Study of *ISR* Production of the $D\bar{D}$ System at *BABAR*

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Summary

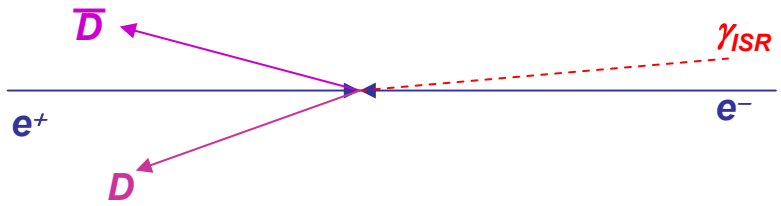
- Motivation
- Reconstruction
- Cross section measurements
- Interpretation of the results
- Conclusions

arXiv:0710.1371 [hep-ex], submitted to Phys. Rev. D rapid communications

Results are preliminary

Motivation

- Several new states with $c\bar{c}$ content recently discovered
  - Many have masses well above open charm threshold
- Ordinary charmonium states at these masses are expected to mostly decay to $D^{(*)}\bar{D}^{(*)}$.
- ISR production of $D\bar{D}$ states allows to study $J^{PC}=1^{--}$ states above threshold
  - Both $D^0\bar{D}^0$ and D^+D^- considered.
  - Previous results on a smaller dataset, 289/fb (hep-ex/0607083).
  - Update to 384/fb

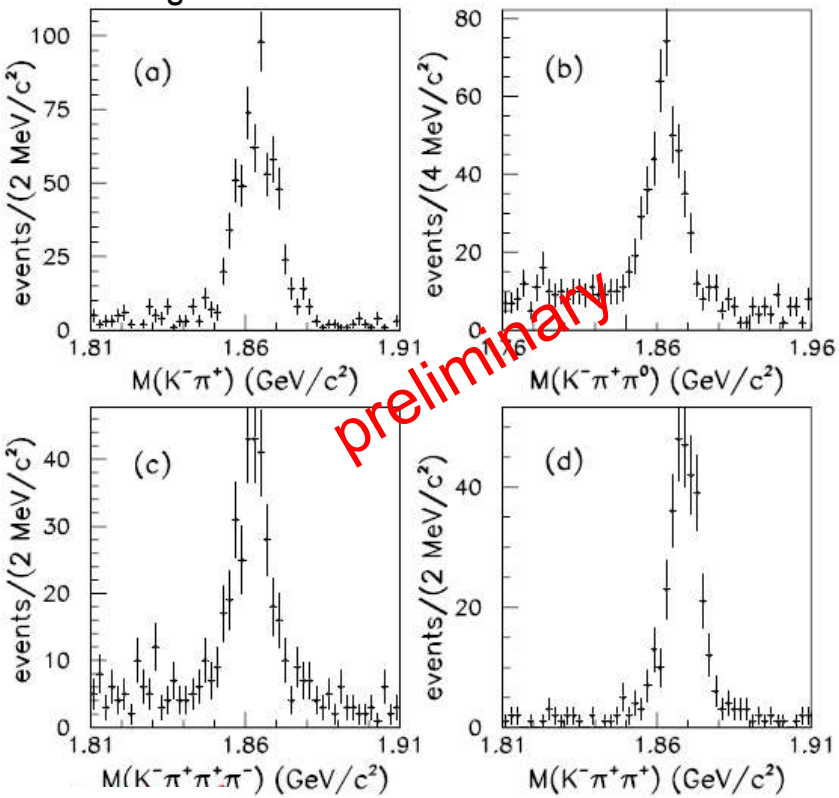


γ_{ISR} detection not requested: reconstructed as missing particle

Reconstruction (I)

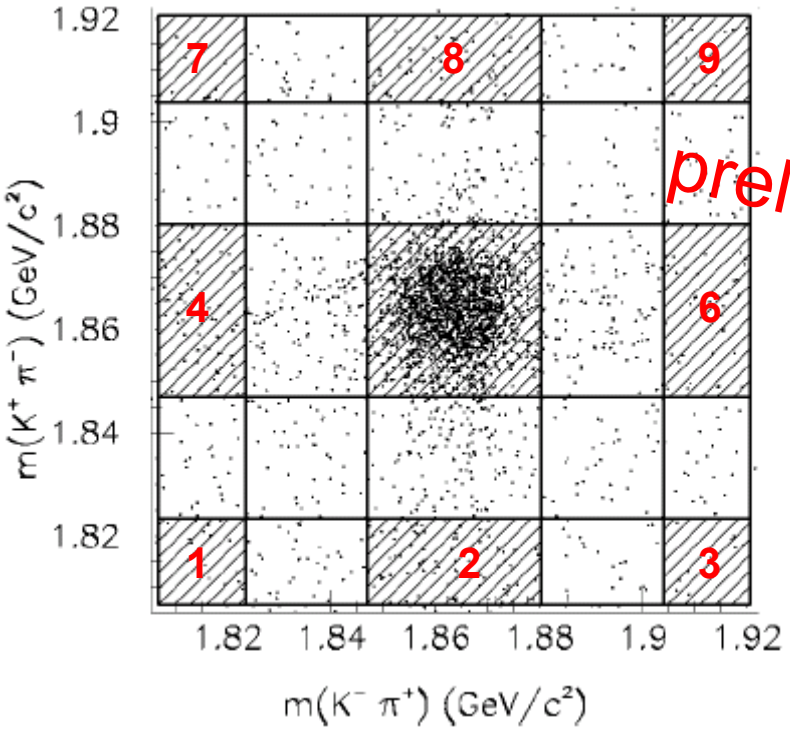
- 7 combinations of *D* decay modes considered:
  - $D^0 \to K^- \pi^+,\ K^- \pi^+ \pi^0,\ K^- \pi^+ \pi^+ \pi^-$
  - $D^+ \to K^- \pi^+ \pi^+,\ K^- K^+ \pi^+,\ K_s \pi^+$

examples

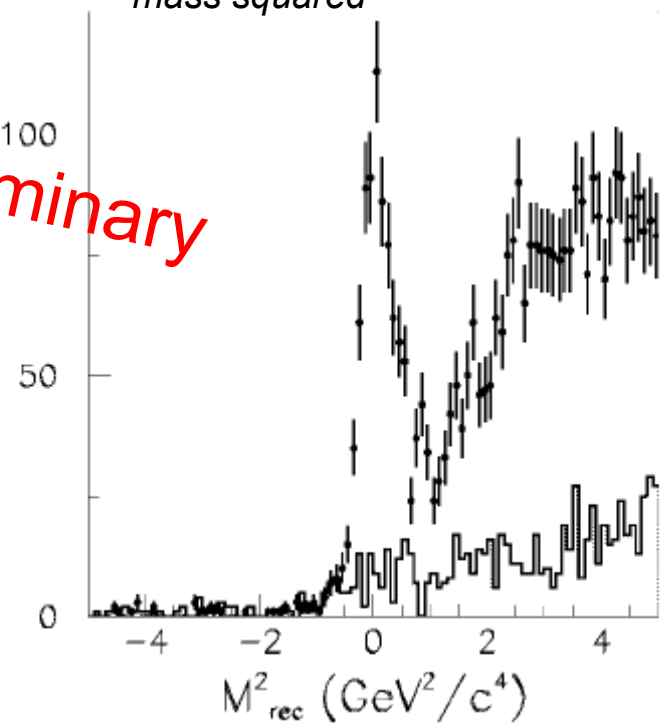


Reconstruction (II)

example



event missing mass squared $M^2_{rec} = (\mathbf{p}_{e+} + \mathbf{p}_{e-} - \mathbf{p}_D - \mathbf{p}_{\bar{D}})^2$



preliminary

background from the 9-tile method:

2+4+6+8-(1+3+7+9)

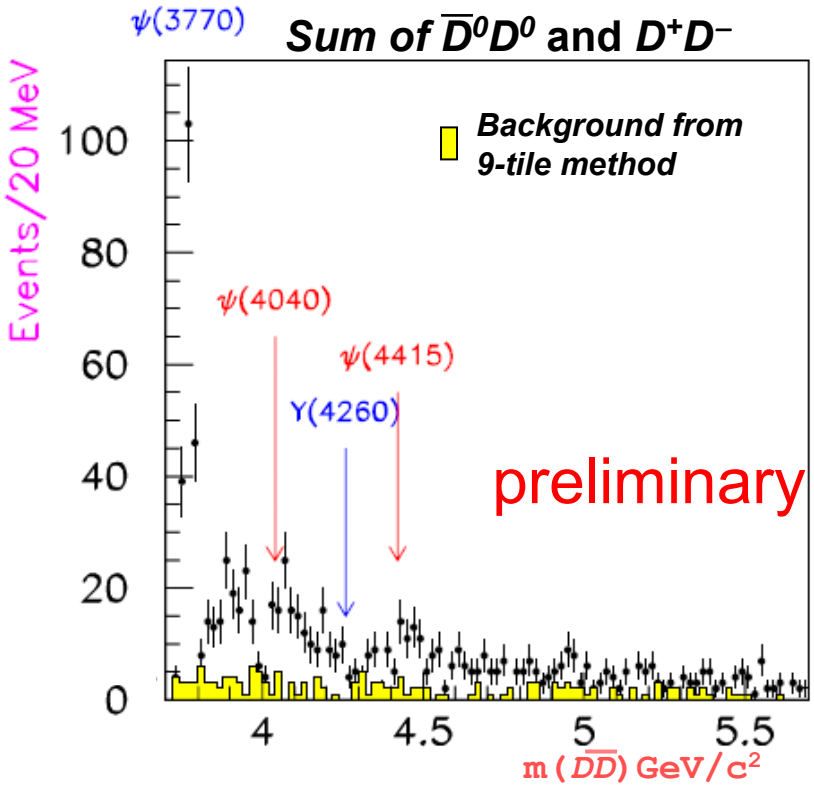
- $|M^2_{rec}| < 1$ GeV^2/c^4
- m($D\bar{D}$) < 6 GeV/c^2 to suppress $e^+e^- \rightarrow D\bar{D}^{(*)}$ events

Background Studies

- 9-tile method shows little background in the signal region.
- Possible background from charmonium decays to $D\bar{D}^*$ with undetected γ or π^0.
  - Very little D^* signal observed in $\Delta m(D^0\gamma)$ and $\Delta m(D^0\pi^0)$ in missing mass signal region.
  - Sideband of missing mass shows prominent D^{*0} component.
- Non ISR events.
  - Sideband of missing mass shows no evidence of any $D\bar{D}$ structure.

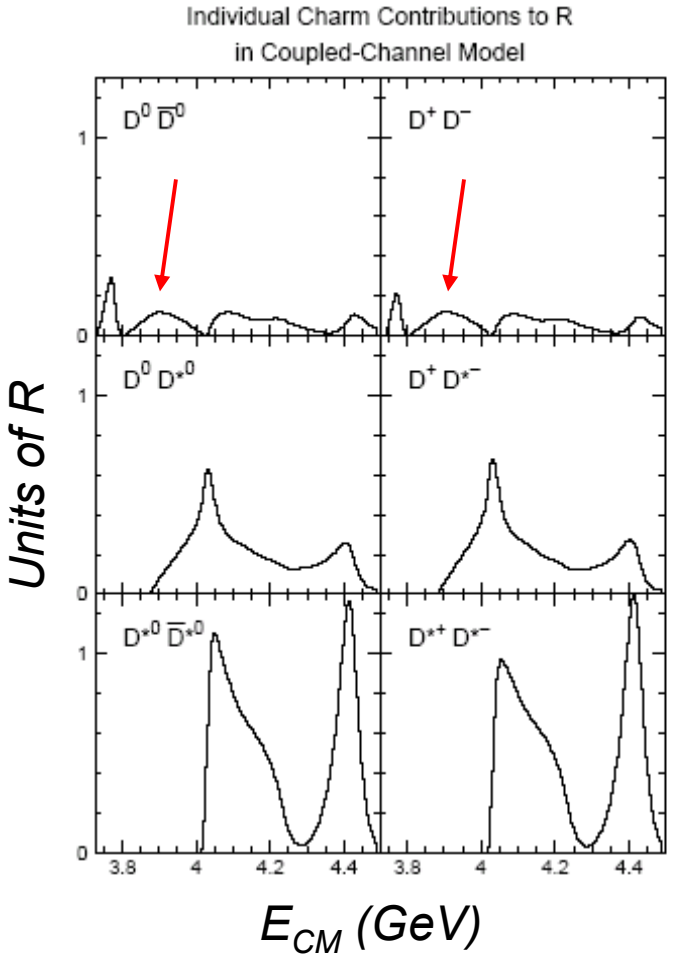
$D\bar{D}$ Mass Spectrum

- Total $\bar{D}^0 D^0$ and $D^+ D^-$ mass spectrum.
- Prominent $\psi(3770)$ peak
- Indication of $\psi(4415)$ and $\psi(4040)$
- No sign of $\psi(4160)$ and $Y(4260)$
- A structure at ~ 3.9 GeV/c^2



Coupled-Channel Effects

- The structure at 3.9 GeV is not necessarily associated to a new state.
- The coupled-channel model (*Phys. Rev.* ***D21****, 203, 1980*) predicts an enhancement in this region.



Cross Section Measurement (I)

- $D\bar{D}$ ISR events simulated with m($D\bar{D}$) at various values; a m($D\bar{D}$)-dependent efficiency is determined for every mode.

$$\varepsilon_i^B(m_{D\bar{D}}) = \varepsilon_i(m_{D\bar{D}}) \times \mathcal{B}_i \qquad \varepsilon^B(m_{D\bar{D}}) = \frac{\Sigma^7_{i=1} N_i(m_{D\bar{D}})}{\Sigma^7_{i=1} N_i(m_{D\bar{D}}) / \varepsilon_i^B(m_{D\bar{D}})}$$

- Differential luminosity[(1)] :

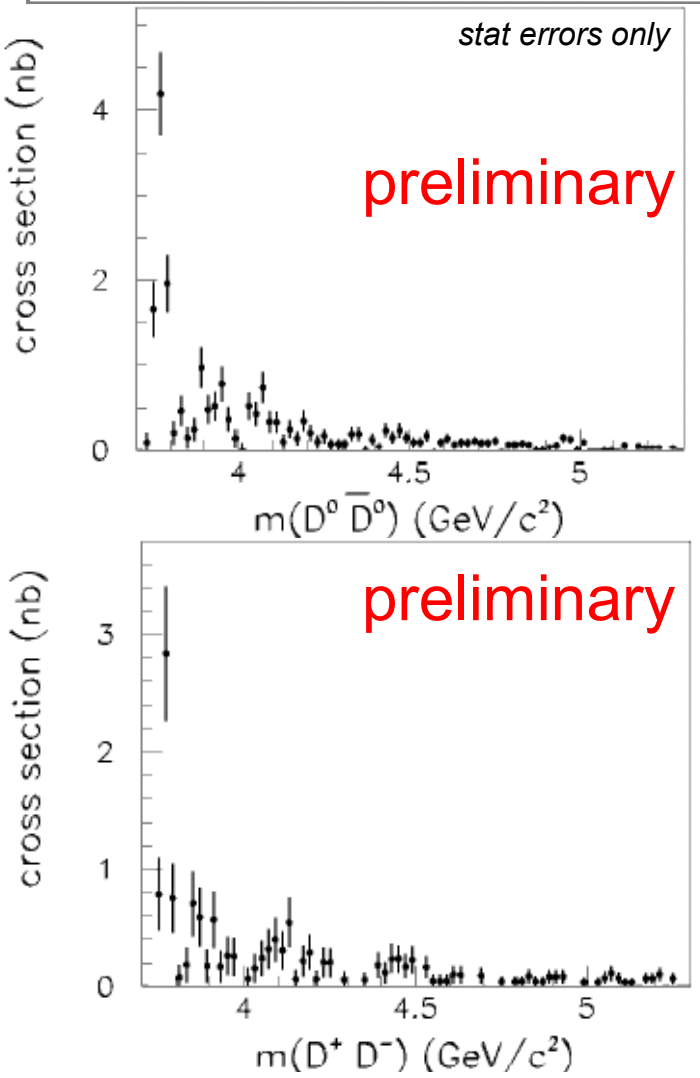
$$\frac{dL}{dm_{D\bar{D}}} = L \frac{2m_{D\bar{D}}}{s} \frac{\alpha}{\pi x} (\ln(s/m^2_e) - 1)(2 - 2x + x^2) \qquad (x = 1 - m^2_{D\bar{D}} / s)$$

- $D\bar{D}$ cross section:

$$\sigma_{e+e- \to D\bar{D}}(m_{D\bar{D}}) = \frac{dN / dm_{D\bar{D}}}{\varepsilon^B(m_{D\bar{D}})\, dL / dm_{D\bar{D}}}$$

(1) M. Benayoun et al. Mod. Phys. Lett. A 14, 2605 (1999)

Cross Section Measurement (II)



- Integrating the $\psi(3770)$ region:

$$\frac{\mathcal{B}(\psi(3770) \to D^0\bar{D}^0)}{\mathcal{B}(\psi(3770) \to D^+D^-)} = 1.78 \pm 0.33 \pm 0.24$$

PDG06: 1.28 ± 0.14

- Systematic errors
  - PID efficiencies, background estimate, imperfect simulation of extra π^0;
  - an overall common scale.

Fit to $D\bar{D}$ Mass Spectrum (I)

- UML fit to the sum of all modes.
- $\psi(4415)$, $\psi(4160)$ and $\psi(4040)$ parameters fixed to BES results.
- Parameters of $\psi(3770)$ and 3.9-GeV structure (a Gaussian) are left free.
- Data are better described including interference between the ψs and non-resonant $D\bar{D}$ background.

$$f\left|P + c_1 W_1 e^{i\phi_1} + c_2\sqrt{G}e^{i\phi_2} + \ldots + c_n W_n e^{i\phi_n}\right|^2 + (1-f)B$$

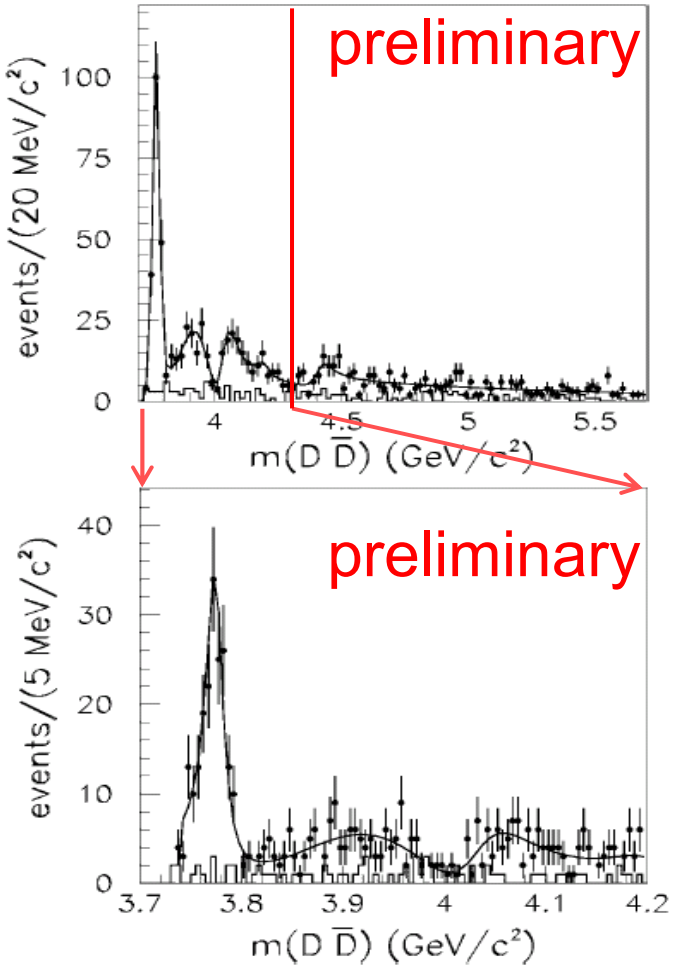
ψs

3.9-GeV structure

non $D\bar{D}$ background

P, B: a threshold function. Also considered a linear function for *P*.

f = 0.829 ± 0.015



Fit to $D\bar{D}$ Mass Spectrum (II)

- A second fit is performed weighting each event with $1/\varepsilon^{B}_{i}$.
- This fit yields:

  $m(\psi(3770)) = (3778.8 \pm 1.9 \pm 0.9)$ MeV/c^2 *PDG06: (3772.4 ± 1.1) MeV/c^2*

  $\Gamma(\psi(3770)) = (23.5 \pm 3.7 \pm 0.9)$ MeV

  $m(G(3900)) = (3943 \pm 17 \pm 12)$ MeV/c^2

  $\sigma(G(3900)) = (52 \pm 8 \pm 7)$ MeV/c^2
- No $Y(4260)$ (nor higher-mass Y states) is found:
  - $N(Y(4260)) = 0.2 \pm 6.1 \pm 2.8$;
  - using *BABAR* measurement of $\mathcal{B}(Y(4260) \to J/\psi\,\pi^+\pi^-)$ [(1)]

$$\frac{\mathcal{B}(Y(4260) \to D\bar{D})}{\mathcal{B}(Y(4260) \to J/\psi\,\pi^+\pi^-)} < 1.0, \quad 90\%\ \text{C.L.}$$

[(1)] Phys. Rev. Lett. 95, 142001 (2005)

Conclusions

- $D\bar{D}$-pair production in ISR is an interesting tool to study vector states with $c\bar{c}$ content.
- Spectrum dominated by $J^{PC}=1^{--}$ ψ resonances.
- In addition, the presence of a broad structrure near 3.9 GeV/c^2 is required.
  - possibly not a new ψ state (coupled-channel effect ?).
- No evidence for $Y(4260)$ (nor other Y states)
  - different behavior wrt ordinary charmonium states.
- Paper submitted to Phys. Rev. D RC

Back-up Slides

The *BABAR* Detector

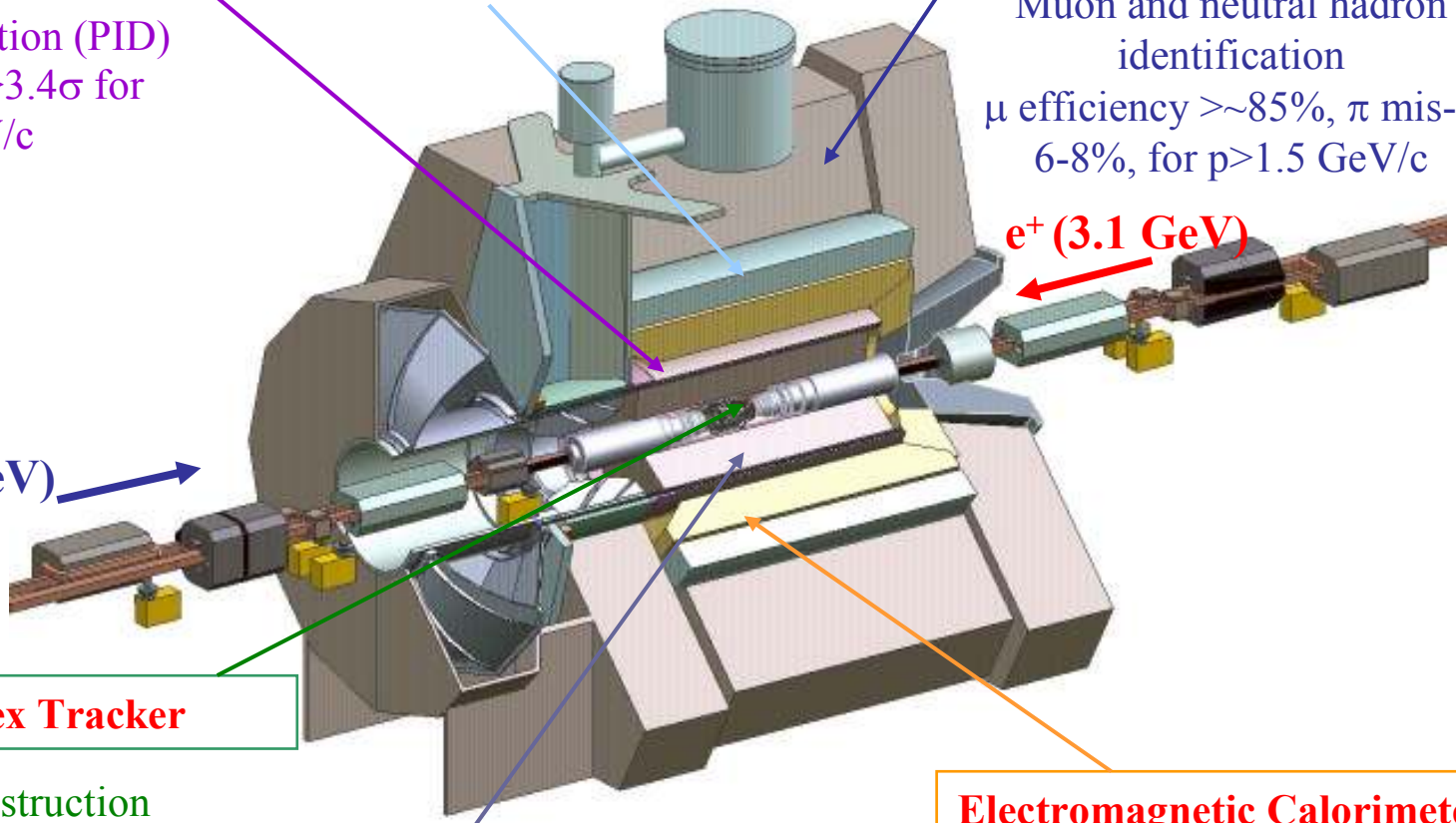
Cherenkov Detector

Particle identification (PID)
K-π separation >3.4σ for
p<3.5GeV/c

Solenoid 1.5T

Instrumented Flux Return

Muon and neutral hadron identification
μ efficiency >~85%, π mis-id 6-8%, for p>1.5 GeV/c



Silicon Vertex Tracker

Vertex reconstruction and tracking + dE/dx.
Efficiency ~ 97%

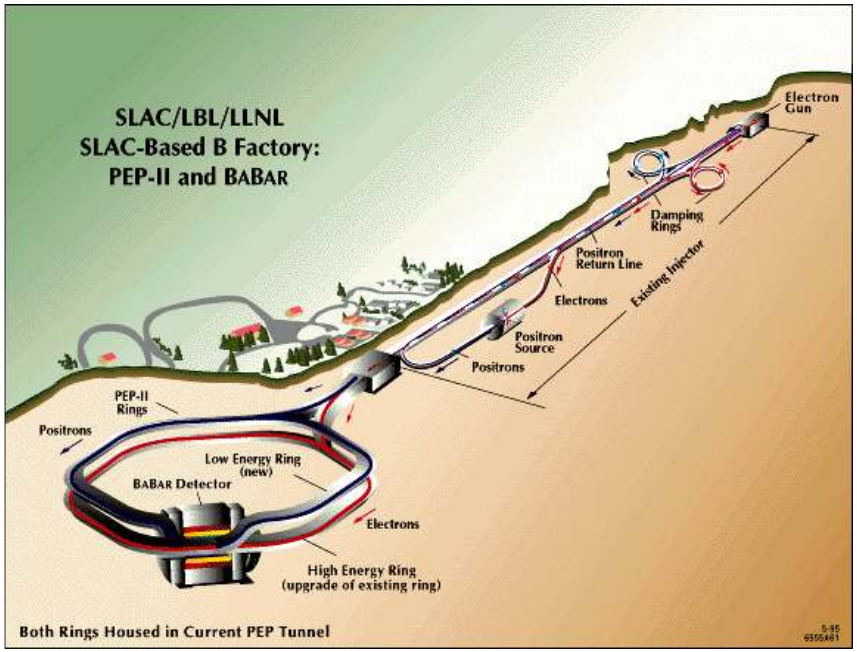
Drift Chamber

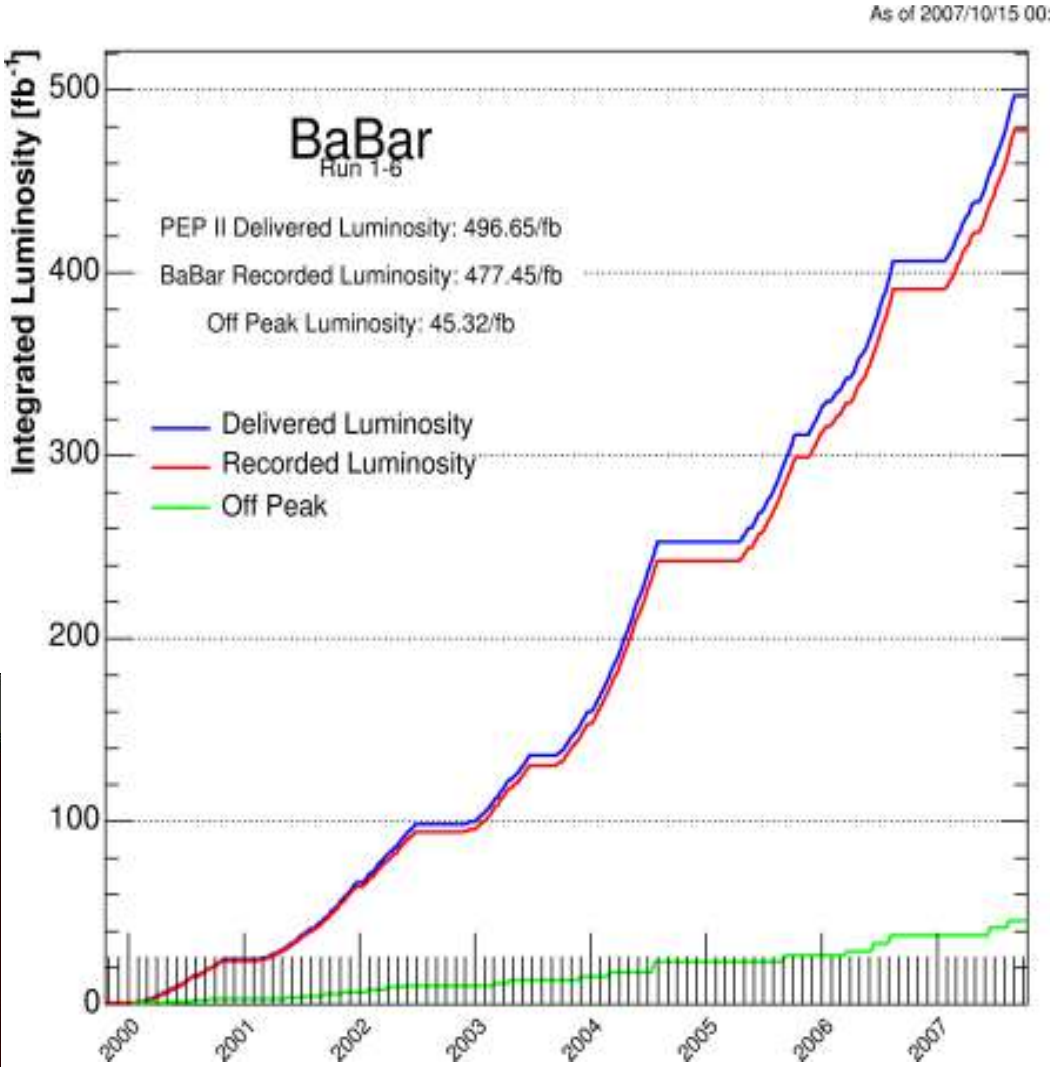
Momentum measurement for charged particles + dE/dx.
$\sigma(p_T)/p_T=0.13\%p_T\oplus0.45\%$

Electromagnetic Calorimeter

Electron and photon energy measurement.
$\sigma(E)/E=1.33\%E^{-1/4}\oplus2.1\%$

- Beam energies: 9 GeV e^- / 3.1 GeV e^+
- Instantaneous luminosity:
  $L_{peak} \approx 12 \times 10^{33}\ cm^{-2}\ s^{-1}$
- Boost: $\beta\gamma \sim 0.56$





Current data sample

Reconstruction

- 7 combinations of *D* decay modes considered

Channel	First D decay mode	Second D decay mode	$\epsilon_i^{\mathcal{B}}(m_{D\bar{D}})$ $(\times 10^{-3})$
1. $D^0\overline{D}^0$	$D^0 \to K^-\pi^+$	$\overline{D}^0 \to K^+\pi^-$	0.14
2. $D^0\overline{D}^0$	$D^0 \to K^-\pi^+$	$\overline{D}^0 \to K^+\pi^-\pi^0$	0.42
3. $D^0\overline{D}^0$	$D^0 \to K^-\pi^+$	$\overline{D}^0 \to K^+\pi^-\pi^+\pi^-$	0.18
4. $D^0\overline{D}^0$	$D^0 \to K^-\pi^+\pi^0$	$\overline{D}^0 \to K^+\pi^-\pi^+\pi^-$	0.26
5. D^+D^-	$D^+ \to K^-\pi^+\pi^+$	$D^- \to K^+\pi^-\pi^-$	0.37
6. D^+D^-	$D^+ \to K^-\pi^+\pi^+$	$D^- \to K^+K^-\pi^-$	0.081
7. D^+D^-	$D^+ \to K^-\pi^+\pi^+$	$D^- \to K^0_S\pi^-$	0.042

$\epsilon^{\mathcal{B}}_i$: efficiency $\times$ branching fraction

- Tracks forming *D* candidates constrained to common vertex (χ^2 vertex prob>0.1%).
- Photon energy for π^0 > 30 MeV.
- $D\overline{D}$ pairs constrained to common vertex and requested to originate from interaction region.
- One extra π^0 candidate only allowed in the event (zero for channel 4); no extra well measured tracks.
- L = 384/fb.

Fit to $\bar{D}D$ Mass Spectrum

- Systematics include uncertainties from
  - masses and widths of the ψs;
  - signal fraction;
  - meson radius in the Breit-Wigner;
  - different parameterization of background;
  - D masses and overall $\bar{D}D$ mass scale;
  - $\varepsilon^{B}(m\bar{D}D)$.