Results from BaBar on the Decays
$B \to K l^+ l^-$ and $B \to K^* l^+ l^-$

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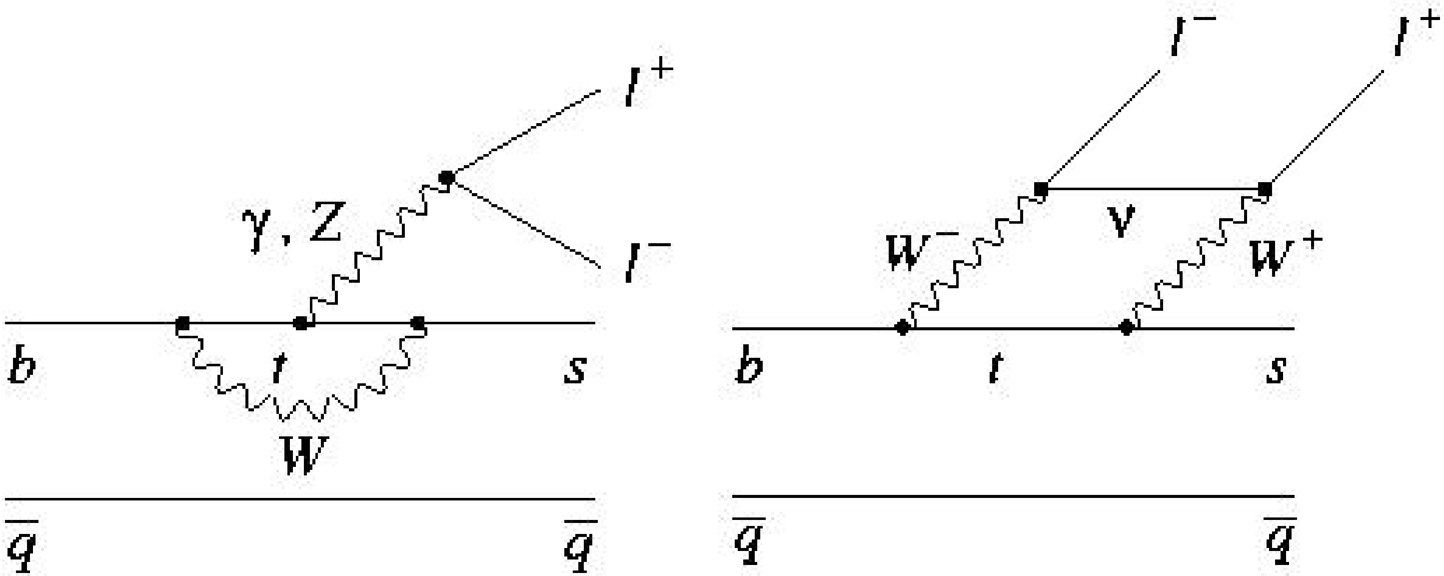
Outline

- Introduction
- Analysis Overview
- Control Samples
- Results

B ® K$^{(*)}$l$^+$l$^-$ in the SM and Beyond



- Flavor changing neutral current: proceeds via loop or box diagrams $\Rightarrow$ quite small SM branching ratios
- Massive particles can contribute to the loop/box: top quark, Higgs, SUSY$\Rightarrow$ sensitivity to New Physics

Branching Fraction Predictions in the Standard Model

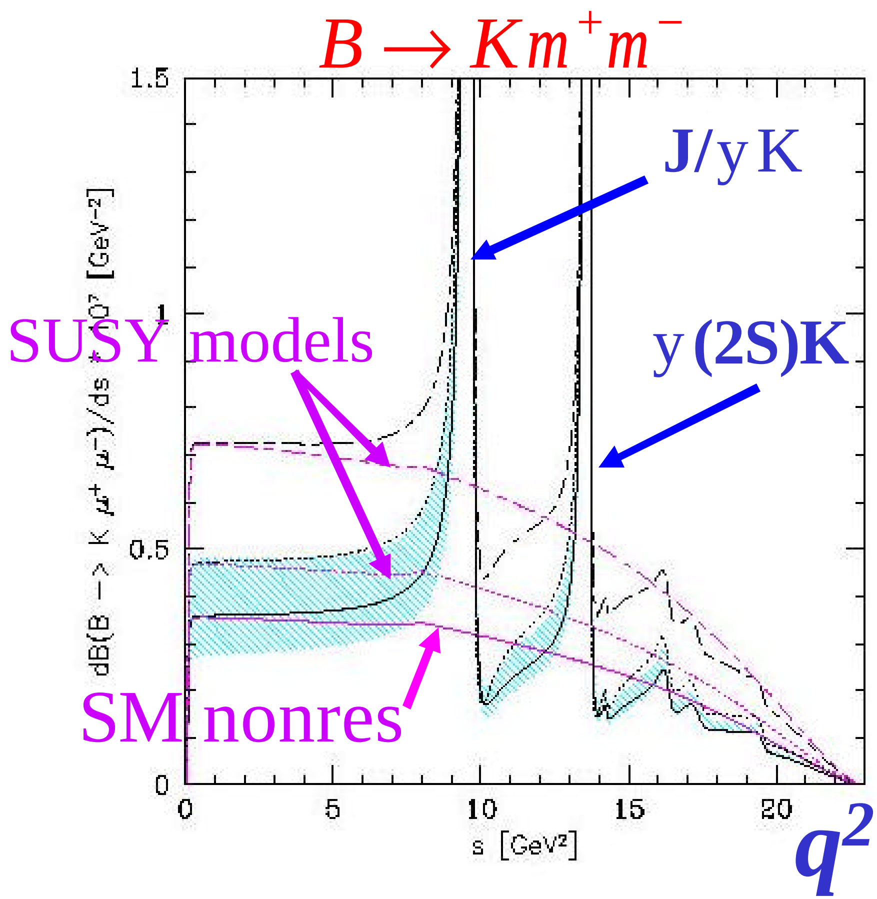
Authors	$\mathcal{B}(B \to K l^+ l^-)$ $/10^{-6}$	$\mathcal{B}(B \to K^* \mu^+ \mu^-)$ $/10^{-6}$	$\mathcal{B}(B \to K^* e^+ e^-)$ $/10^{-6}$
Ali *et al.* 2000	$0.57^{+0.17}_{-0.10}$	$1.9^{+0.5}_{-0.4}$	$2.3^{+0.7}_{-0.5}$
Ali *et al.* 2001 (NNLO)	0.35 ± 0.12	1.19 ± 0.39	1.58 ± 0.49
Colangelo *et al.*	0.3	1.0	
Melikhov *et al.*	0.44	1.15	1.50
Aliev *et al.*	0.31 ± 0.09	1.4	
Geng and Kao	0.5	1.4	

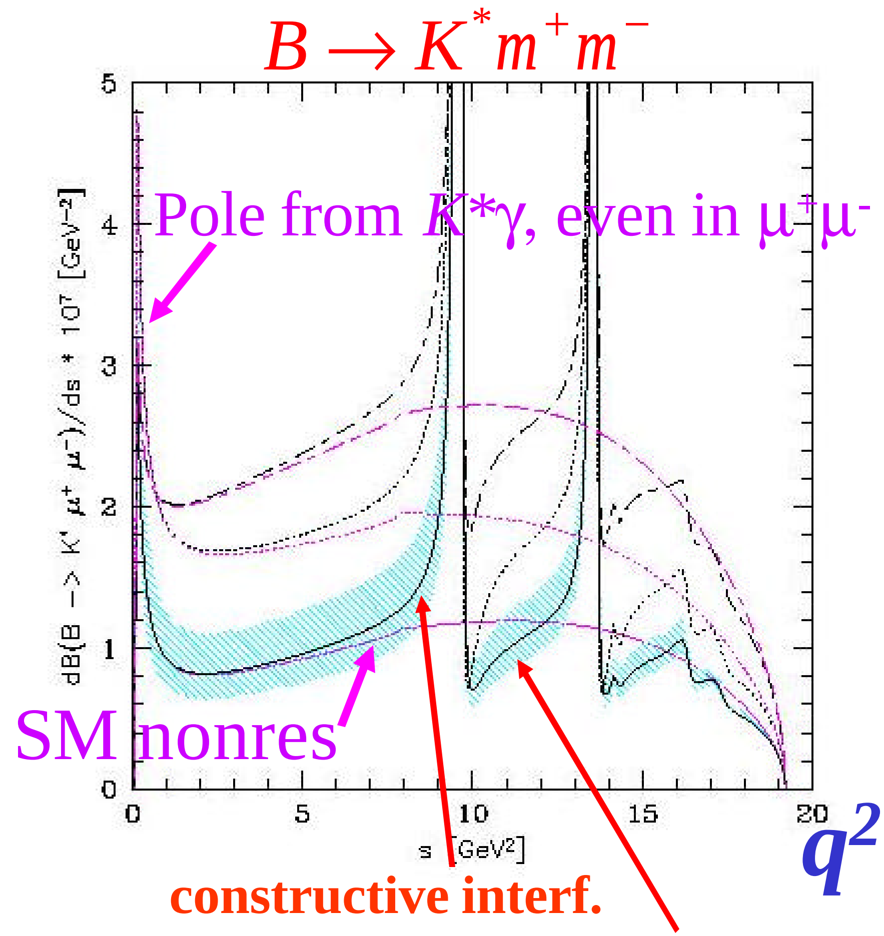
New Ali *et al.* predictions are lower!

- $\mathcal{B}(B \to K \ell^+ \ell^-) =$
  $(0.35 \pm 0.11(\text{form fac.}) \pm 0.04(\mu_b) \pm 0.02(m_{t,\text{pole}}) \pm 0.0005(m_c/m_b)) \times 10^{-6}$
  [Ali, Lunghi, Greub, Hiller, hep-ph/0112300, 2001]
- $\mathcal{B}(B \to X_s \mu^+ \mu^-) = (4.15 \pm 0.70) \times 10^{-6}$
  $\mathcal{B}(B \to X_s e^+ e^-) = (6.89 \pm 1.01) \times 10^{-6}$

(All predictions exclude J/y contribution.)

Decay rate vs. q^2 in the SM and SUSY





- Solid line+blue bands: SM range (±35%); Ali *et al.* form factors
- Dotted line: SUGRA model ($R_7 = -1.2$, $R_9 = 1.03$, $R_{10} = 1$; $R_i = C_i/C_i^{\rm SM}$)
- Long-short dashed line: SUSY model ($R_7 = -0.83$, $R_9 = 0.92$, $R_{10} = 1.61$)

Recent Experimental Results

- Belle has published a signal based on 29.1 fb^{-1}.

$$B(B \to K l^+ l^-) = (0.75^{+0.25}_{-0.21} \pm 0.09) \times 10^{-6}$$

$$B(B \to K m^+ m^-) = (0.99^{+0.40+0.13}_{-0.32-0.14}) \times 10^{-6}$$

$$B(B \to K^* m^+ m^-) < 3.1 \times 10^{-6}$$

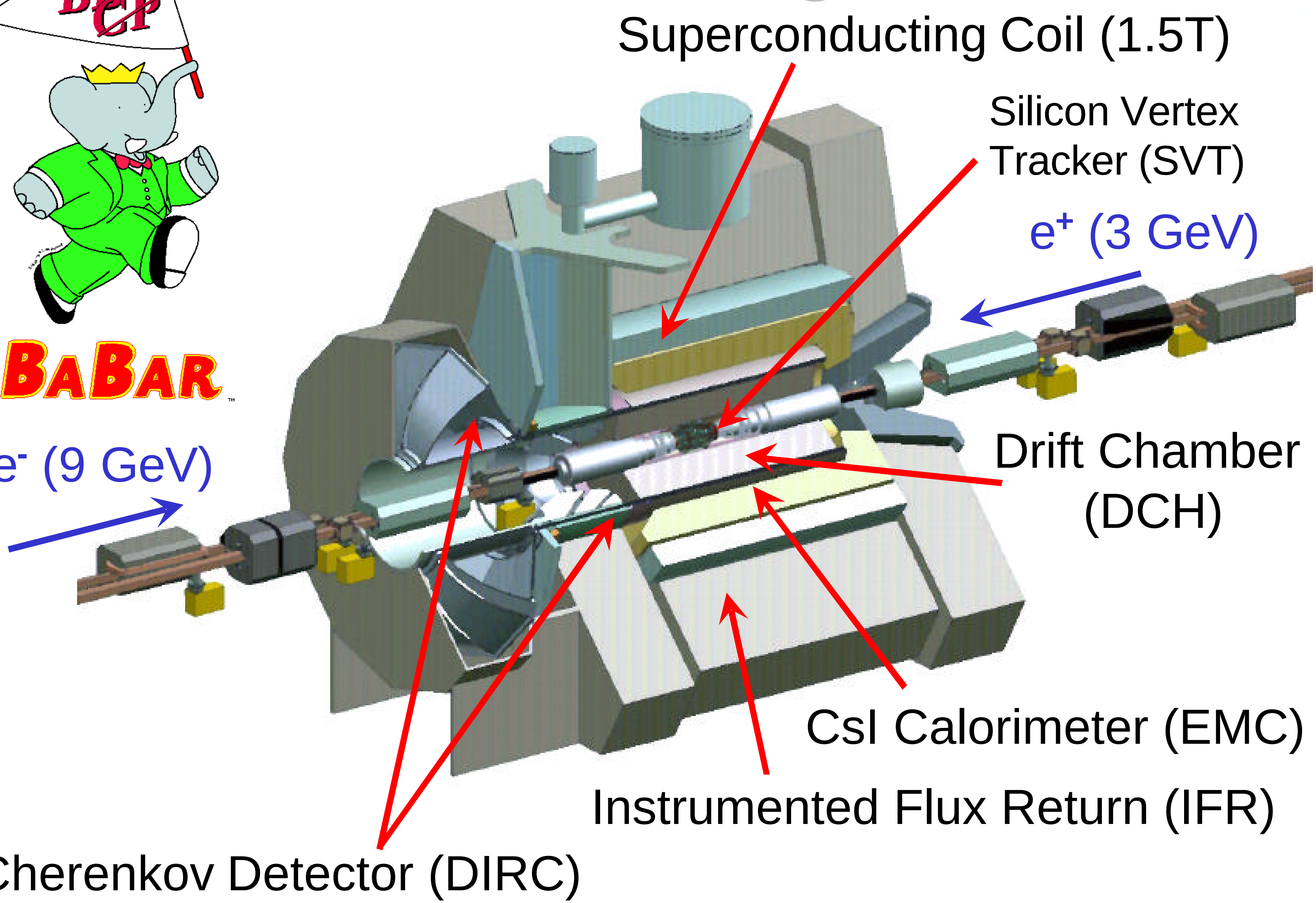
$$B(B \to K^* e^+ e^-) < 5.6 \times 10^{-6}$$

- Our upper limit from Run 1 (based on 20.7 fb^{-1}, submitted to PRL):

$$B(B \to K l^+ l^-) < 0.51 \times 10^{-6} \quad 90\% \text{ C.L.}$$

$$B(B \to K^* l^+ l^-) < 3.1 \times 10^{-6} \quad 90\% \text{ C.L.}$$

BaBar Detector @ PEP II



B Meson Reconstruction at Υ(4s)

$$e^+e^- \to \Upsilon(4S) \to B\overline{B}$$

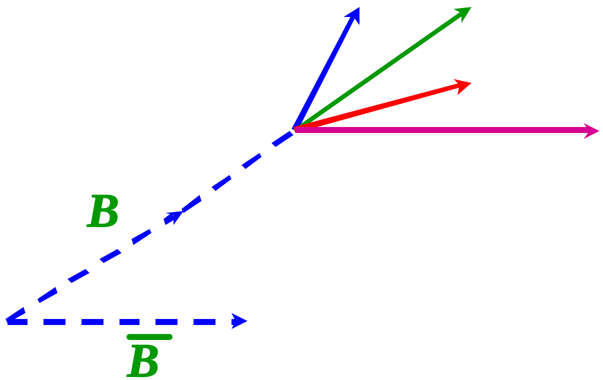
$$m_{ES} = \sqrt{E_{beam}^{*\,2} - (\sum_i p_i^*)^2}$$

$$\Delta E = \sum_i \sqrt{p_i^{*\,2} + m_i^2} - E_{beam}^*$$

Typical resolutions:

$\sigma(m_{ES}) \approx$ **2.5 MeV**

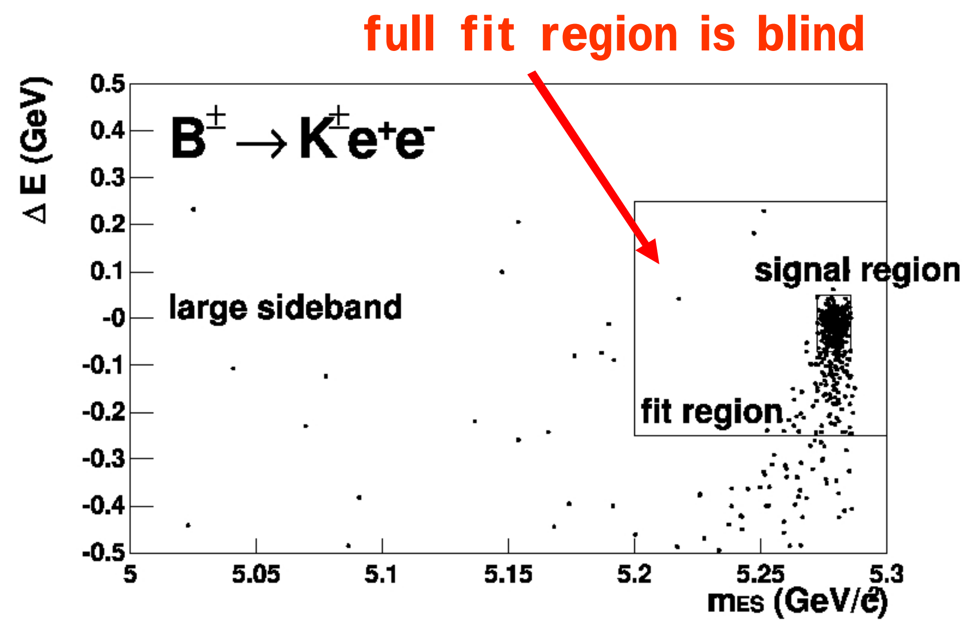
$\sigma(\Delta E) \approx$ **25 - 40 MeV**



(*) ≡ measured in Υ(4S) rest frame

$E_i \longleftrightarrow E^*_{beam}$ ➔ Improve resolution

- Define 3 regions in ΔE, m_{ES} plane:
  - A – Signal region
  - B –Fit region
  - C – Large Sideband region



Analysis Strategy I

- Lepton and kaon ID, candidates formed for the different channels:
  - $B^+ \to K^+ l^+ l^-$, where l is either e or μ
  - $B^+ \to K^{*+} l^+ l^-$, where $K^{*+} \to K^0 \pi^+$ and $K^0 \to \pi^+ \pi^-$
  - $B^0 \to K^0 l^+ l^-$
  - $B^0 \to K^{*0} l^+ l^-$, where $K^{*0} \to K^+ \pi^-$

This talk: 56.4 fb^{-1} on peak

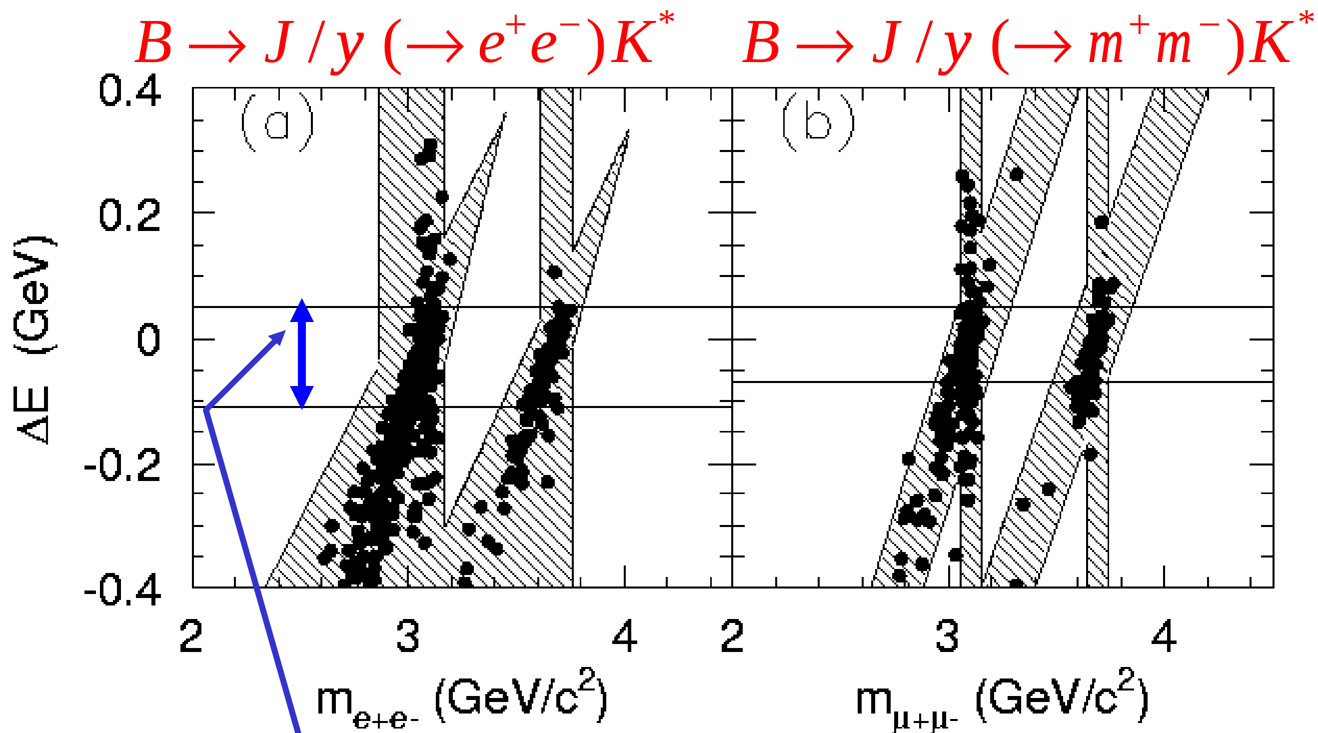
- Apply selection to suppress backgrounds from:
  - Continuum events – event shape
  - BB events – vertexing, E_{miss}
  - $B \to J/\psi(\to l^+ l^-)K$ decays – exclude regions in ΔE, $m(l^+ l^-)$ plane
  - Peaking backgrounds (small)
- Selection criteria optimized on simulated or "large sideband" events. The full fit region is blind.

Analysis Strategy II

- Monte Carlo is used for signal efficiencies and to estimate contributions from the peaking backgrounds.
- We use *control samples* in the data to check the MC:
  - **Decays to charmonium**. Each signal-mode final state has a "signal-like" control sample that is identical except for the restricted range of q^2. (Also a serious background!)
  - **"Large sideband" in m_{ES} vs. ΔE plane**: checks comb. bkgd.
  - **$K^{(*)}e^-\mu^+$ combinations**: checks comb. bkgd.
- The signal is extracted from a 2-D fit to the m_{ES} vs. ΔE plane. Both the background normalization and its shape float. The signal shapes are taken from MC + tuning from J/ψ samples.

B®J/y(®l^+l^-)K : Background Source

- Actually, this channel is "part" of the signal, with $q^2 = m(\psi)^2$
- However, we are not interested in this part of the signal and it must be removed by direct veto.



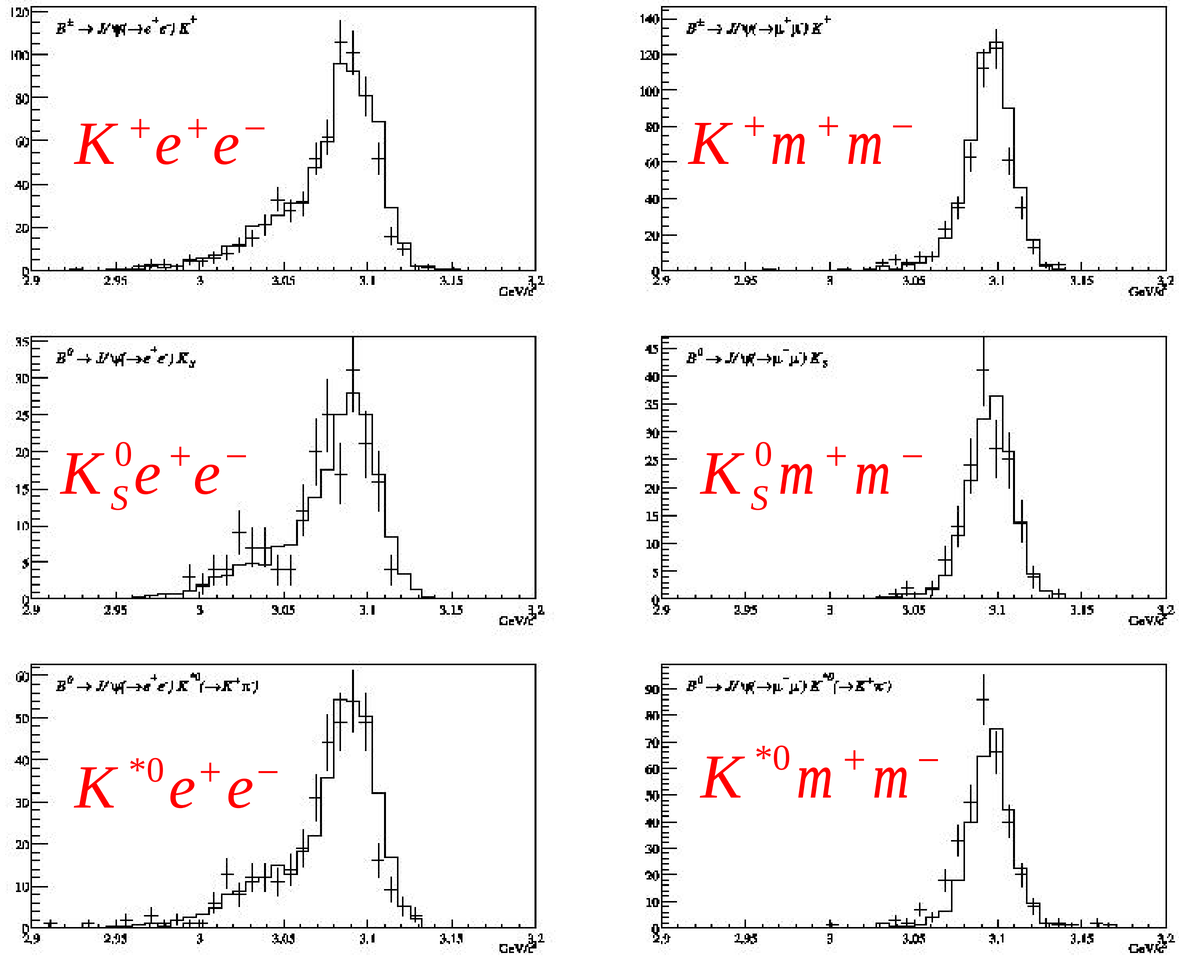
Nominal signal region

- When the leptons from J/ψ->l^+l^- *radiate* or are *mismeasured*, the event shifts in both *m*(ψ) and in Δ*E*.
- Remove these events from BG region as well: simplify fit in m_{ES} vs. ΔE plane

B®J/y(®l$^+$l$^-$)K : Control Sample

- Kinematics very similar to the signal
- Sample of such events can be used to verify efficiencies of essentially all selection criteria
- Excellent agreement found in data/MC comparison

E.g. study tails in M(l$^+$l$^-$) distribution



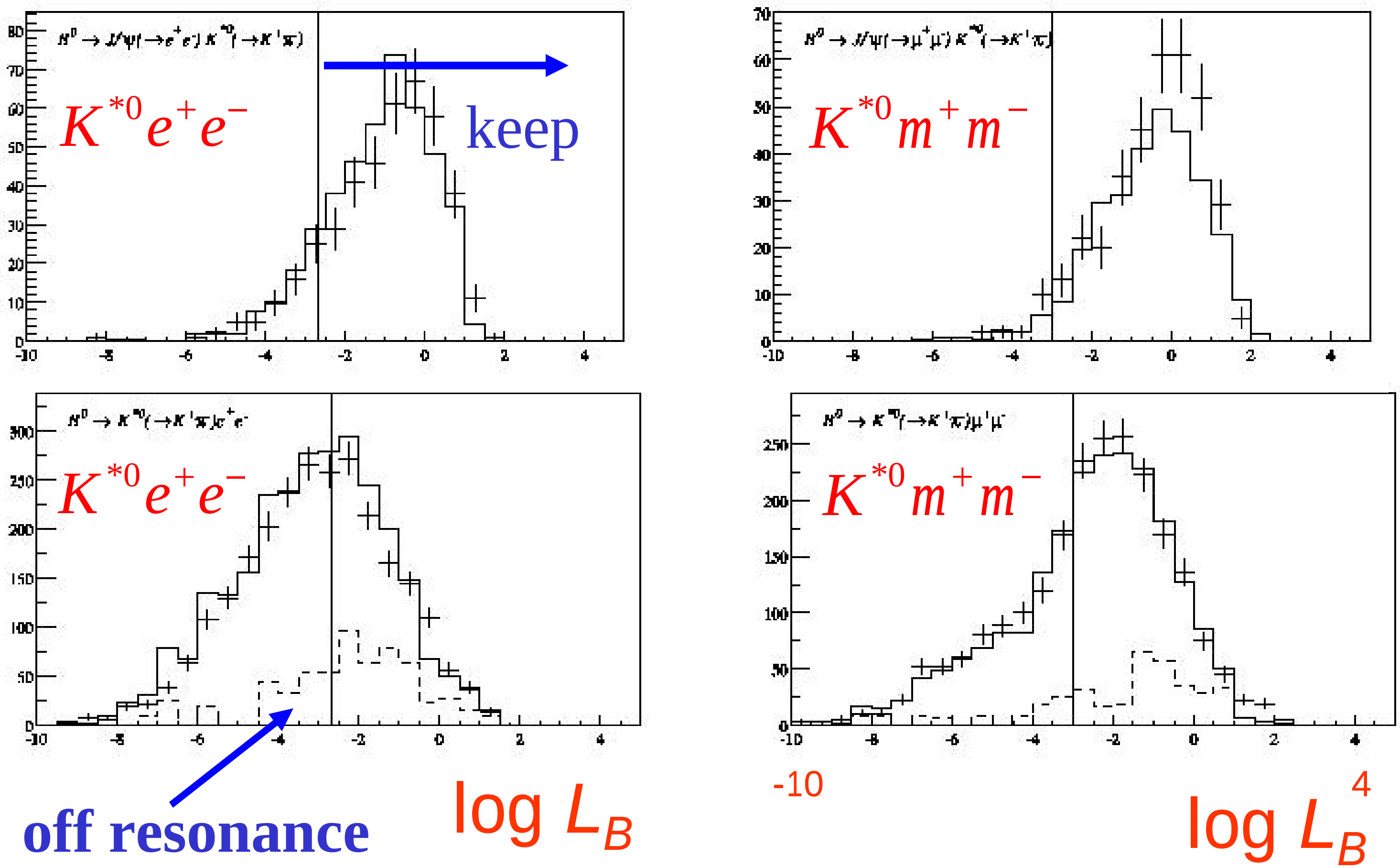
Points: data
Histo: MC

M(l$^+$l$^-$)

J/ψ and Large Sideband Control Sample Study: *B* Likelihood Variable

J/ψ Sample: signal-like

Large SB Sample: background-like

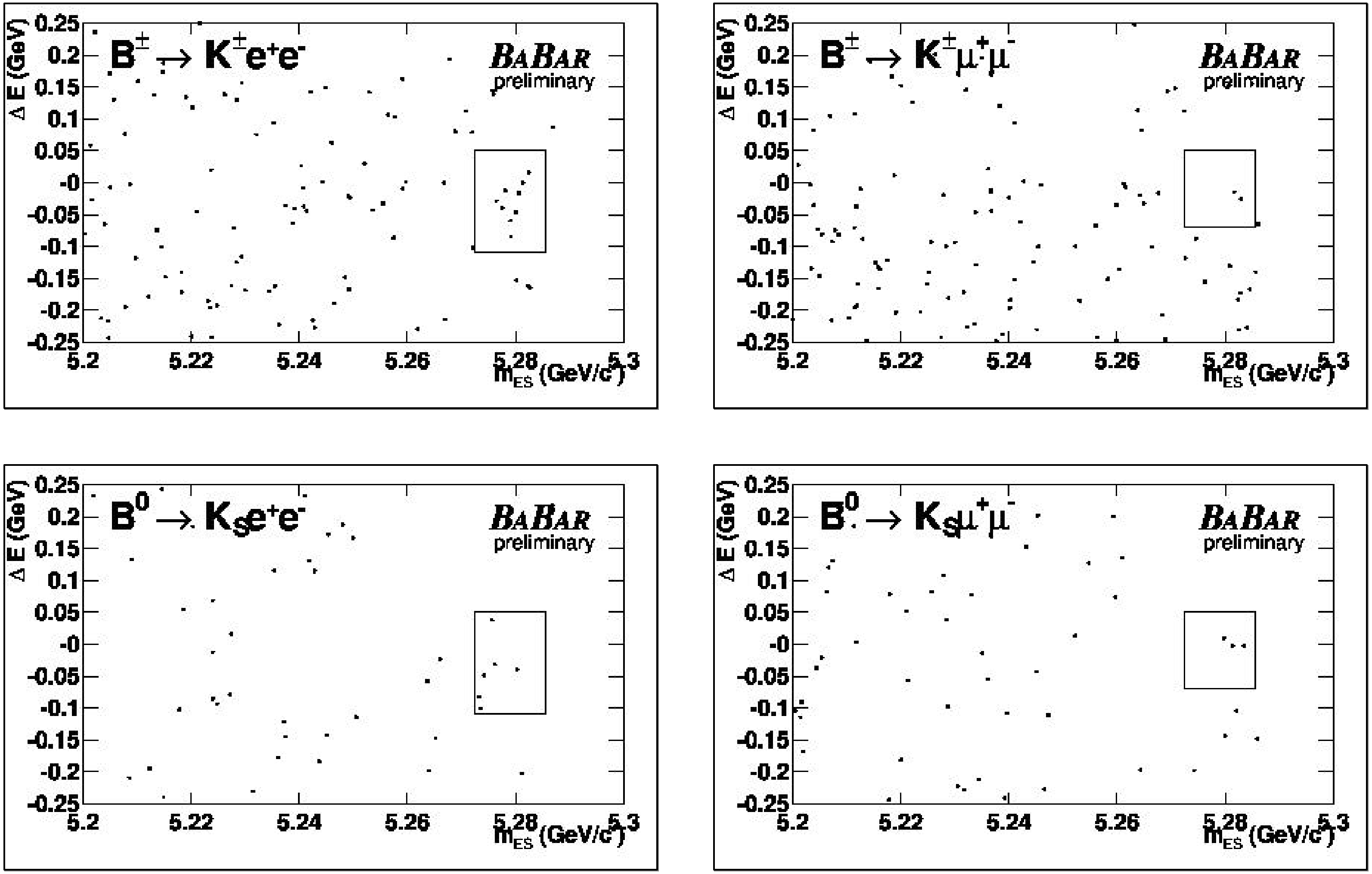


Charmonium Control Samples: Yields in Data vs. Simulation

Mode	ϵ (%)	MC Yield	Data Yield	Data/MC (%)
$B^+ \to K^+ e^+ e^-$	18.0	669	660	98.6 ± 4.3
$B^+ \to K^+ \mu^+ \mu^-$	15.9	553	502	90.8 ± 4.5
$B^0 \to K^0 e^+ e^-$	18.4	191	190	99.4 ± 7.3
$B^0 \to K^0 \mu^+ \mu^-$	16.0	157	161	102.6 ± 8.2
$B^0 \to K^{*0} e^+ e^-$	12.3	375	367	97.9 ± 5.6
$B^0 \to K^{*0} \mu^+ \mu^-$	10.2	293	343	117.3 ± 7.1
$B^+ \to K^{*+} e^+ e^-$	9.5	114	102	89.6 ± 9.2
$B^+ \to K^{*+} \mu^+ \mu^-$	7.8	88	89	101.7 ± 11.2
$B \to K^+ \ell^+ \ell^-$ $(e + \mu)$		1222	1162	95.0 ± 3.1
$B \to K^0 \ell^+ \ell^-$ $(e + \mu)$		348	351	100.9 ± 5.4
$B \to K^{*0} \ell^+ \ell^-$ $(e + \mu)$		667	710	106.4 ± 4.4
$B \to K^{*+} \ell^+ \ell^-$ $(e + \mu)$		201	191	94.9 ± 7.1
All $e^+ e^-$ modes		1349	1319	97.8 ± 2.8
All $\mu^+ \mu^-$ modes		1090	1095	100.5 ± 3.2
All modes		2439	2414	99.0 ± 2.1

Unblinded Run 1+2 data

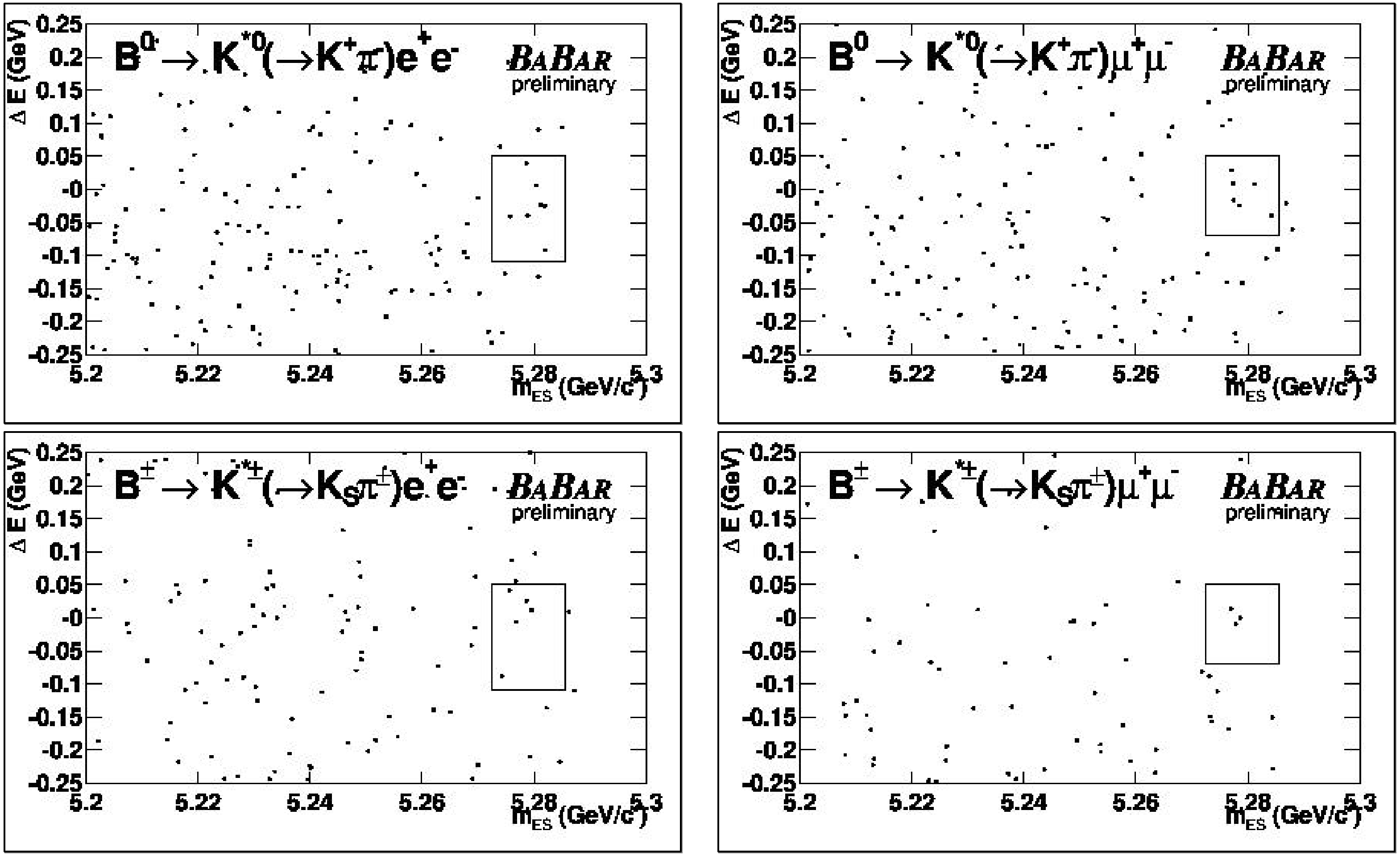
DE



m_{ES}

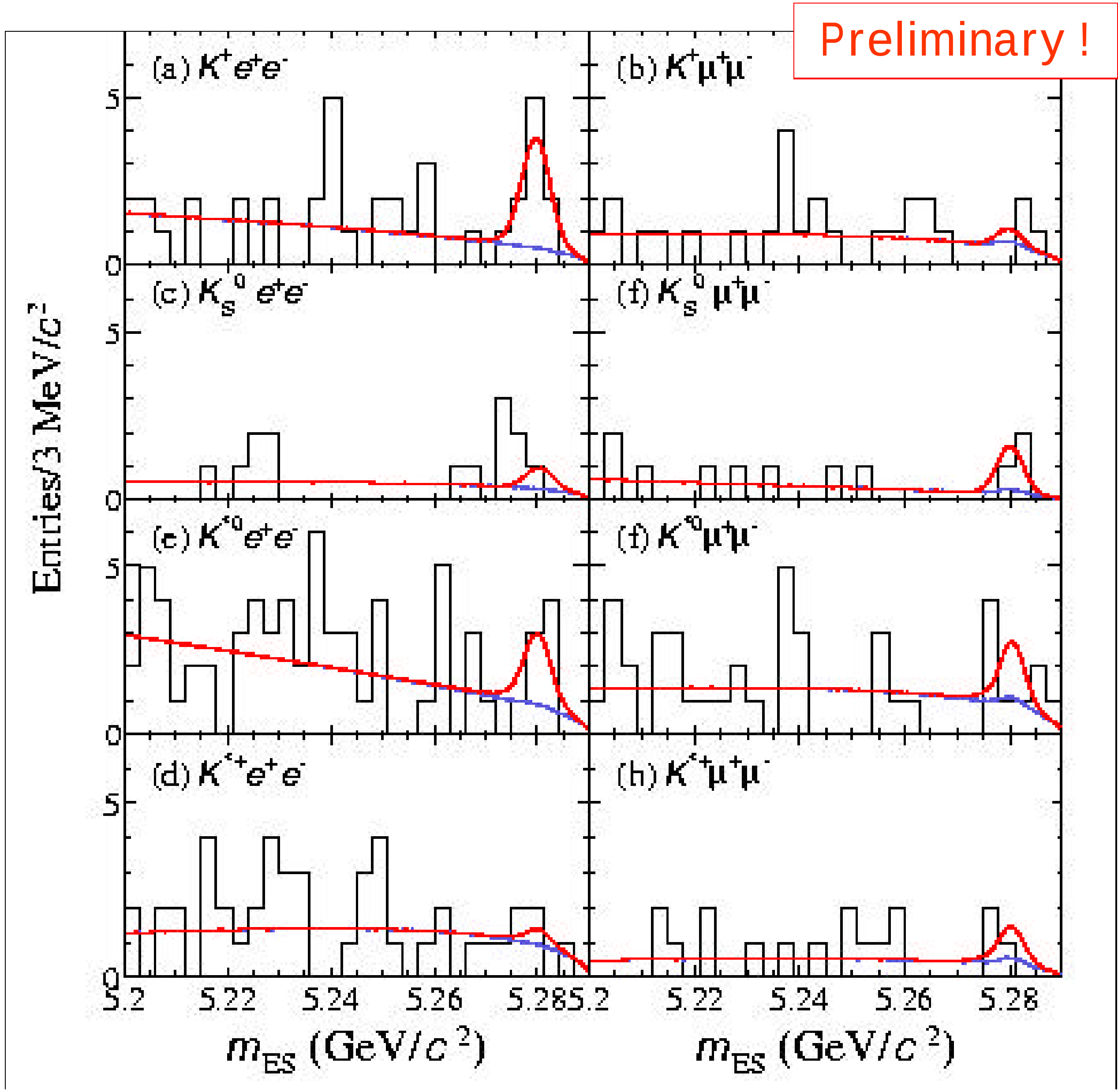
Unblinded Run 1+2 data

ΔE



m_{ES}

Run 1,2 Unblinded: m_{ES}



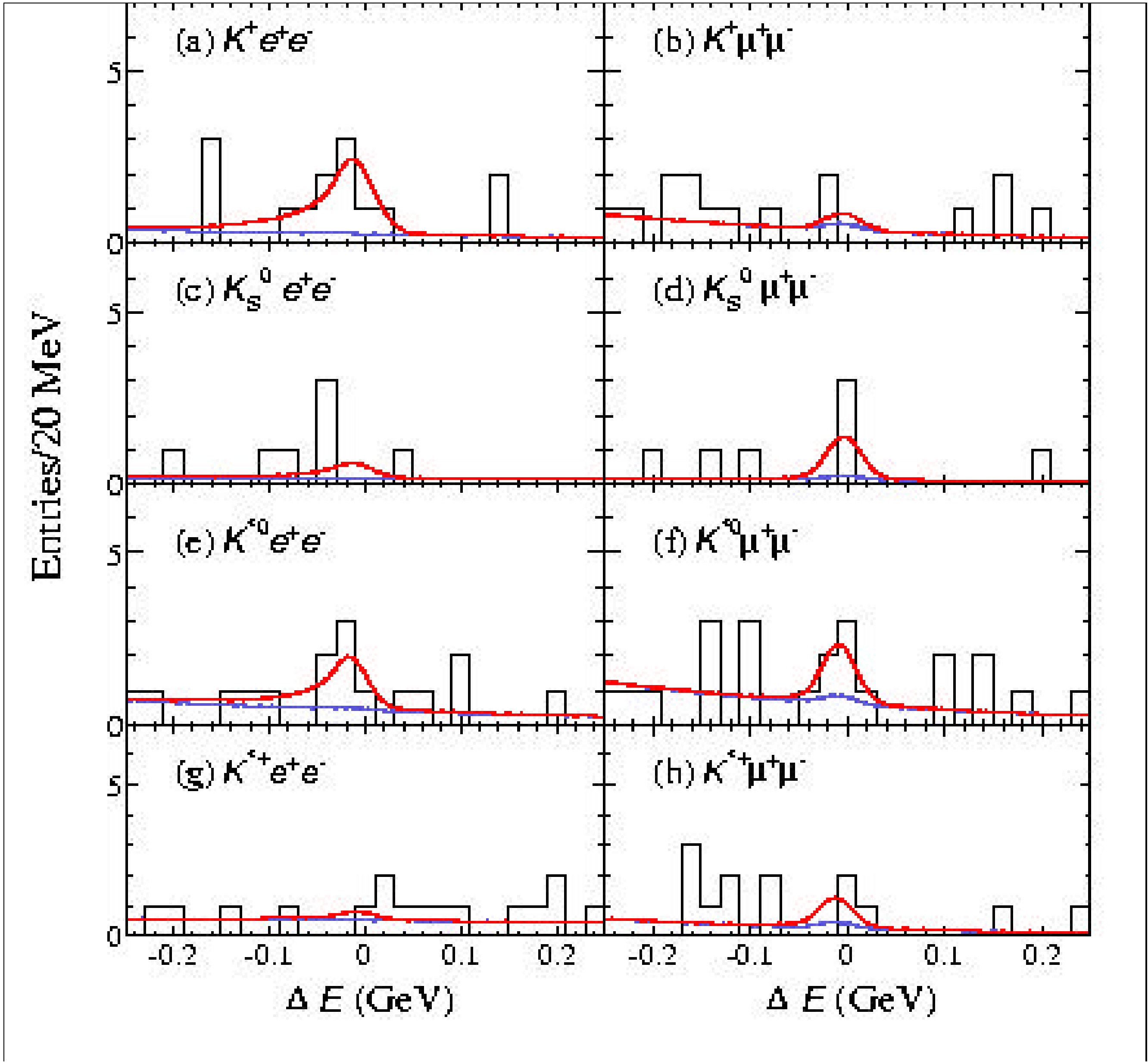
2D fit projections after D*E* cut:

e: -110<DE<50 MeV
m: -70<DE<50 MeV

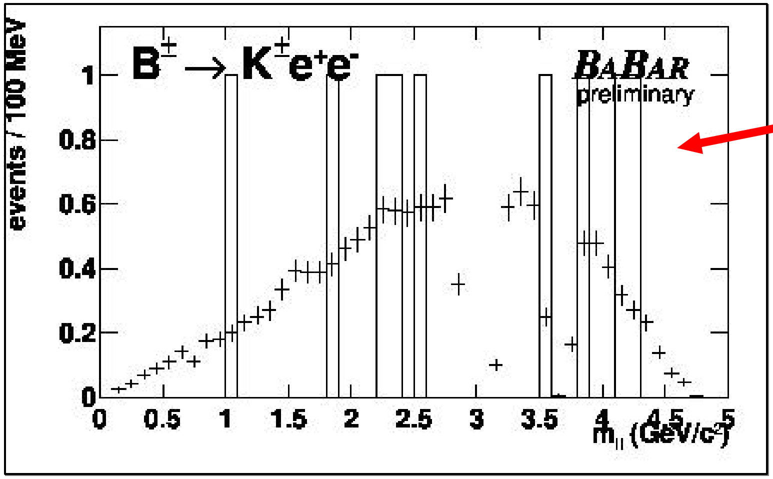
Run 1,2 Unblinded: *D**E***

2D fit projections after m_{ES} cut

5.2724<m_{ES}<5.2856 GeV



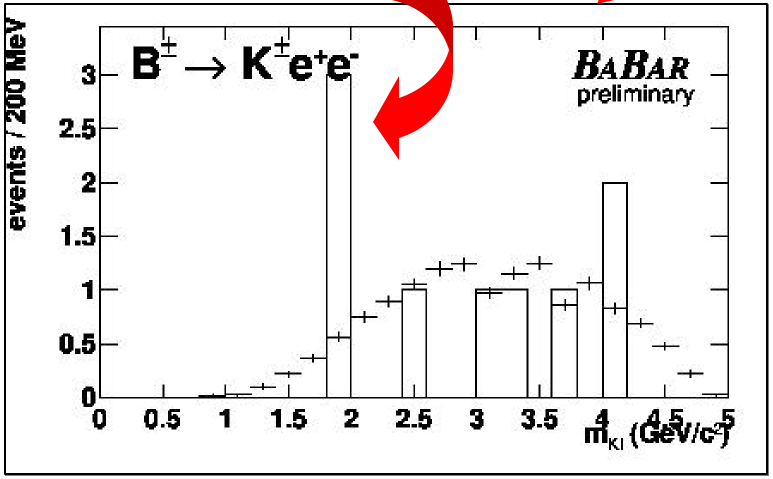
Signal Candidate Properties



- **M(ll)** – no apparent pileup near the J/ψ vetoes

Preliminary !

2 of these consistent with D mass



- **M(Kl)** – possible background from $B \rightarrow D\pi$, $D \rightarrow K\pi$, both π's mis-id'd as electrons. (Note, this peaking BG is explicitly vetoed in Kμμ channel).
- Simulation predicts 0.06 events of this background for this channel
- Studies of electron mis-id probabilities show no indication of problem.
- Nevertheless, include systematic error to account for possibility that 2 of these events are BG.

Fit Results I

Preliminary !

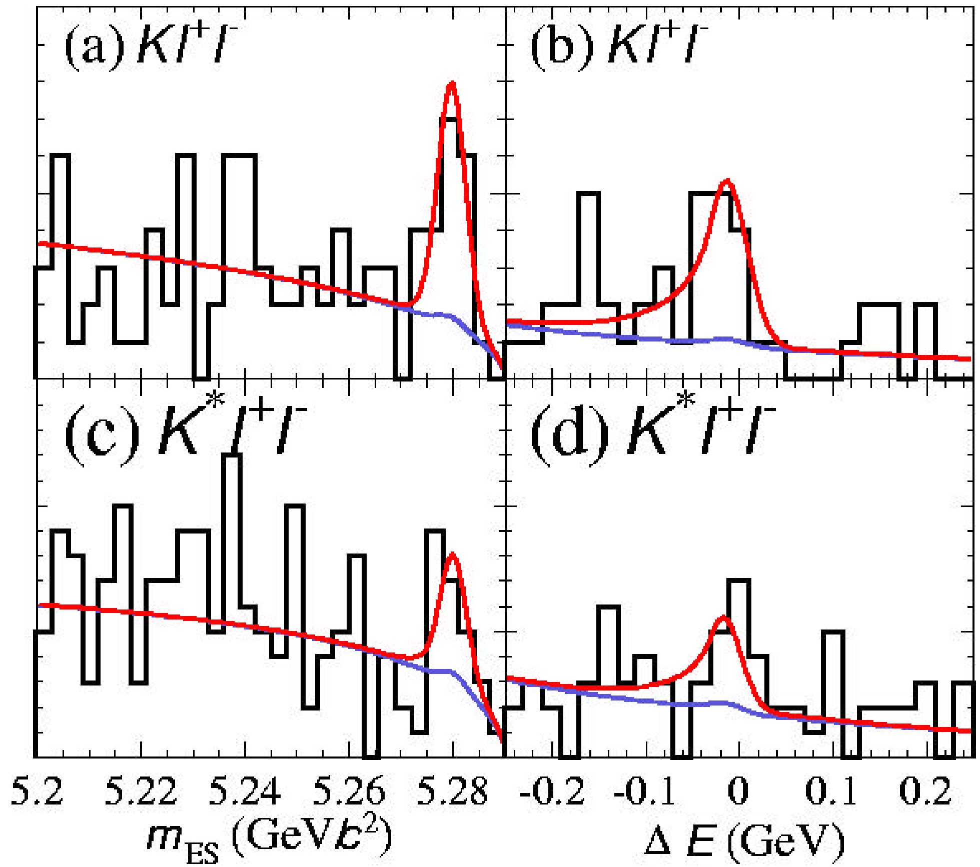
- Results of max likelihood fit in $\Delta E - m_{ES}$ plane for the 8 channels

Mode	Signal yield	Eff. bkgd	ε (%)	$(\Delta\mathcal{B}/\mathcal{B})_\varepsilon$ (%)	$(\Delta\mathcal{B})_{fit}$ (10^{-6})	$\mathcal{B}$ (10^{-6})
$B^+ \to K^+ e^+ e^-$	$9.6^{+4.6}_{-3.3}$	1.9	17.1	± 6.8	$^{+0.11}_{-0.23}$	$0.91^{+0.42+0.13}_{-0.32-0.24}$
$B^+ \to K^+ \mu^+ \mu^-$	$0.8^{+2.5}_{-1.3}$	1.2	9.9	± 6.8	± 0.10	$0.13^{+0.37}_{-0.23} \pm 0.10$
$B^0 \to K^0 e^+ e^-$	$1.8^{+2.8}_{-1.3}$	1.1	18.1	± 8.0	± 0.35	$0.47^{+0.69}_{-0.39} \pm 0.35$
$B^0 \to K^0 \mu^+ \mu^-$	$2.9^{+2.7}_{-1.5}$	0.4	10.3	± 7.8	± 0.22	$1.34^{+1.16}_{-0.78} \pm 0.25$
$B^0 \to K^{*0} e^+ e^-$	$7.3^{+4.7}_{-3.5}$	3.4	10.2	± 7.7	± 0.48	$1.66^{+1.08}_{-0.83} \pm 0.50$
$B^0 \to K^{*0} \mu^+ \mu^-$	$4.6^{+4.2}_{-2.9}$	2.3	6.6	± 9.3	± 0.39	$1.68^{+1.57}_{-1.09} \pm 0.42$
$B^+ \to K^{*+} e^+ e^-$	$1.5^{+4.0}_{-2.0}$	4.9	9.8	± 9.7	$^{+1.04}_{-1.06}$	$1.07^{+2.86+1.04}_{-1.51-1.06}$
$B^+ \to K^{*+} \mu^+ \mu^-$	$2.8^{+3.5}_{-2.0}$	1.5	5.4	± 11.1	± 1.82	$3.68^{+4.39}_{-2.88} \pm 1.86$

Fit Results II

Preliminary !

- Combining channels: m_{ES} and ΔE projections for Kll and K*ll



B(B→K*ee)/B(B→K*μμ)=1.21
from Ali, *et al*, is used in combined K*ll fit.

$$B(B \to K\ell^+\ell^-) = (0.84^{+0.30+0.10}_{-0.24-0.18})\times 10^{-6}$$

$$B(B \to K^*\ell^+\ell^-) = (1.89^{+0.84}_{-0.72} \pm 0.31)\times 10^{-6}$$

Systematic Uncertainties

Systematic errors on the efficiency

Largest sources:

- Trk eff.
- Model dependence

~ 7 – 11 %

Systematic errors on the fit yields

- Signal shapes
- Background shapes
  - o includes peaking background uncertainty

~ 0.5 – 2.0 events

Signal Statistical Significance

- Statistical significance of signal is computed:
  - Toy MC: fit to background-only toy experiments and observe how often we obtain signal larger than observed signal in data.
  - Consider change in ln L when fixing the signal component to zero in fit (Gaussian approximation).
  - Results:

$Kl^+l^- \Rightarrow 5.0\sigma$, if systematics included $\Rightarrow$ still $> 4\sigma$

$K^*l^+l^- \Rightarrow 3.5\sigma$

- Based on the $K^*l^+l^-$ result we place an upper limit for this channel:

$$B(B \to K^* \ell^+ \ell^-) < 3.5 \times 10^{-6} \qquad @\ 90\%\ \text{CL}$$

Preliminary !

Comparison to Our Run 1 Result

- Run 1:

$$B(B \to K l^+ l^-) < 0.51 \times 10^{-6} \quad 90\% \text{ C.L.}$$

$$B(B \to K^* l^+ l^-) < 3.1 \times 10^{-6} \quad 90\% \text{ C.L.}$$

- Run 1+2:

$$B(B \to K \ell^+ \ell^-) = (0.84^{+0.30+0.10}_{-0.24-0.18}) \times 10^{-6}$$

$$B(B \to K^* \ell^+ \ell^-) < 3.5 \times 10^{-6}$$

Preliminary !

- All data fully reprocessed for Run 1+2 results: improvements in tracking, vertex detector alignment, etc. ⇒ resulted in migration of events in/out of signal region. Sensitivity of this analysis is mostly unchanged by the reprocessing (some improvement in K_S modes).
- Migration of events into/out of signal region checked with control samples ⇒ results are compatible
- The probability for a **Kll** branching fraction at our new value to give our Run 1 result is at the 2-3% level.

Conclusions

- We have studied the channels $B \to Kl^+l^-$ and $B \to K^*l^+l^-$ using 56.4 fb-1 of data at the BaBar experiment at PEP-II.
- We obtain the following results:

Preliminary !

$$B(B \to K\ell^+\ell^-) = (0.84^{+0.30+0.10}_{-0.24-0.18}) \times 10^{-6}$$

$$B(B \to K^*\ell^+\ell^-) < 3.5 \times 10^{-6}$$

- The statistical significance for $B \to Kl^+l^-$ is computed to be $> 4\sigma$ including systematic uncertainties.

Peaking Backgrounds

- Usually due to particle mis-idenficiation, e.g.:

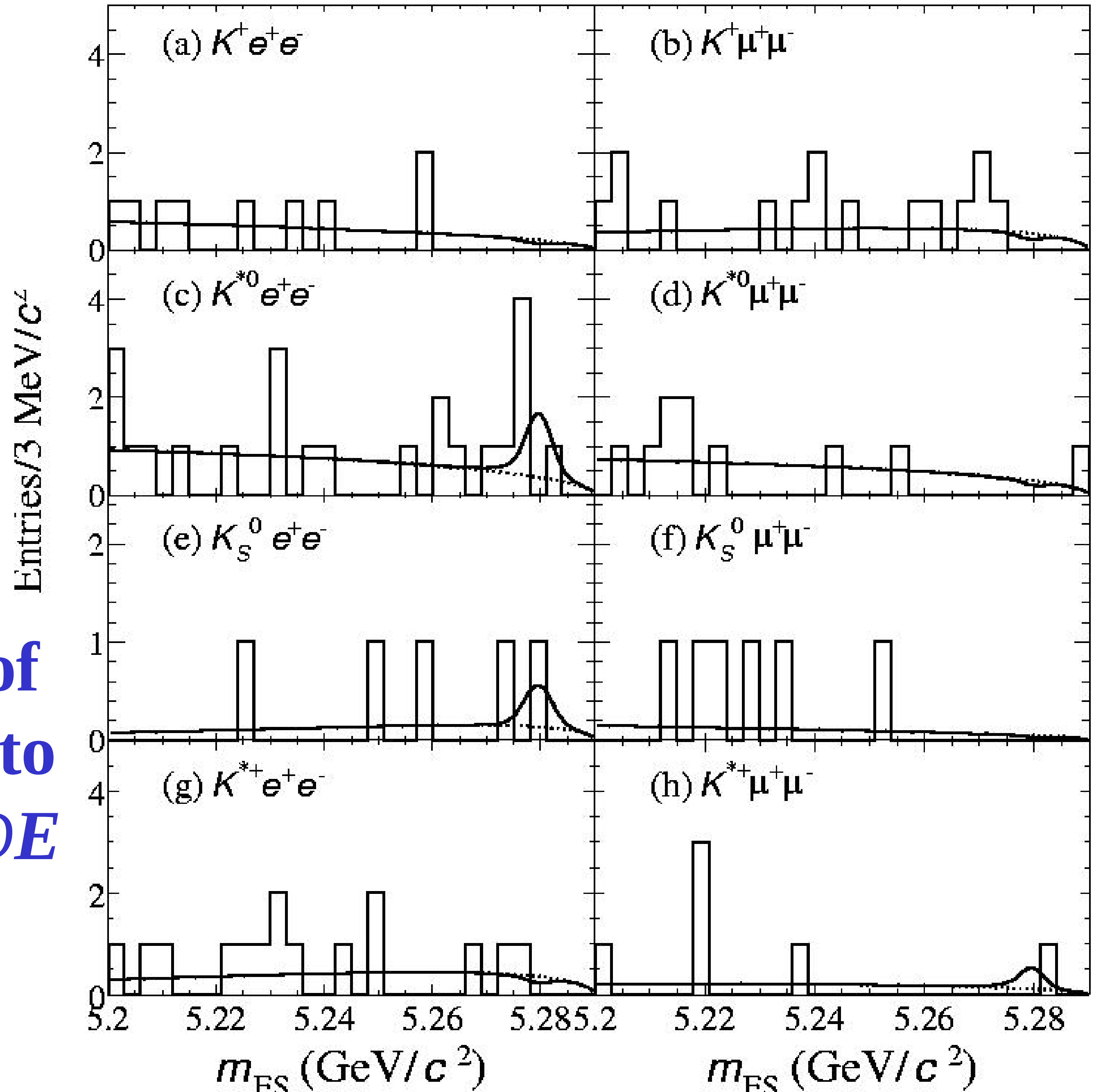
$$? \to Dp$$
$$\quad \llcorner\; Kp$$

Mis-id'd as muons ⇒ Kμμ background

- Since mis-id probability is higher for muons than for electrons, explicit vetoes are applied for the muon modes.
- Summary of peaking backgrounds as obtained from high statistics Monte Carlo sample.
- These are included in fit to extract signal.

Mode	Peaking background
$B^{\pm} \to K^{\pm} e^{+} e^{-}$	$0.06^{+0.7}_{-0.06}$
$B^{\pm} \to K^{\pm} \mu^{+} \mu^{-}$	0.5 ± 0.5
$B^{0} \to K^{0}_{s} e^{+} e^{-}$	$0.0^{+0.1}_{-0.0}$
$B^{0} \to K^{0}_{s} \mu^{+} \mu^{-}$	0.3 ± 0.3
$B^{0} \to K^{*0} e^{+} e^{-}$	0.3 ± 0.3
$B^{0} \to K^{*0} \mu^{+} \mu^{-}$	0.8 ± 0.8
$B^{\pm} \to K^{*\pm} e^{+} e^{-}$	$0.05^{+0.3}_{-0.05}$
$B^{\pm} \to K^{*\pm} \mu^{+} \mu^{-}$	0.7 ± 0.7

BaBar Run 1 Analysis (20.7 fb^{-1})



Projections of the 2D fit onto m_{ES} after a DE cut.

Belle results (29.1 fb^{-1})

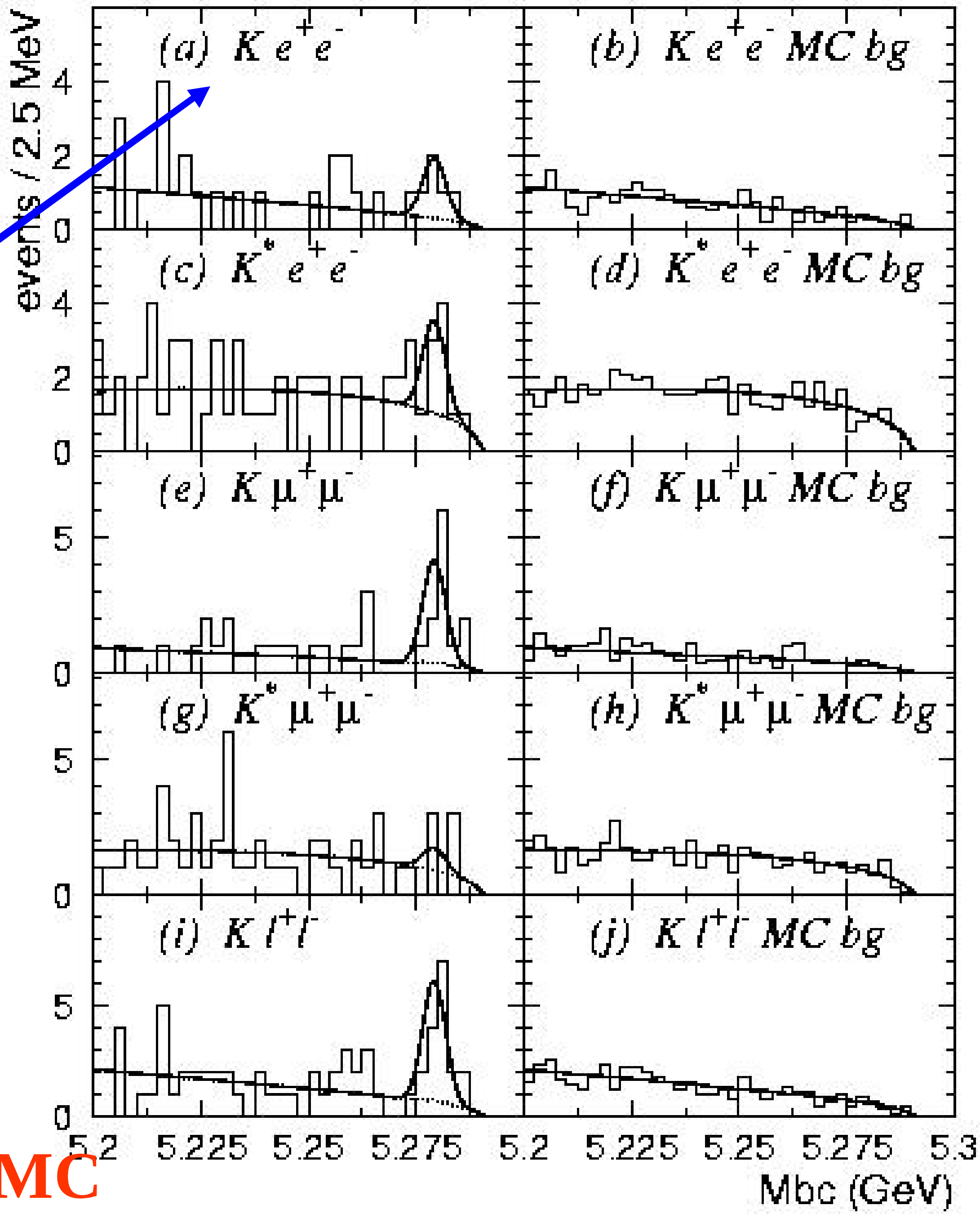
$4.1^{+2.7+0.6}_{-2.1-0.8}$ evts

$6.3^{+3.7+1.0}_{-3.0-1.1}$ evts

$9.5^{+3.8+0.8}_{-3.1-1.0}$ evts

$2.1^{+2.9+0.9}_{-2.1-1.0}$ evts

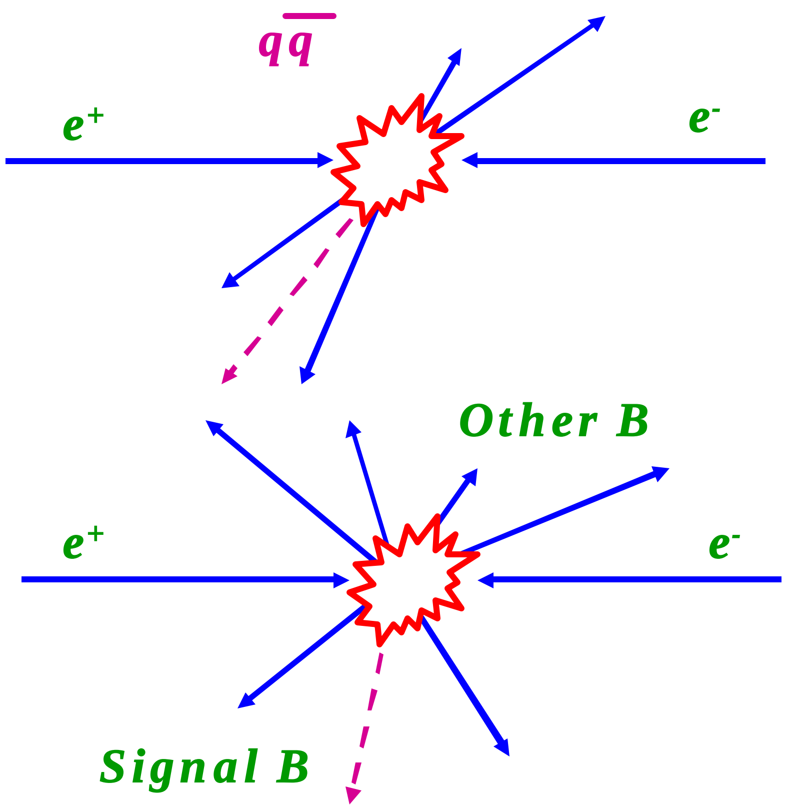
$13.6^{+4.5+0.9}_{-3.8-1.1}$ evts



Bkgd shape fixed from MC

Continuum Background Suppression

- Continuum suppression: exploit fact that continuum events are more jet-like than BB events
  - R_2: W-F 2nd moment
  - Cos θ_{thrust}: angle of candidate thrust axis
  - Cos θ_B : angle of B in CM
  - m_{Kl} : Kl invariant mass
- Combine optimally using Fisher discriminant
- Put plot here.



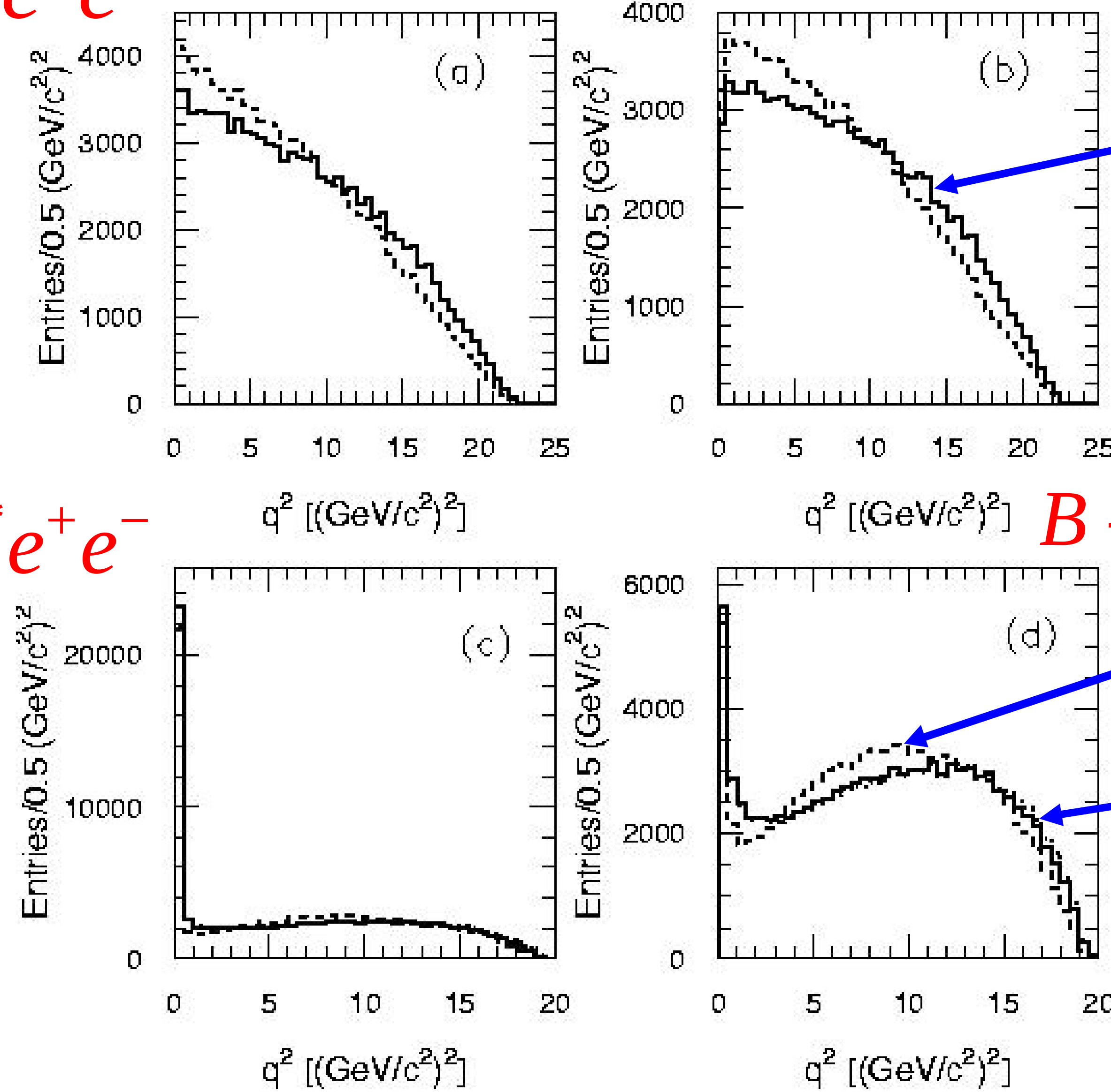
Generator-level q^2 Distributions from Form-Factor Models

$B \rightarrow K e^+ e^-$

$B \rightarrow K m^+ m^-$

$B \rightarrow K^* e^+ e^-$

$B \rightarrow K^* m^+ m^-$



Ali et al. 2000 (solid line)

Colangelo 1999 (dashed line)

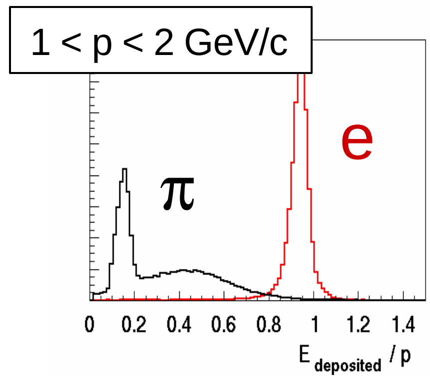
Melikhov 1997 (dotted line)

Shapes are very similar!

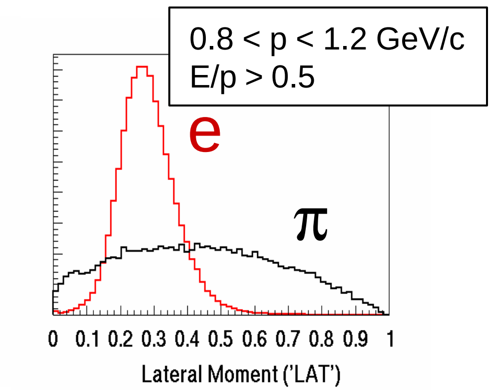
Particle Identification

- Electrons – p* > 0.5 GeV
  - •shower shapes in EMC
  - •E/p match
- Muons – p* > 1 GeV
  - Penetration in iron of IFR
- Kaons
  - dE/dx in SVT, DCH
  - θ_C in DRC

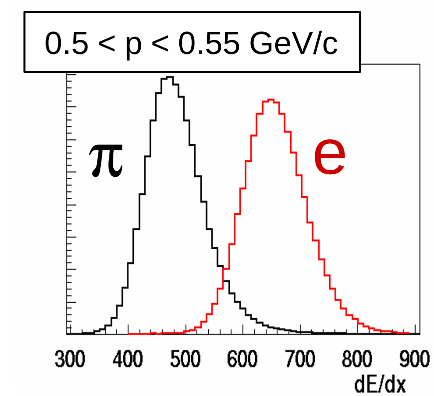
E/p from E.M.Calorimeter



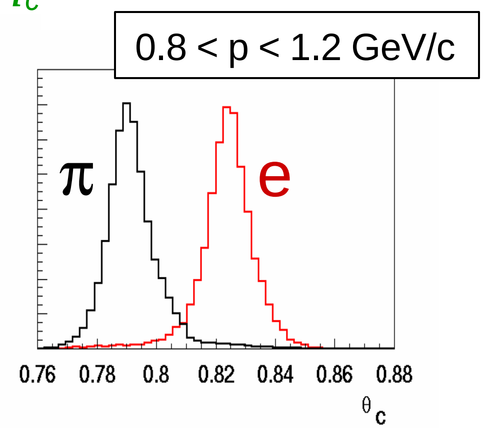
Shower Shape



dE/dx from Dch

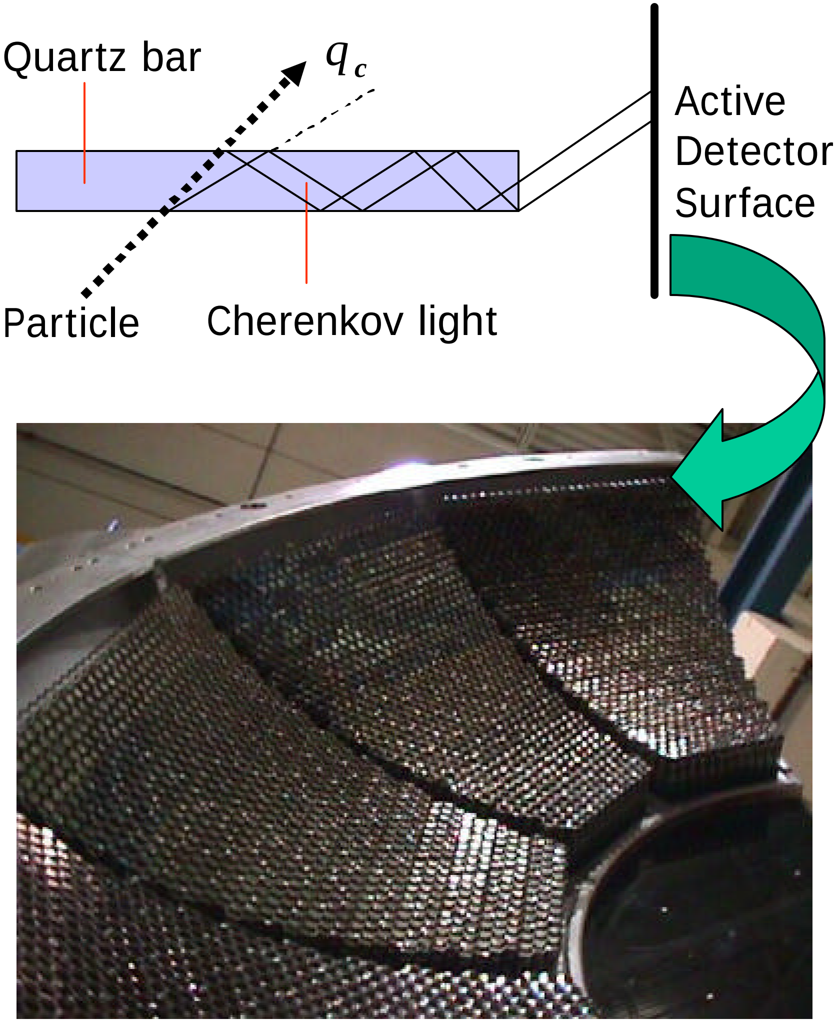


q_c from Cerenkov Detector



Kaons with DIRC

- The **DIRC** is able to identify particles via a measurement of the cone angle of their emitted Cherenkov light in quartz



$$\cos\theta_c = 1/n\beta$$

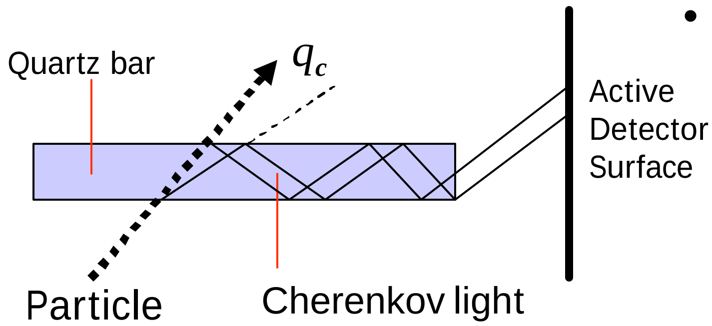
$$p = m\beta\gamma$$

DCH (→ p) DIRC (→ $\beta\gamma$)

- Provides good π/K separation for wide momentum range (up to ~4 GeV/c)

Particle Identification (DIRC)

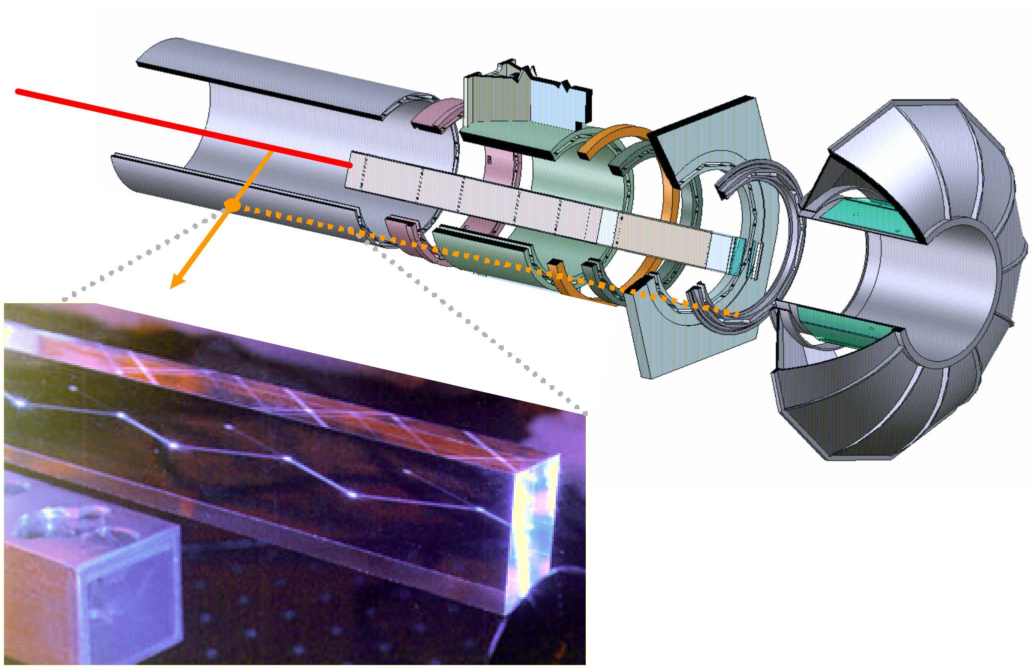
(Detector of Internally Reflected Cherenkov Light)

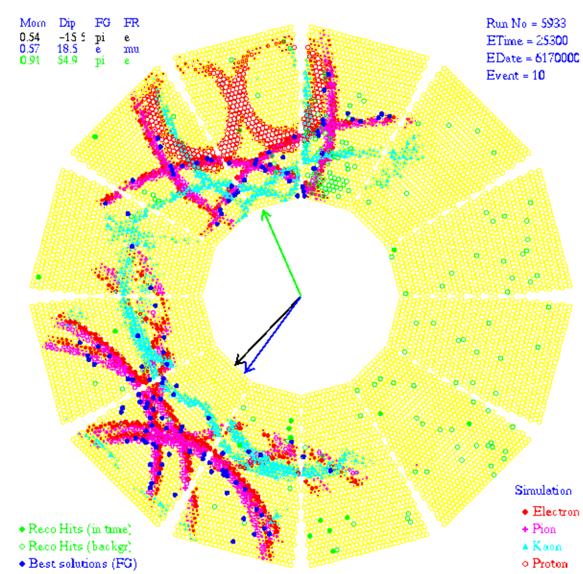


- Measure Angle of Cherenkov Cone in quartz

$$\cos\theta_c = \frac{1}{n\beta},\ p = m\beta\gamma$$

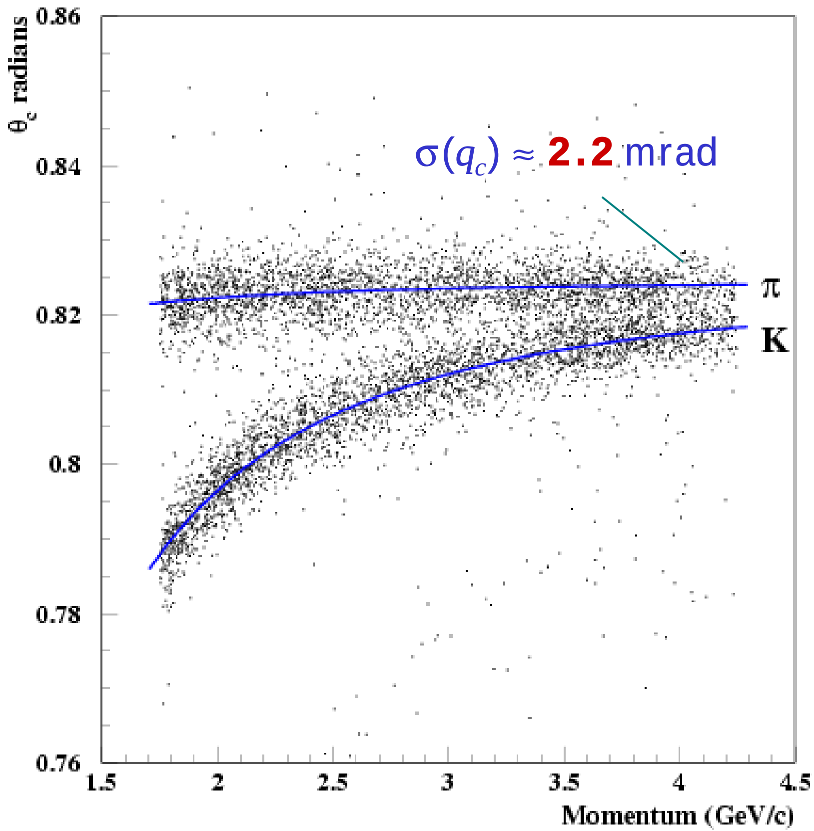
  - Transmitted by internal reflection
  - Detected by PMTs

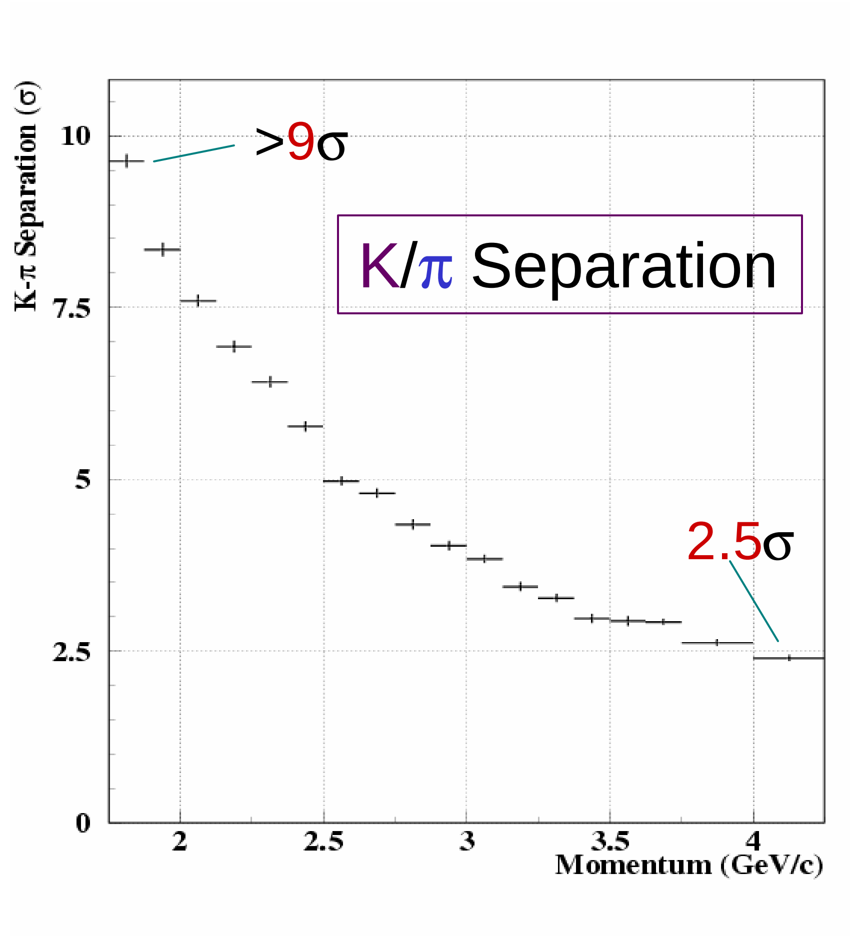




Particle Identification (DIRC) cont'.

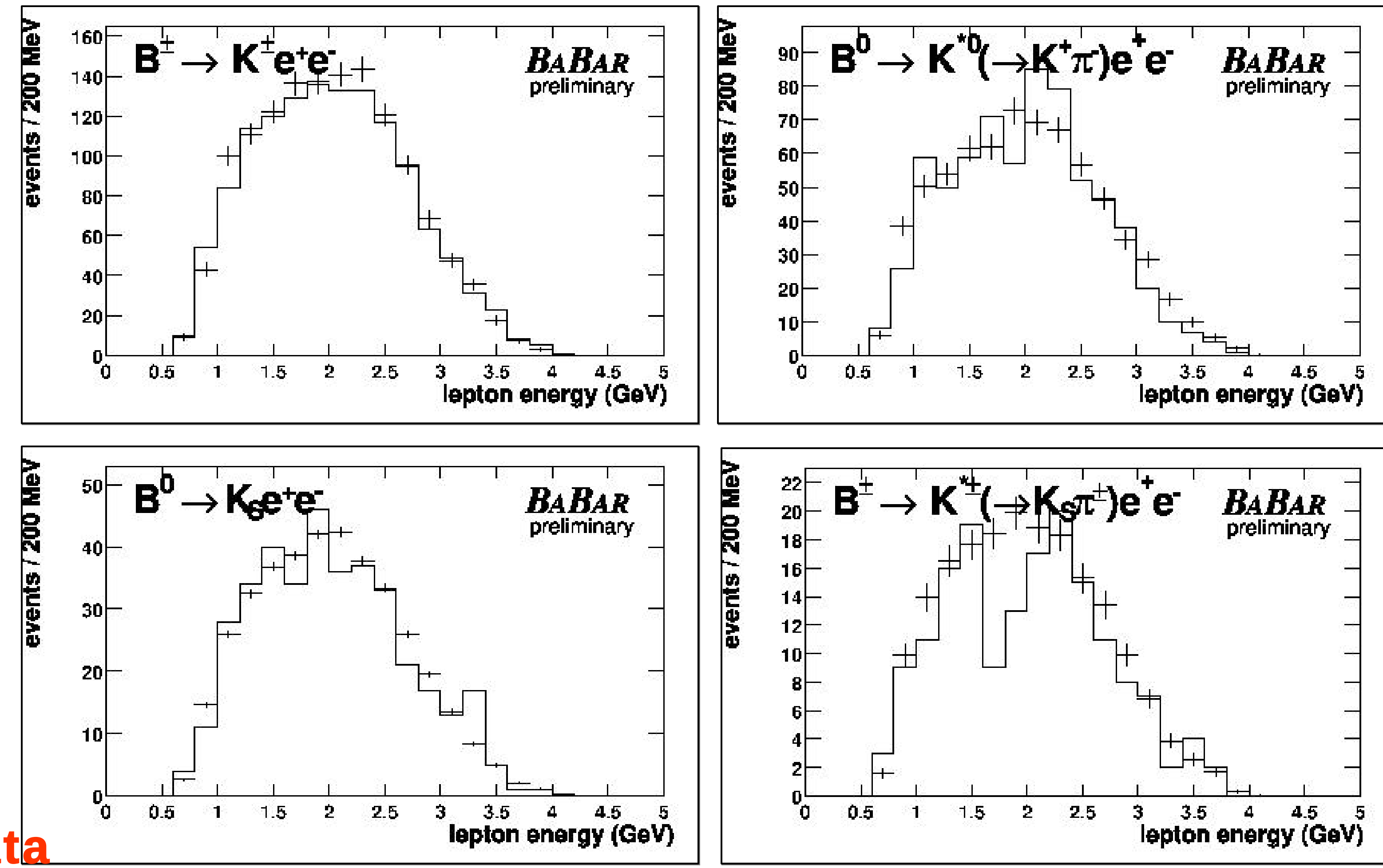
- DIRC θ_c resolution and K-π separation measured in data $\Rightarrow D^{*+} \rightarrow D^0\pi^+ \rightarrow (K^-\pi^+)\pi^+$ decays





J/ψ Control Samples: Lepton energy distributions

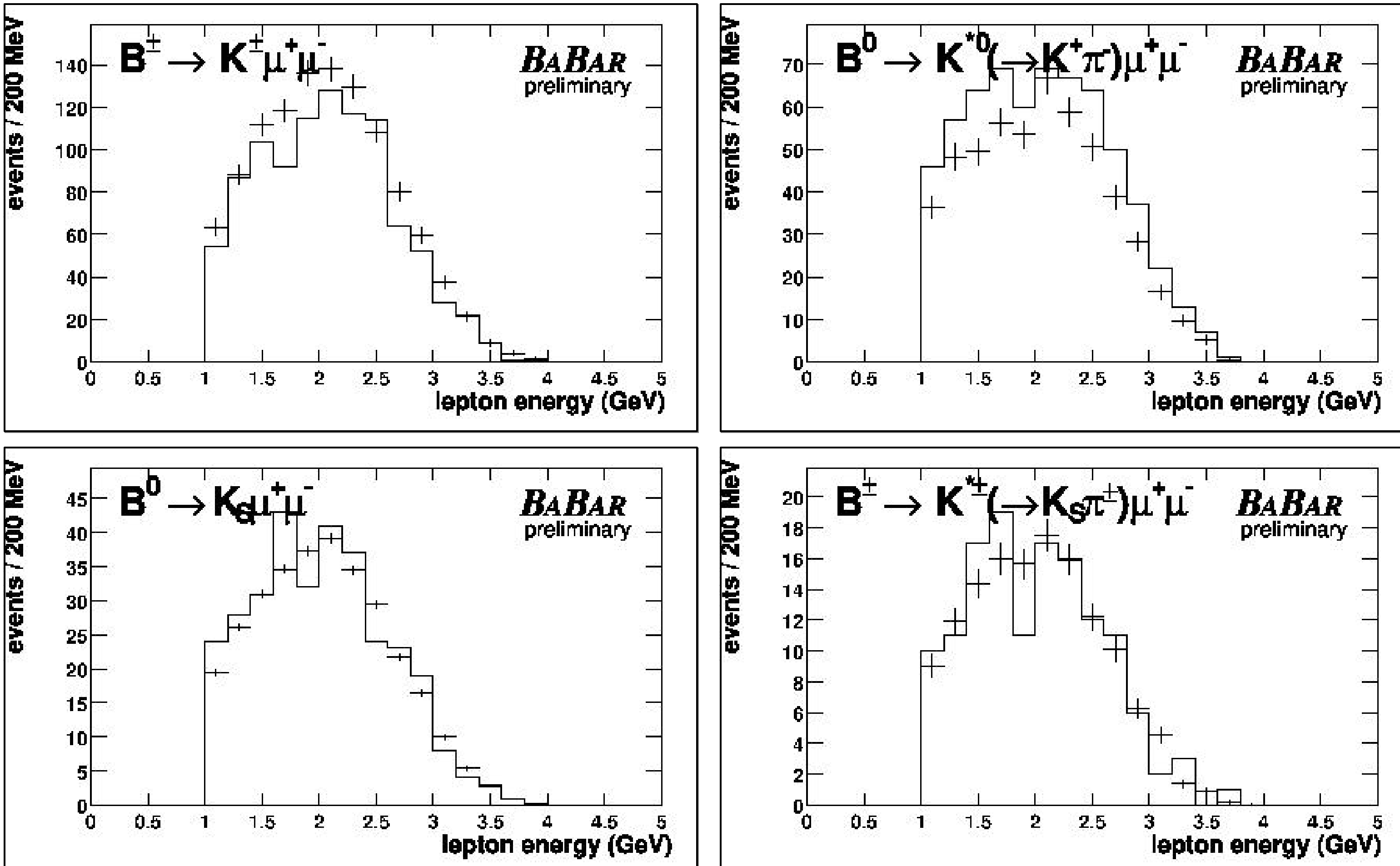
Electron channels



Points: data
Histo: MC

J/y Control Samples: Lepton energy distributions

Muon channels



Points: data
Histo: MC

Data Sample

- $e^+ e^- \rightarrow \Upsilon(4s) \rightarrow B\overline{B}$ data used for this talk

Run 1: 20.6 fb^{-1} (1999-2000)

23 million BB events

Run 2: 55 fb^{-1} (2001-2002)

60 million BB events

(so far)

- $e^+ e^-$ annihilation

40 MeV below $\Upsilon(4s)$

Run 1: 2.6 fb^{-1}

Run 2: 6.2 fb^{-1}

This talk: 56.4 fb^{-1} on peak