at least one D_s^*.
  - ~95% of these will decay to a D_s.
- Cross-sections taken from *BaBar* physics book.
- Efficiencies determined by reconstructing MC.
- Numbers scaled to an integrated luminosity of 209 fb^{-1} to estimate the number of expected events for each channel.
- Expect all signal from ccbar (bbbar is excluded by x_p cut).
- Use standard formula on the right to estimate the significance.

Mode	Cross-section (nb)
uds	2.09
$c\bar{c}$	1.30
B^+B^-	0.55
$B^0\bar{B}^0$	0.55
$\tau^+\tau^-$	0.94

Assume BR($D_s^+ \rightarrow K^+\pi^0$) ~ 3 x 10^{-4}

$$sig. = \frac{N_S}{\sqrt{N_S + N_B}}$$

After Optimisation

Optimised Cuts
$3.85 < M(D_s^{*+} + D_s^{+}) < 4.15$ GeV/c^2
$0.13 < M(D_s^{*+} - D_s^{+}) < 0.15$ GeV/c^2
D_s^{*+} scaled $p > 0.75$
D_s^{+} $\lvert\cos\theta_H\rvert < 0.6$
γ $E_{lab} > 0.05$, $E_{cms} > 0.1$ GeV γ Lat. Mom. < 0.8
π^0 from γ must fail $E_{cms} > 0.2$ GeV && $0.115 < M_\pi < 0.155$ GeV/c^2

Mode	Efficiency	Events (209 fb^{-1})
Signal	0.028	213
$c\bar{c}$	2e-6	543
uds	3.3e-6	1456
B^+B^-	<7.7e-7	<88
$B^0\bar{B}^0$	<7.7e-7	<88
$\tau^+\tau^-$	<7.7e-7	<150

$$\frac{N_S}{\sqrt{N_S + N_B}} \geq 4.2$$

Summary

Conclusions:

- Cut optimisation has yielded a reasonable significance.
  - Fit should improve further on this.
- Major backgrounds are uds and $c\bar{c}$ in that order.
  - Find better discrimination between these major backgrounds: event shape parameters, quantities for the rest of the event etc…
- Good chance of observing/measuring this mode with *BaBar*.

Current Status and Future Work:

- Likelihood fit is in development:
  - Using ΔM and ΣM as uncorrelated variables for the fit with an optimised cut in x_p.
  - All cuts are re-optimised for the fit.
- Currently pre-selecting on the full dataset and preparing for full ntuple production.
- A reference mode will be reconstructed in parallel to measure a ratio of branching fractions because the D_s^* production rate is not well known. (current choice is $D_s^+ \rightarrow K_s K^+$).