



# Physics Results from BELLE

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- BELLE Physics Now
- BELLE Physics Perspective
- Conclusion

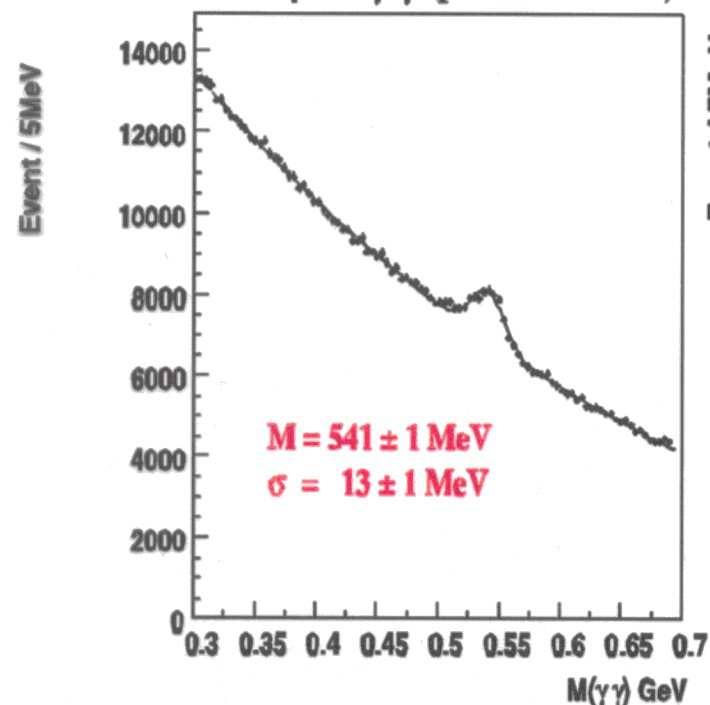
# BELLE Physics Now

$\sim 0.2 / \text{fb}$  (today)

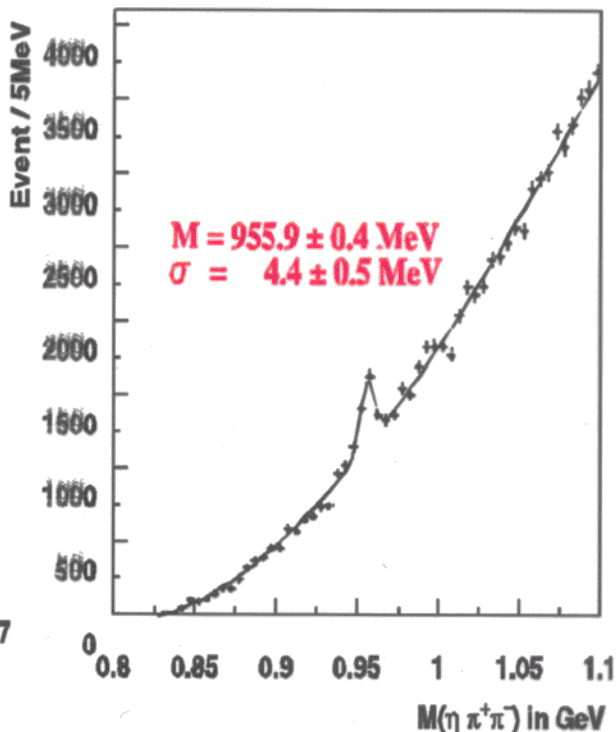
- Now =  $\sim 0.1 / \text{fb}$ ,  $t = 6$  months from turn-on
- Spectroscopy
  - Invariant masses
  - $B \rightarrow D \pi, D^* \pi$
- Inclusive lepton spectra
- $D^0$  lifetime
- $\tau$  physics

# Invariant mass analysis

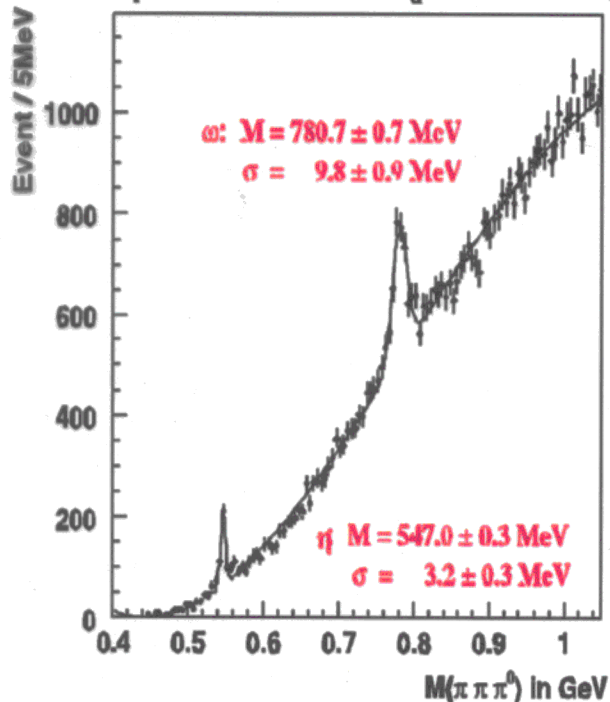
$\eta \rightarrow \gamma\gamma$  ( $p > 0.7$  GeV)



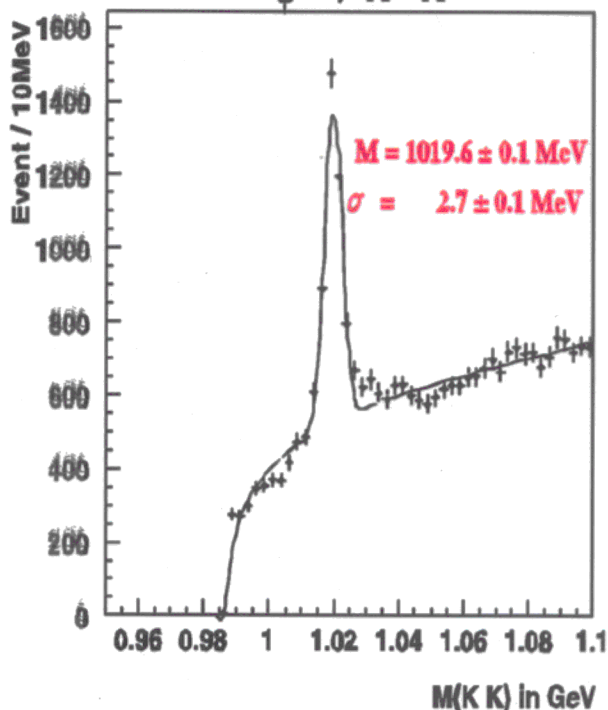
$\eta' \rightarrow \eta \pi^+ \pi^-$  ( $p > 2$  GeV)



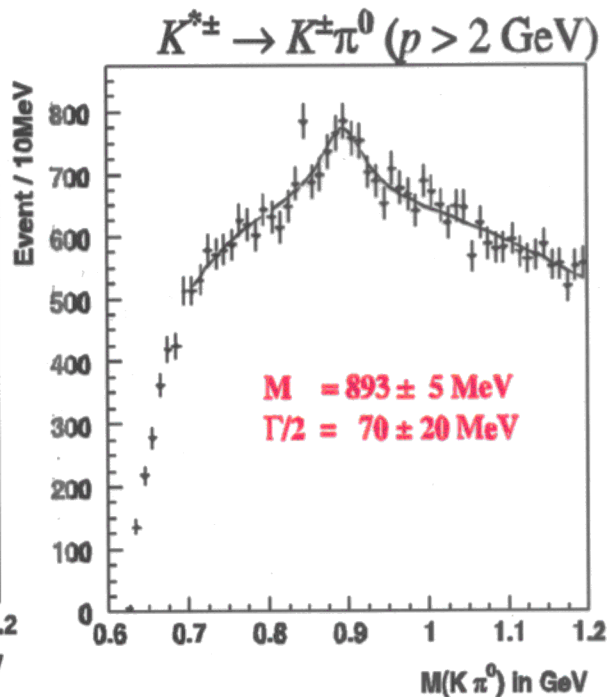
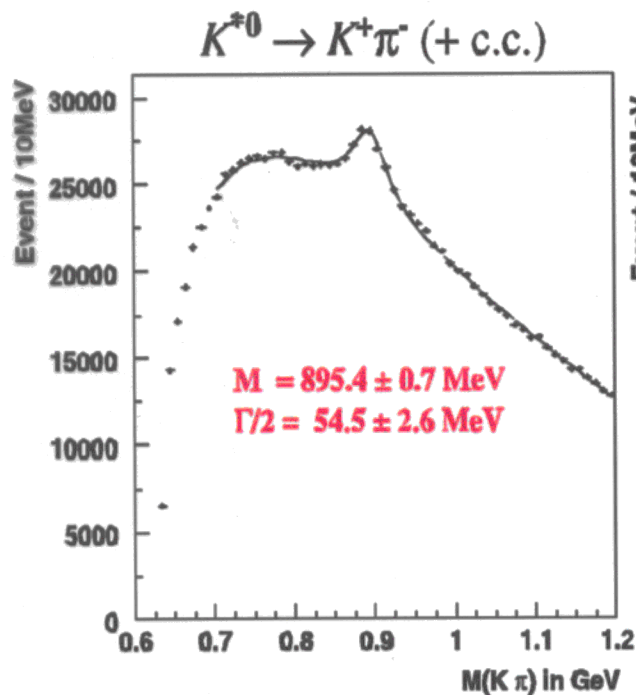
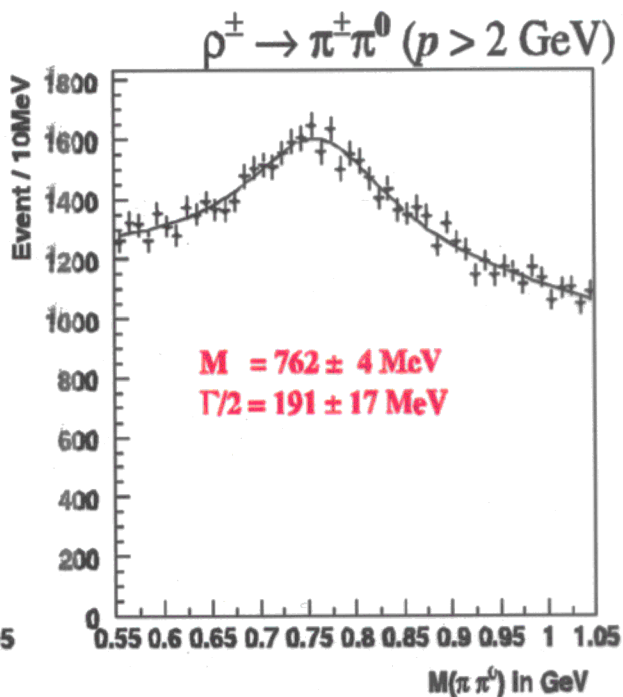
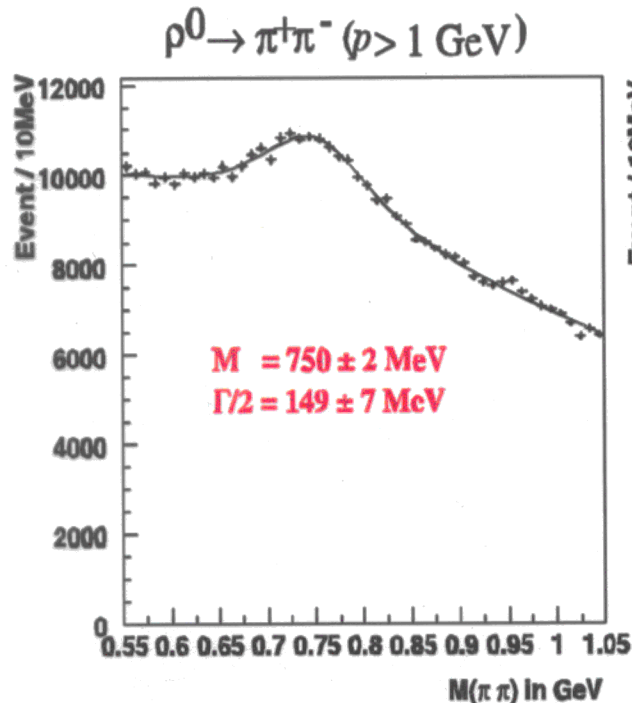
$\eta / \omega \rightarrow \pi \pi \pi^0$  ( $p > 2$  GeV)



$\phi \rightarrow K^+ K^-$

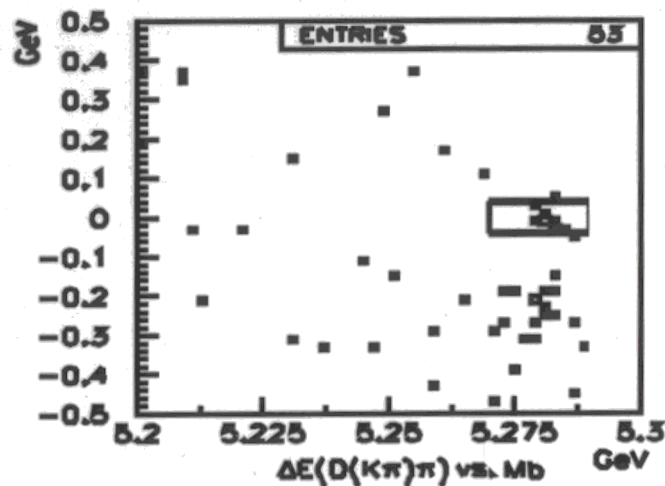
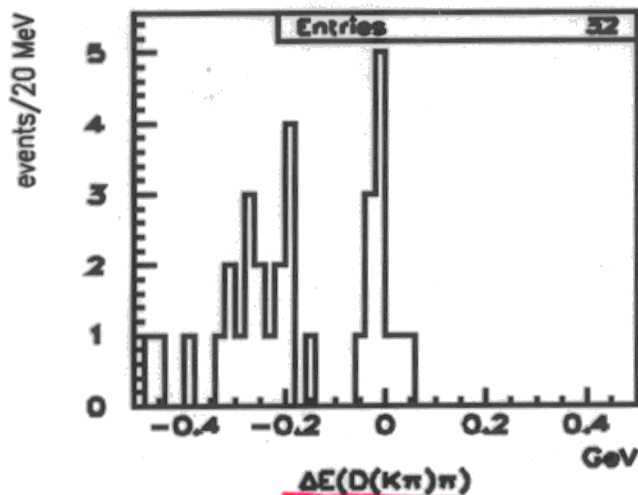


# Invariant mass analysis





# $B^- \rightarrow D^0(K^- \pi^+) \pi^-$ (and c.c.)



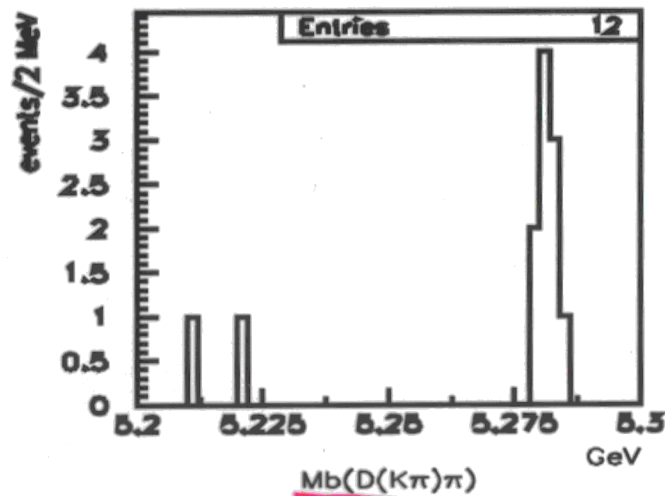
(with  $M_B$  constraint)  
 $5.27 < M_B < 5.29$

$$\Delta E = E_D + E_\pi - E_{beam} \text{ in CMS}$$

$$M_B = \sqrt{E_{beam}^2 - P_{D\pi}^2}$$

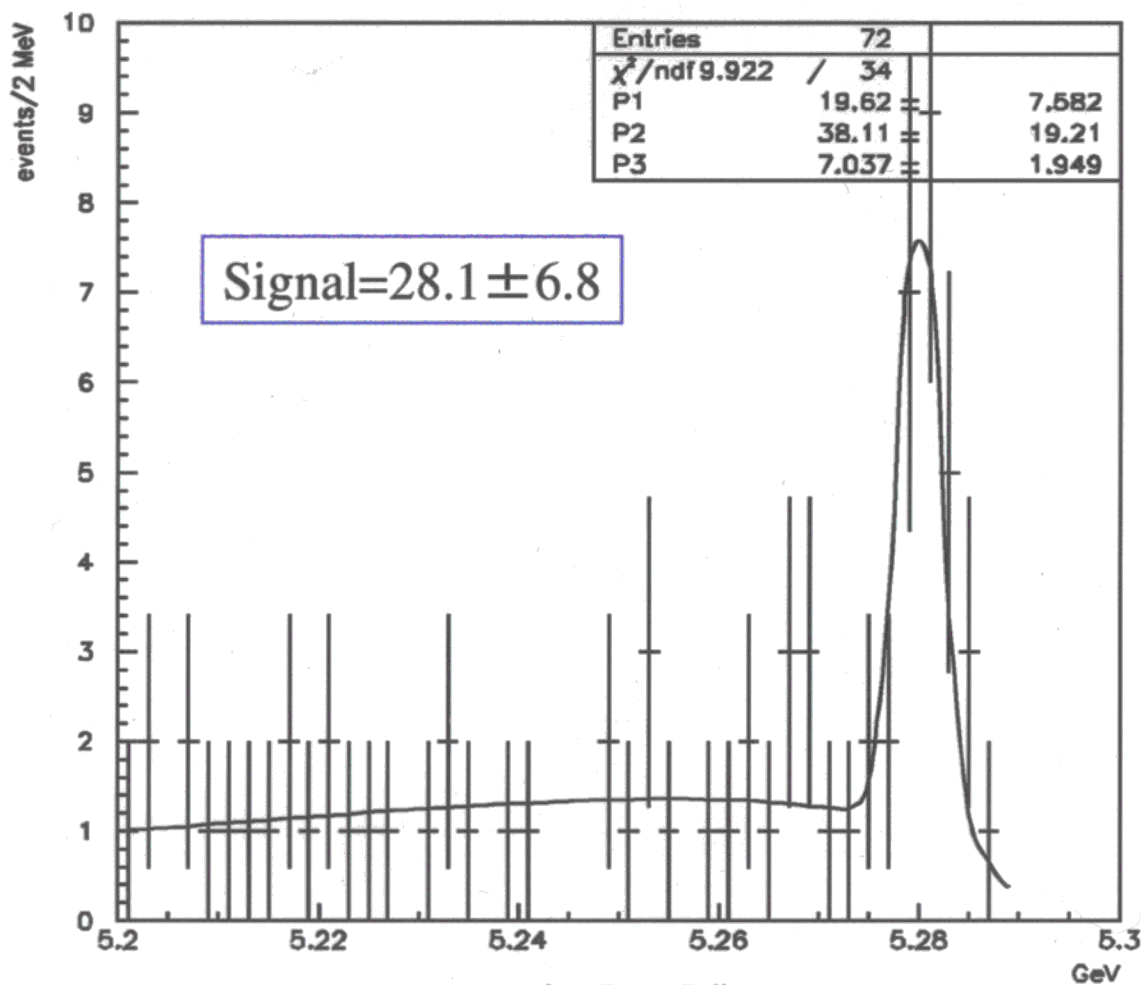
$\uparrow$  beam energy constrained mass

$\sim 125 \text{ pb}^{-1}$



(with  $\Delta E$  constraint)  
 $\pm 40 \text{ MeV}$

$B^- \rightarrow D^0(K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-)\pi^-$  combined



Beam energy constrained mass

(with  $\Delta E$  cut)

$\sim 125 \text{ pb}^{-1}$

## Partial reconstruction of $B \rightarrow D^* \pi$ decays

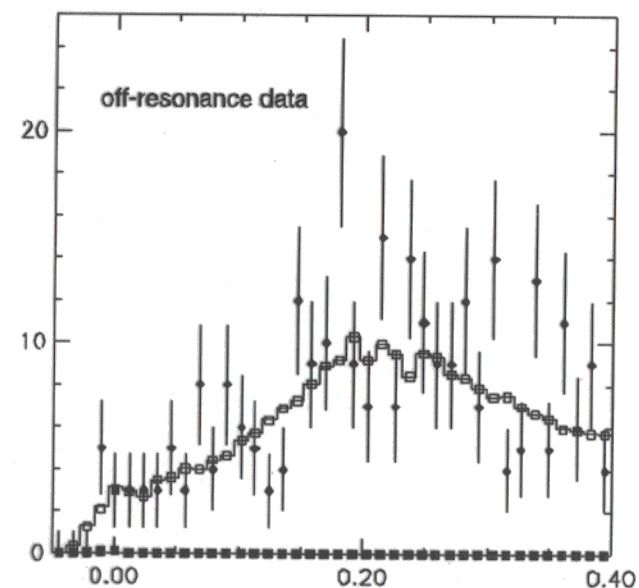
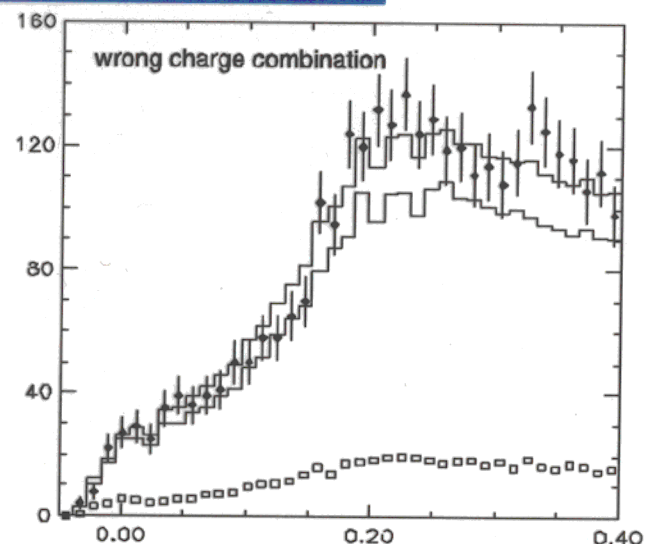
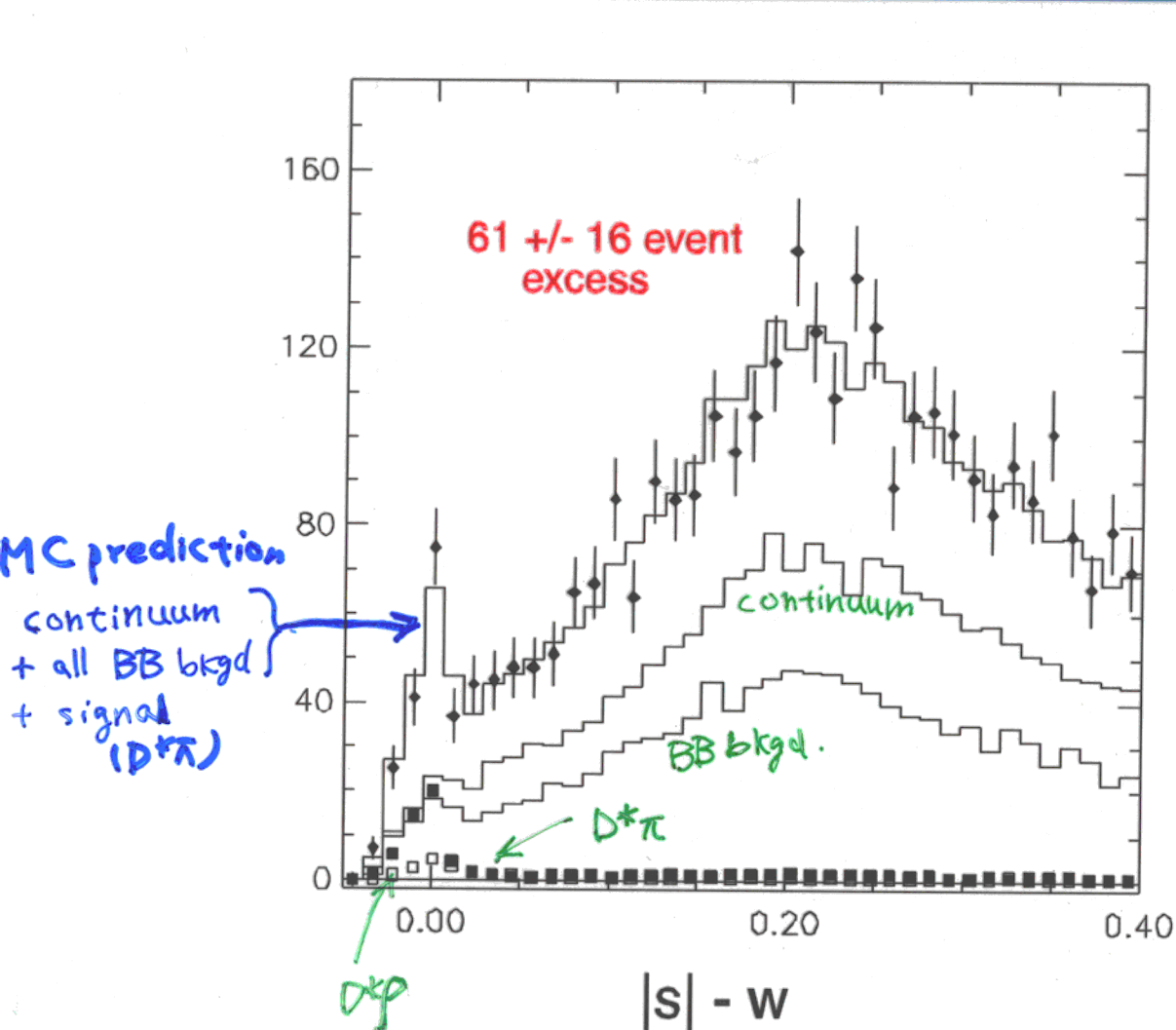
- Efficiency of the full reconstruction is too small.
- Due to kinematical constraints of 2-body decays of  $B \rightarrow D^* \pi_{\text{fast}}$  and  $D^* \rightarrow D \pi_{\text{slow}}$ , momenta  $\mathbf{p}_{\text{fast}}, \mathbf{p}_{\text{slow}}$  of these two fast/slow pions (6 degrees of freedom) can determine the event topology.
- The angle  $\phi$  between  $B \rightarrow D^* \pi$  and  $D^* \rightarrow D \pi$  decay planes is determined by  $\mathbf{p}_{\text{fast}}, \mathbf{p}_{\text{slow}}$  :

$$\cos \phi = \frac{s(\mathbf{p}_{\text{fast}}, \mathbf{p}_{\text{slow}})}{w(\mathbf{p}_{\text{fast}}, \mathbf{p}_{\text{slow}})}$$

- MC shows that  $|s| \cdot w$  peaks at 0 for signal.

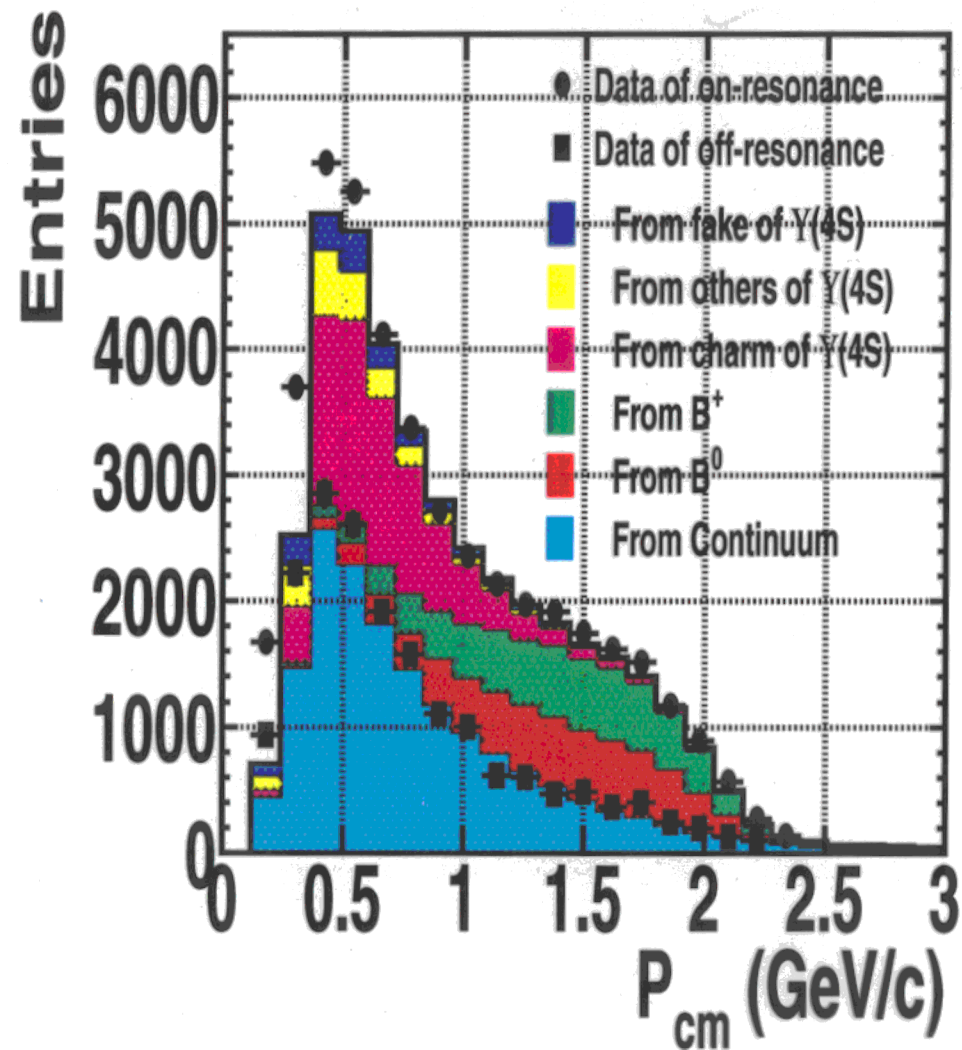


# $B \rightarrow D^* \pi$ partial reconstruction

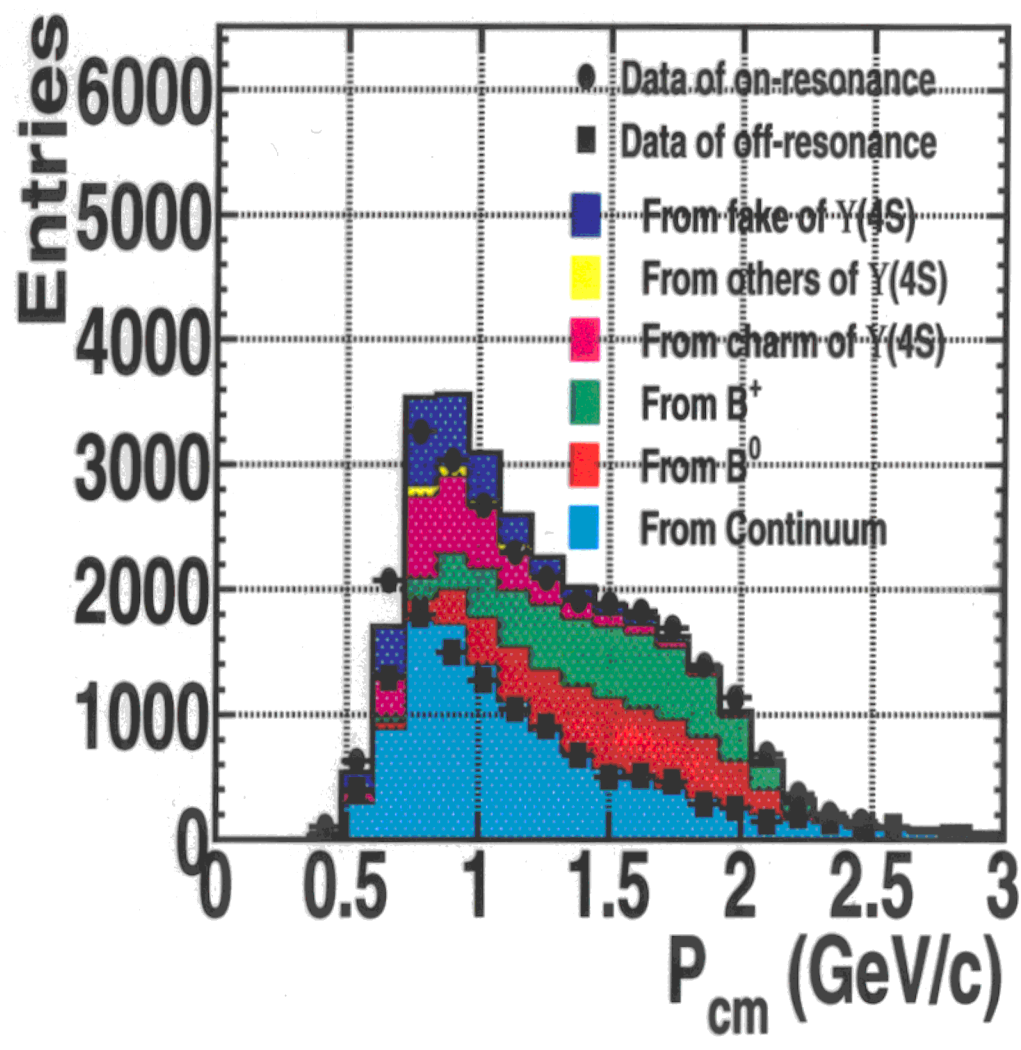


# Lepton inclusive spectra at Upsilon(4s) $\sim 150\text{pb}^{-1}$

## Electrons



## Muons



# D0 lifetime

- Select  $D0(K \pi)$  from charm (not from b) to avoid b lifetime effect.
  - Event shape variable  $R2 > 0.2$
  - $2.5 < P^*(D0) < 5.3$  GeV
- Select D0 without  $D^*$  requirement to gain statistics.
- Select D0 with  $D^*$  presence to minimize background.



# D0 lifetime

- Lifetime was calculated from flight distance of D0 from IP in the x-y plane.

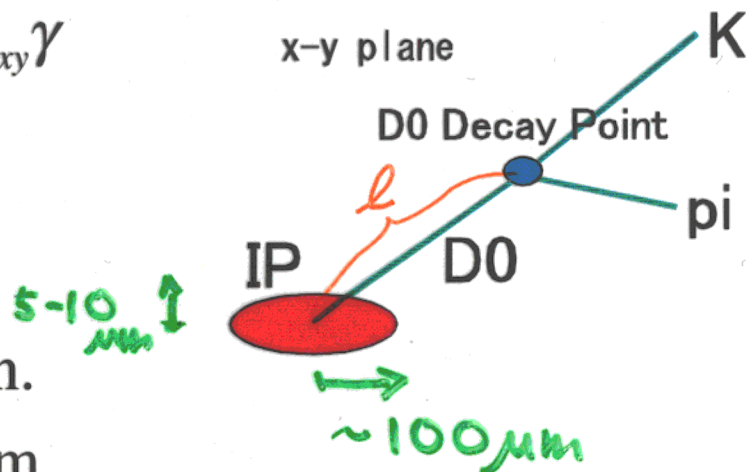
$$\underline{l} = \{ \vec{r}(D^0) - \vec{r}(IP) \} \cdot \frac{\vec{p}_{xy}}{p_{xy}} = ct\beta_{xy}\gamma$$

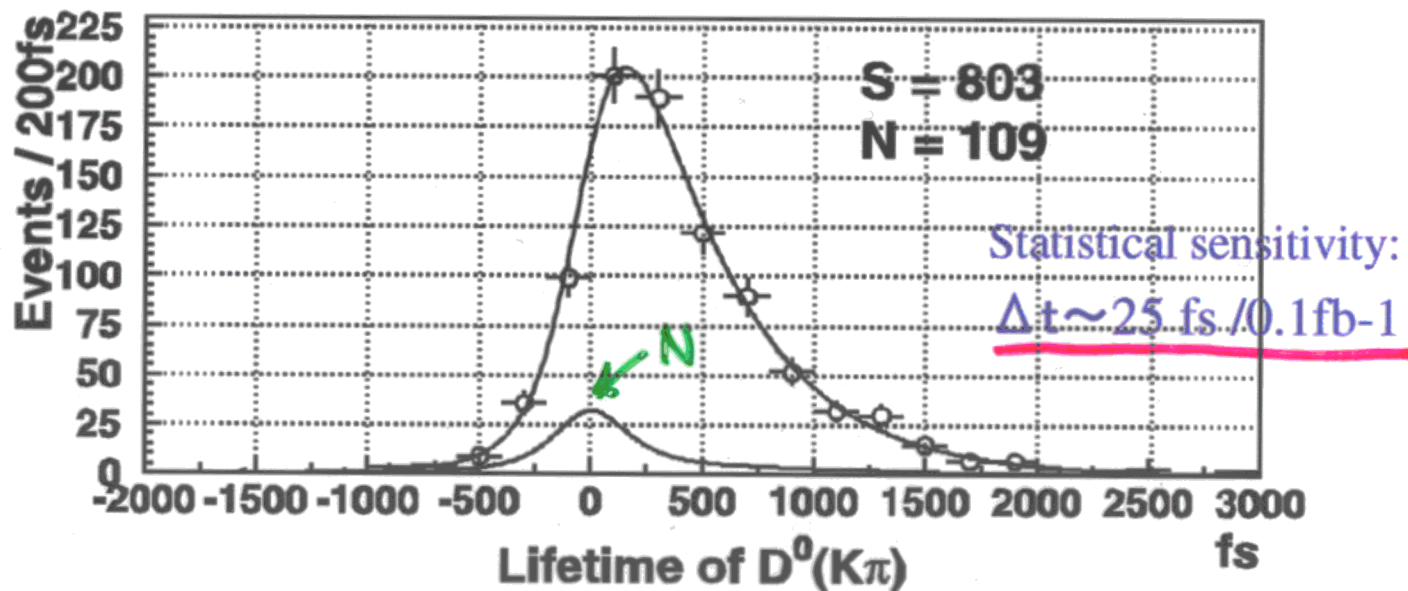
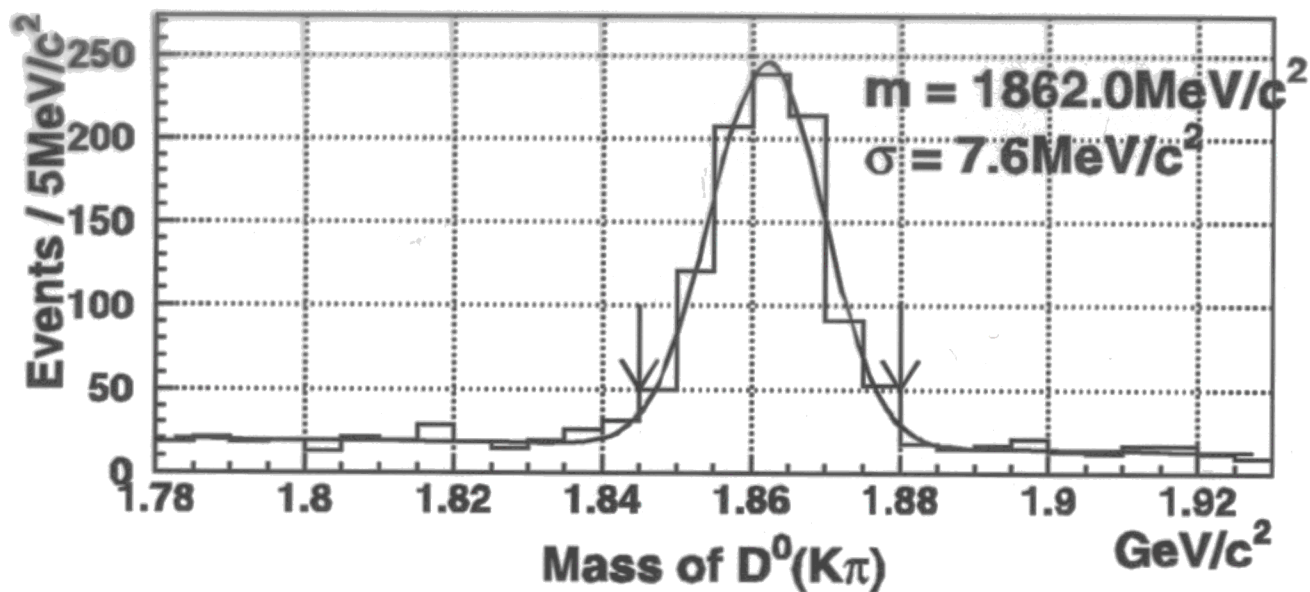
$$t = \frac{l}{c\beta_{xy}\gamma} = \frac{l}{c} \cdot \frac{m_{D^0}}{p_{xy}}$$

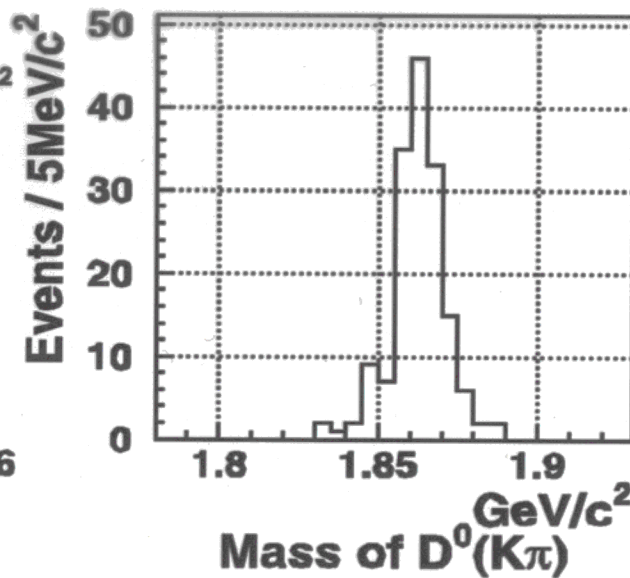
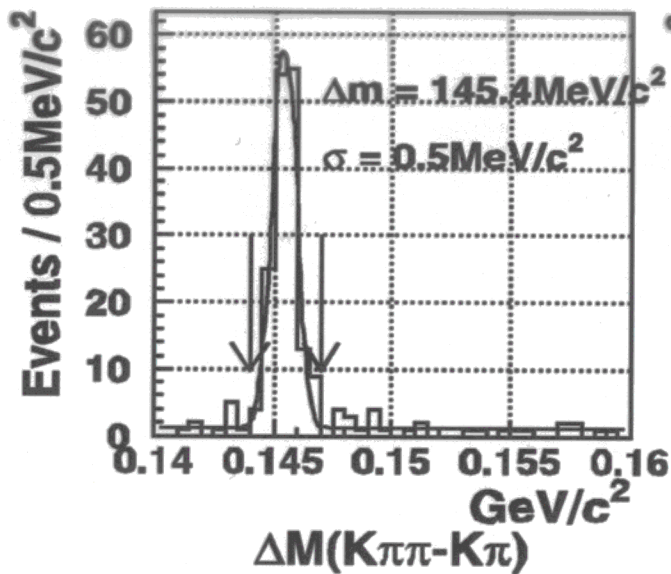
- IP profile measured run by run.

$$\sigma_x = \sim 100 \mu\text{m}, \sigma_y = 5-10 \mu\text{m}$$

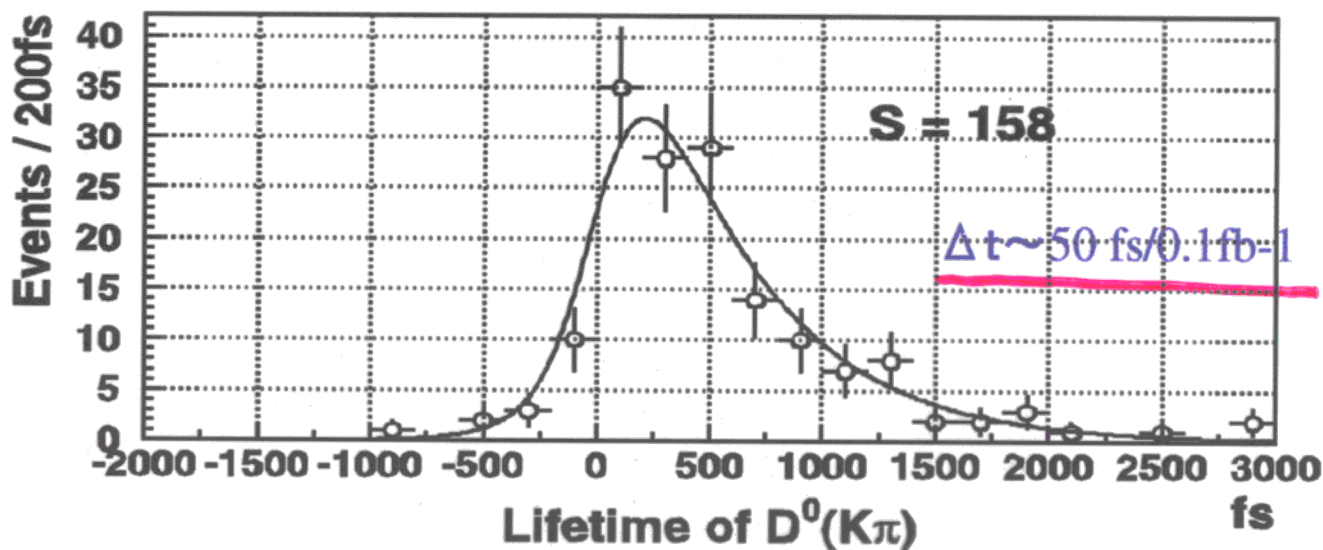
- Resolution estimated event-by-event from IP and extrapolated D0 flight path. It is about  $60 \mu\text{m}$  in flight length or 200 fs in proper time.







$\sim 0.15 \text{ fb}^{-1}$



**BELLE**

Exp 3 Run 466 Farm 1 Event 20237  
 Eher 8.00 Eler 3.50 Sun Aug 1 15:56:19 1999  
 TrglD 0 DelVer 0 MagID 0 BField 1.50 DspVer 4.06  
 Plot(ch) 3.9 Elot(gm) 2.5 SVD-M 0 CDC-M 0 KLM-M 0

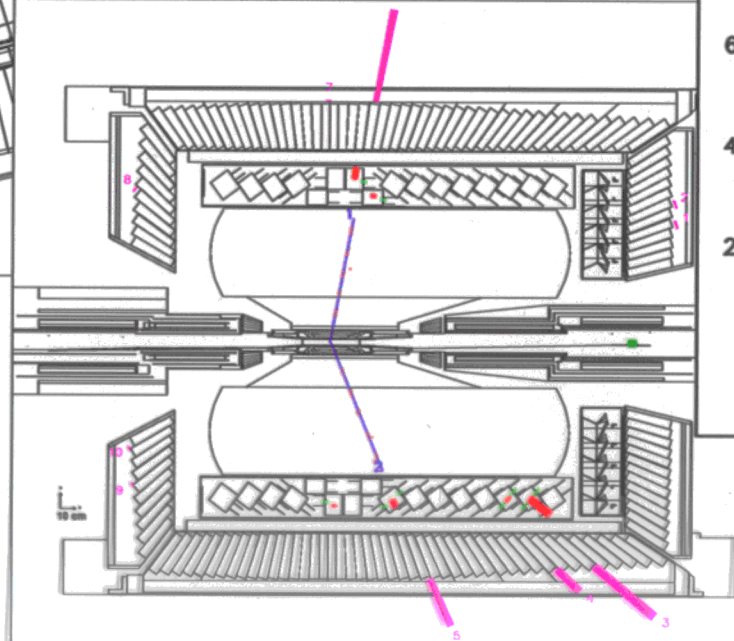
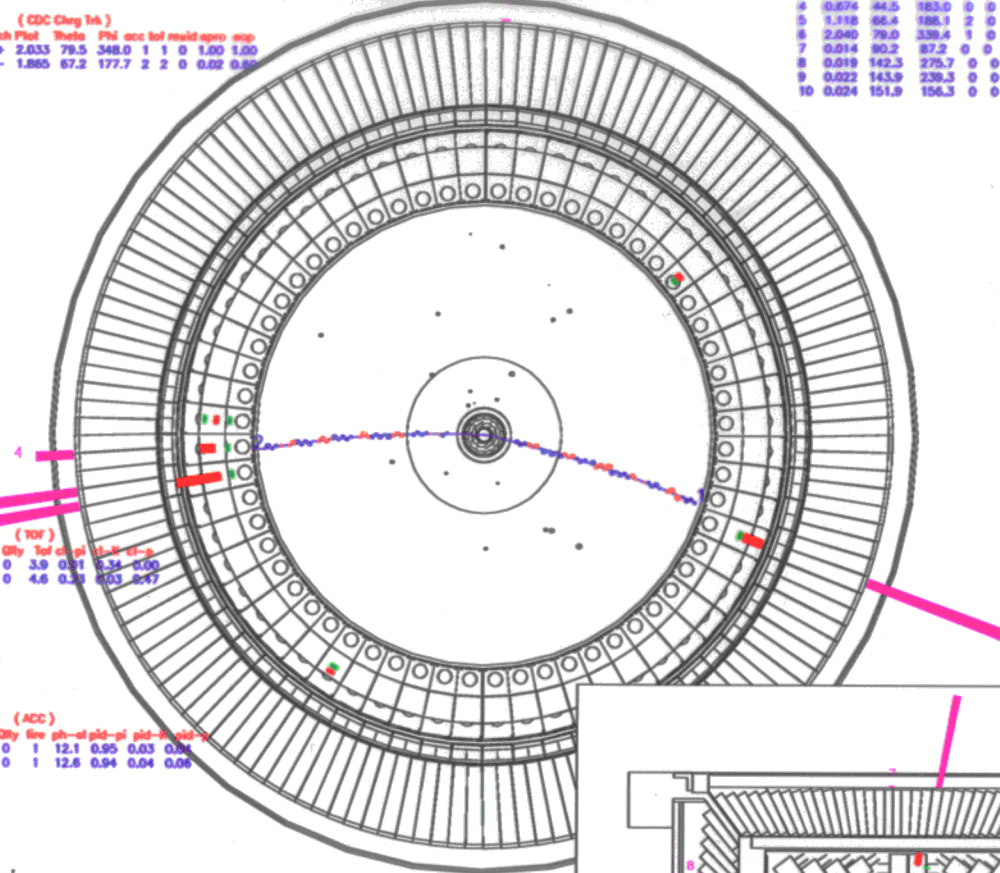
(CDC)

Trk	E	Theta	Pid match	sfld
1	0.043	16.8	71.3	0 0
2	0.035	21.8	342.9	0 0
3	1.704	36.8	190.1	0 0
4	0.674	44.5	183.0	0 0
5	1.118	66.4	186.1	2 0
6	2.040	79.0	339.4	1 0
7	0.014	90.2	87.2	0 0
8	0.019	142.3	275.7	0 0
9	0.022	143.9	239.3	0 0
10	0.024	151.9	156.3	0 0

(CDC Chg Trk)  
 Trk ch Pld Theta Pld acc tot mld appn acc  
 1 + 2.033 79.5 348.0 1 1 0 1.00 1.00  
 2 - 1.885 67.2 177.7 2 2 0 0.02 0.02

(TOF)  
 Trk Chg Tot ch pl tot ch pl  
 1 0 3.9 0.91 0.34 0.00  
 2 0 4.6 0.23 0.03 0.47

(ADC)  
 Trk Chg fsc ph-at pld-pl pld-at pld-pl  
 1 0 1 12.1 0.95 0.03 0.04  
 2 0 1 12.6 0.94 0.04 0.06

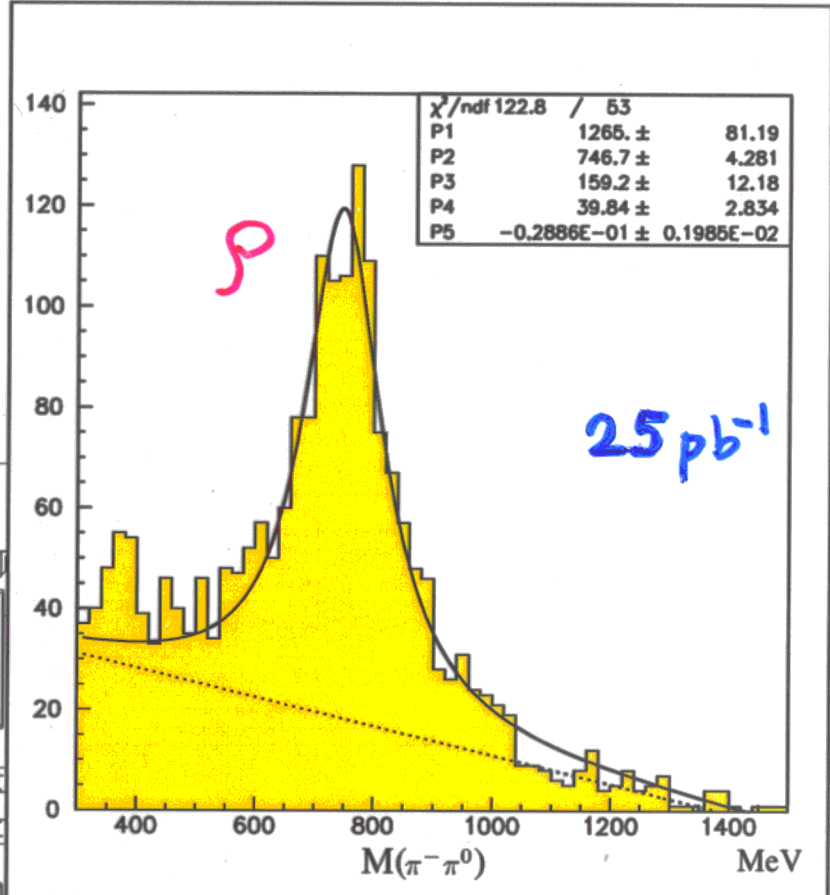


# $\tau$ event candidate

$$e^+e^- \rightarrow \tau^+\tau^-$$

$$\tau^+ \rightarrow e^+\nu_e\bar{\nu}_\tau$$

$$\tau^- \rightarrow \pi^-\pi^0\nu_\tau$$





## BELLE Physics Perspective

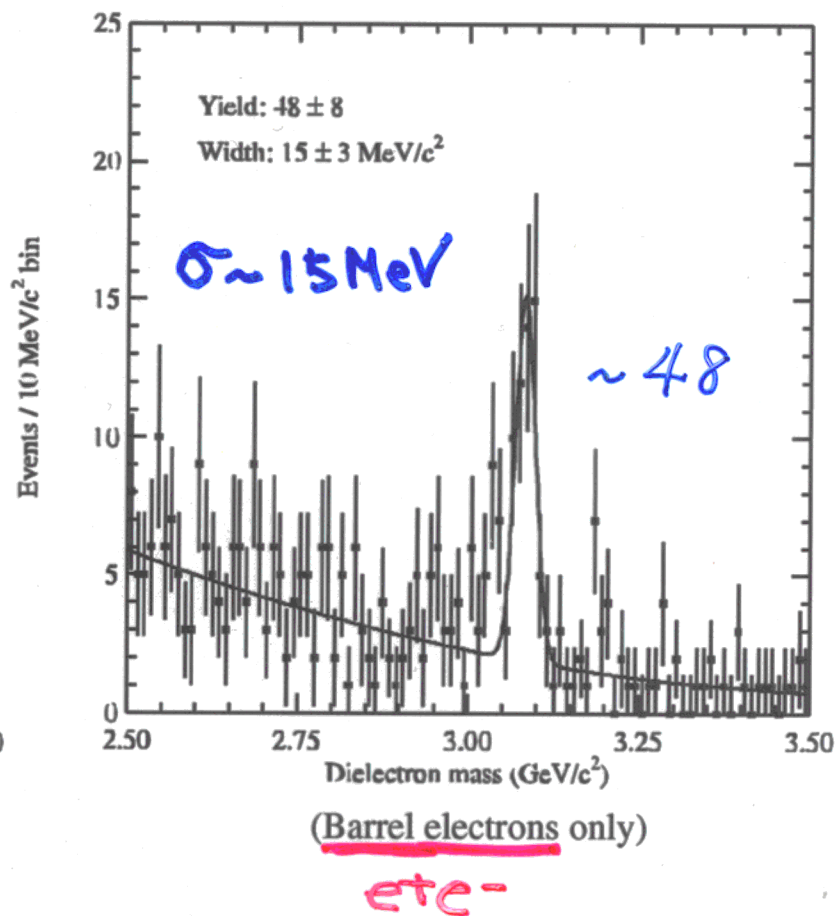
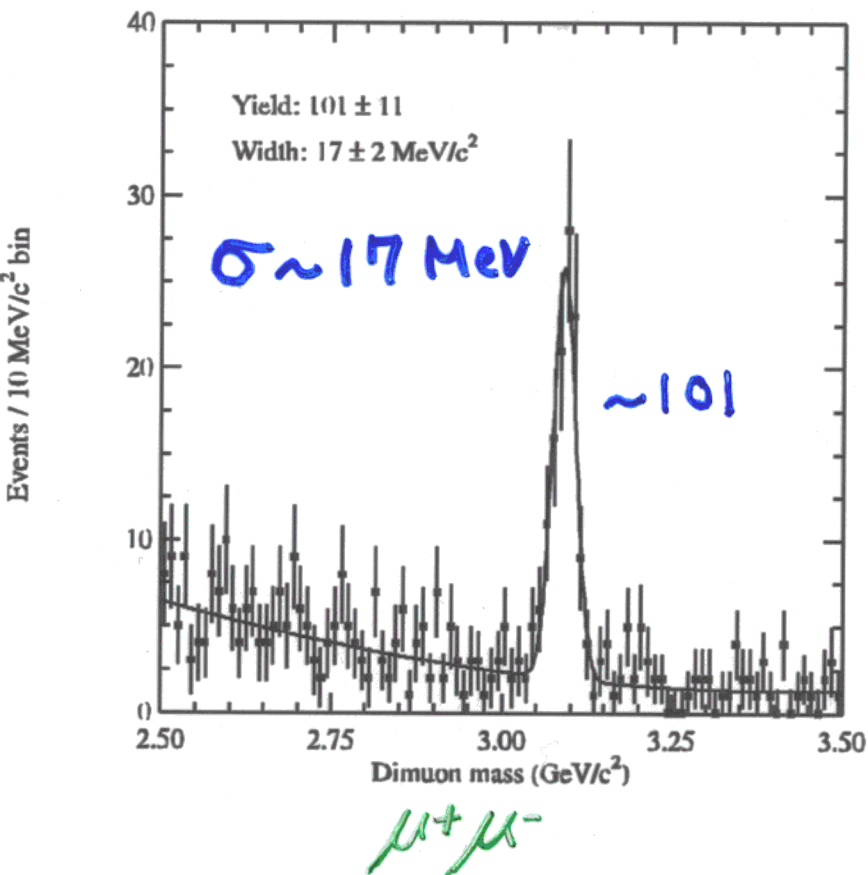
- Sensitivity to CP Violation parameter(s):

$$\sin 2\phi_1 = \sin 2\beta$$

$$\phi_1 = \pi - \arg \left( \frac{-V_{tb}^* V_{td}}{-V_{ub}^* V_{cd}} \right)$$

- Reconstruction of CP mode, in particular,  $J/\psi$  Ks
  - First step is to detect  $J/\psi$  inclusive
  - Second step is to reconstruct  $J/\psi$  exclusive final states such as  $J/\psi$  Ks,  $J/\psi$   $K^\pm$ ,  $K^*$  (figures)
- Flavor tagging
  - Tagging efficiency/Wrong tag fraction
    - Monte Carlo estimation
    - Estimation based on flavor specific decay modes (figures/tables)
- Sensitivity estimates

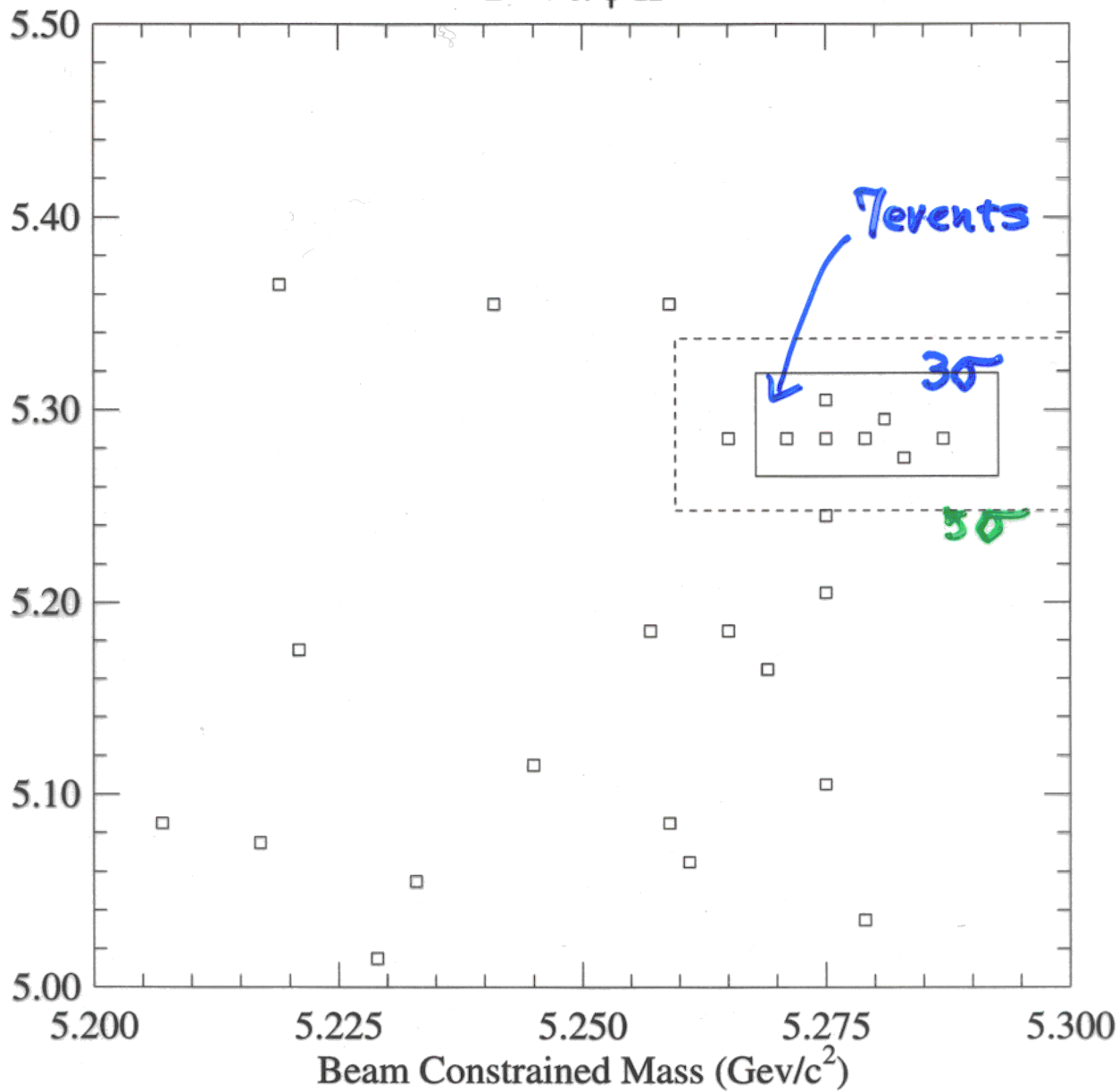
# J/ψ inclusive (from 0.12/fb)





$B \rightarrow J/\psi K^\pm$

B Candidate Energy (GeV)



0.125 fb<sup>-1</sup>

$B \rightarrow J/\psi K_s$

B Candidate Energy (GeV)

5.50

5.40

5.30

5.20

5.10

5.00

5.200

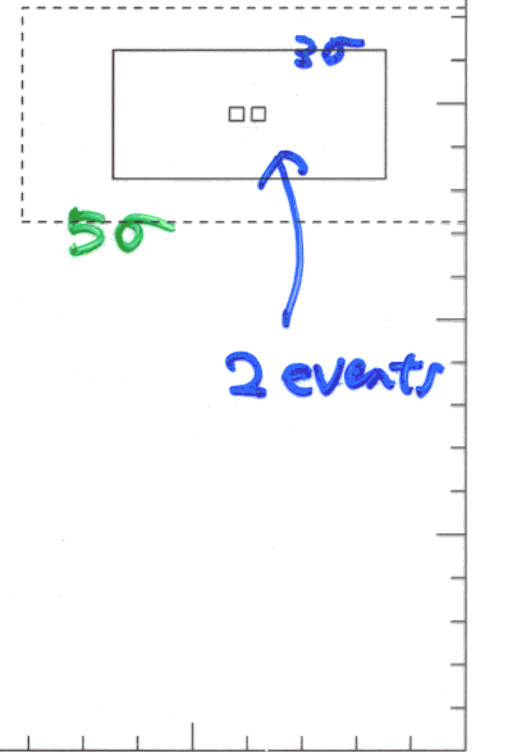
5.225

5.250

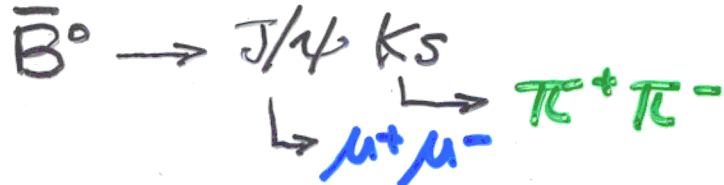
5.275

5.300

Beam Constrained Mass ( $\text{GeV}/c^2$ )

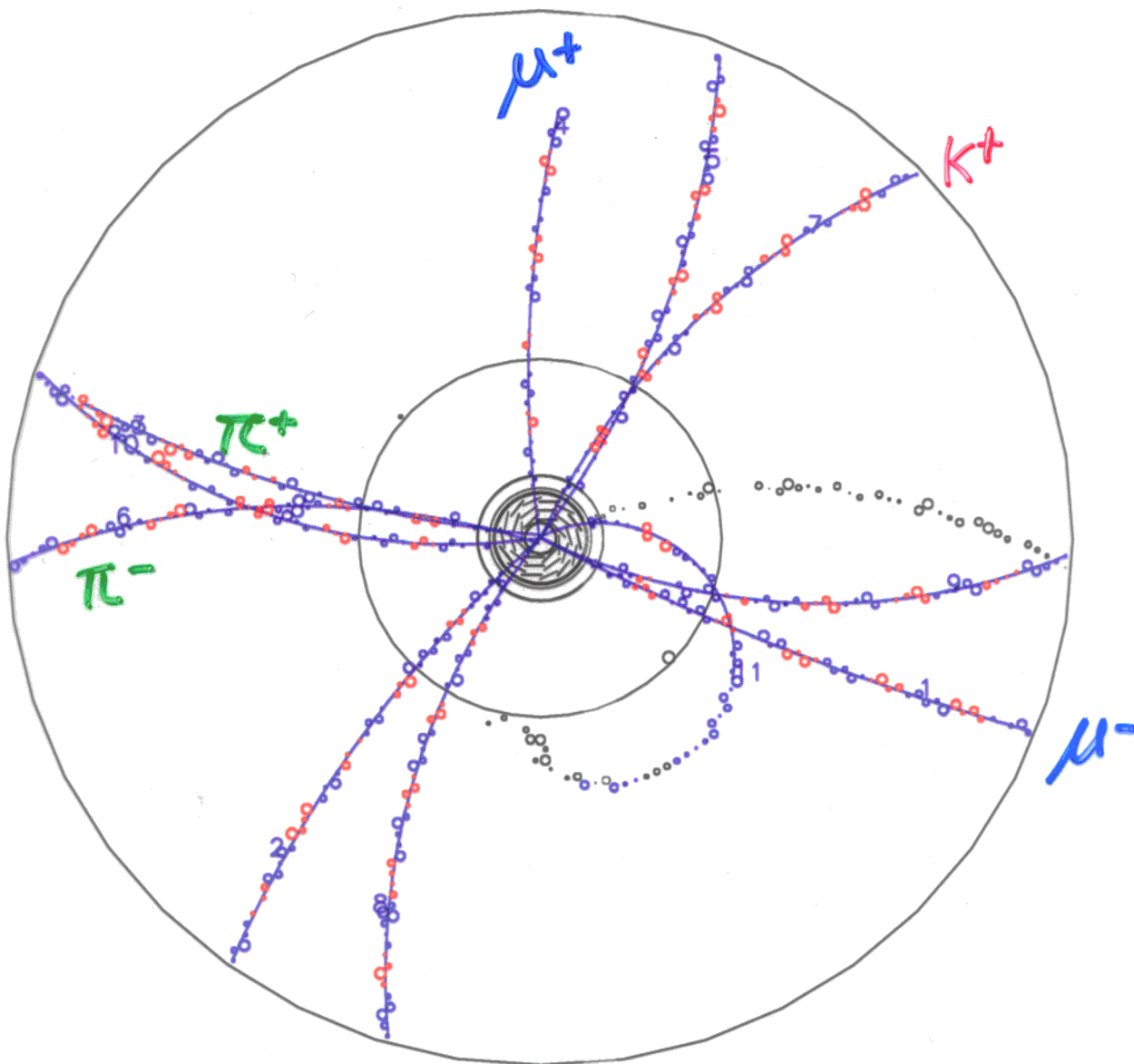


$0.125 \text{ fb}^{-1}$



**BELLE**

Exp 5 Run 272 Farm 5 Event 10889  
 Eher 8.00 Eler 3.50 Tue Nov 16 23z12z08 1999  
 TrglD 0 DetVer 0 MagID 0 BField 1.50 DspVer 4.06  
 Ptot(ch) 10.3 Etot(gm) 0.2 SVD-M 0 CDC-M 0 KLM-M 0



$\begin{array}{c} y \\ \uparrow \\ x \end{array}$   
 10 cm

# BELLE

Exp 5 Run 272 Farm 5 Event 10889  
 Eher 8.00 Eler 3.50 Tue Nov 16 23z12z08 1999  
 TrgID 0 DetVer 0 MagID 0 BField 1.50 DspVer 4.06  
 Ptot(ch) 10.3 Etot(gm) 0.2 SVD-M 0 CDC-M 0 KLM-M

(CDC Chrg Trk)

Trk	ch	Ptot	Theta	Phi	acc	tof	muid	epro	eop
1	-	2.272	54.9	332.5	1	1	3	0.01	0.26
2	-	1.100	60.1	222.9	2	2	0	0.00	0.17
3	+	1.487	35.4	175.5	3	3	0	0.01	0.60
4	+	1.209	136.3	98.1	4	0	3	0.00	0.12
5	-	0.884	48.8	53.1	5	4	0	0.00	0.33
6	-	0.662	58.2	162.3	6	5	0	0.00	0.08
7	+	0.602	64.4	65.0	7	6	-1	0.00	0.52
8	-	0.949	32.7	231.7	8	0	0	0.00	0.20
9	-	0.488	108.2	333.9	9	7	-1	0.00	1.05
10	+	0.463	116.6	189.1	10	8	-1	0.00	0.39
11	+	0.143	45.6	26.1	11	0	-1	0.00	99.00

(ECL)

Trk	E	Theta	Phi	match	elid
1	0.031	18.7	174.4	0	0
2	0.018	22.8	1.4	0	0
3	0.019	29.2	211.8	0	0
4	0.898	35.0	155.1	3	0
5	0.194	30.7	265.0	8	0
6	0.169	46.2	256.7	0	0
7	0.293	51.0	82.2	5	0
8	0.052	55.5	194.8	6	0
9	0.582	55.1	340.2	1	0
10	0.033	57.2	351.7	1	0
11	0.029	57.3	34.4	7	0
12	0.312	63.2	31.5	7	0
13	0.087	61.4	202.4	0	0
14	0.073	64.0	205.7	0	0
15	0.190	60.9	242.3	2	0
16	0.023	98.9	21.4	0	0
17	0.512	110.1	14.6	9	0
18	0.181	118.9	144.6	10	0
19	0.018	121.0	171.4	0	0
20	0.148	137.0	82.4	4	0

(TOF)

Trk	Qty	tof	el-pi	el-K	el-p
1	0	5.1	0.04	0.42	0.12
2	0	4.8	0.80	0.00	0.00
3	0	7.0	0.12	0.00	0.00
4	0	5.8	0.37	0.00	0.00
5	0	5.6	0.97	0.11	0.00
6	0	4.9	0.26	0.00	0.00
7	0	6.6	0.00	0.73	0.00
8	0	5.4	0.02	0.00	0.00

(ADC)

Trk	Qty	fire	ph-el	pid-pi	pid-K	pid-p
1	0	1	7.3	0.94	0.07	0.06
2	0	0	1.7	0.32	0.94	0.94
3	0	0	1.7	0.19	0.95	0.94
4	1	0	0.0	0.00	0.00	0.00
5	0	0	0.0	0.90	0.94	0.94
6	0	0	0.0	0.95	0.94	0.94
7	0	0	0.5	0.96	0.94	0.94
8	0	1	2.3	0.11	0.06	0.06
9	0	0	0.0	0.96	0.96	0.96
10	0	0	0.0	0.96	0.96	0.96
11	1	0	0.0	0.00	0.00	0.00

(KLM)

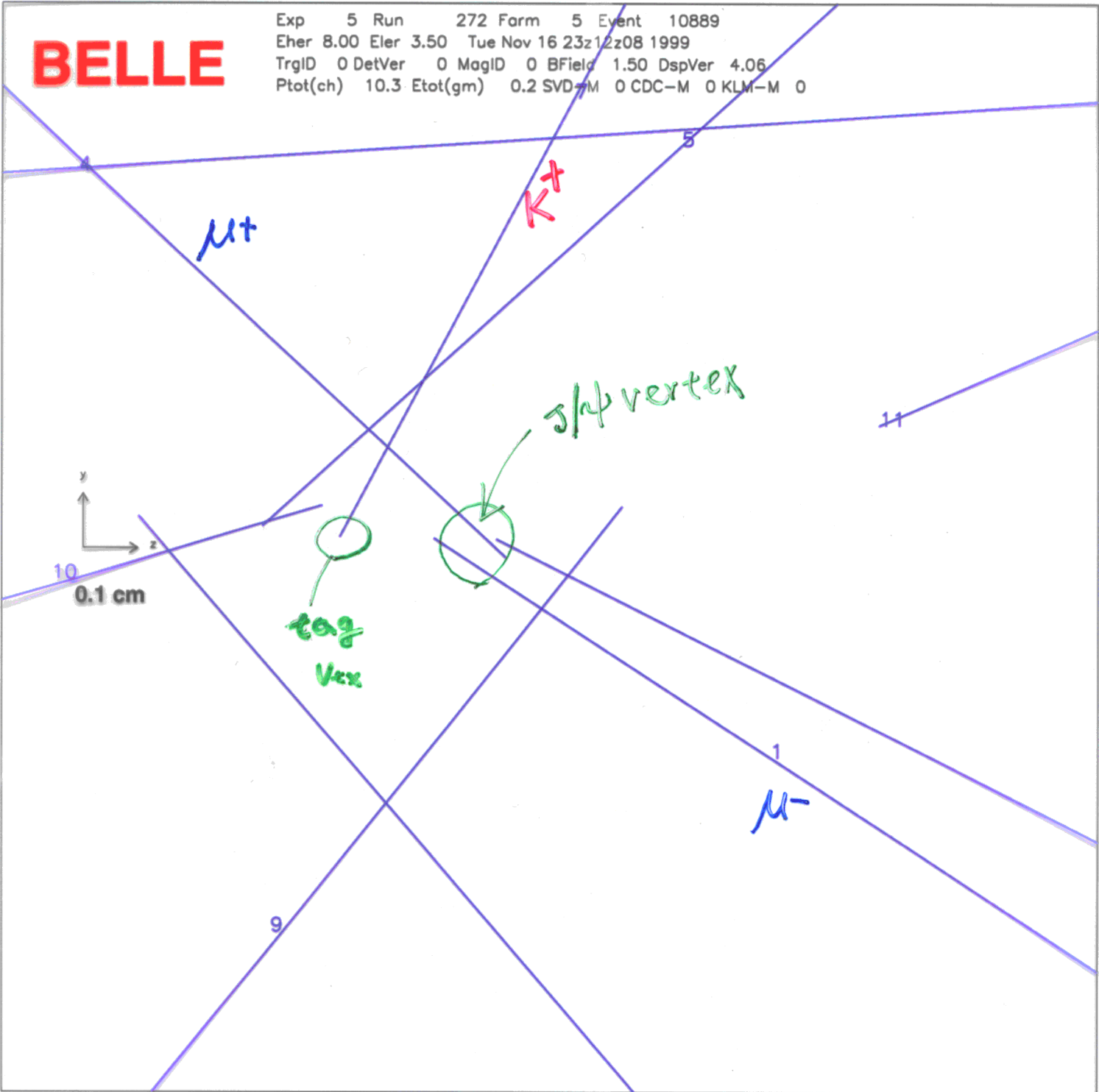
Trk	Theta	Phi	Quality	layer
1	54.8	359.8	0	14
2	137.2	1.1	0	9
3	60.8	358.1	0	2
4	29.7	358.5	0	1
5	49.2	1.8	0	1
6	131.7	357.4	0	1

gdl-in =0,1,2,3,4,5,6,8,9,12,13,14,15,16,17,18,19,20,23,26,30,31,34,47,z  
 ftdl-out=0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,19,21,23,24,25,27,28,29,30,31,32,33,34,35,  
 gdl-out=0,4,10,12,13,14,19,24,25,40,42,44,45,z

Note: Noise hits removed.

# BELLE

Exp 5 Run 272 Form 5 Event 10889  
Eher 8.00 Eler 3.50 Tue Nov 16 23:12:08 1999  
TrgID 0 DetVer 0 MagID 0 BField 1.50 DspVer 4.06  
Ptot(ch) 10.3 Etot(gm) 0.2 SVD-M 0 CDC-M 0 KLM-M 0

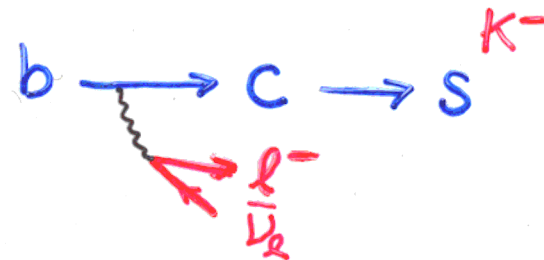


→ boost axis

# Flavor tagging

- Tagging algorithm

- Sign of high  $p^*( > 1.1 \text{ GeV}/c )$   $e$  or  $\mu$
- Sign of (the sum) of Kaon charges



- Expected performance based on the full simulation

	Efficiency(%)	Wrong tag fraction (%)	Effective efficiency (%)
Lepton	12.2	8.2	8.5
Kaon	29.0	16.6	13.0
Sum			21.5

$\epsilon$

$\omega$

$(1-2\omega)^2 \cdot \epsilon$



## A tagging performance study using $D^* \ell \nu$

- Identify the flavor of one B by reconstructing  $B^0 \rightarrow D^{*-} \ell^+ \nu$  and  $B^0 \rightarrow D^- \ell^+ \nu$  then look for a lepton or a kaon.

- See how often we get right tags :

$$S^{obs} = (1 - \omega) S + \omega O$$

$$O^{obs} = \omega S + (1 - \omega) O$$

$$\text{mixing parameter} : \chi_d \equiv \frac{S}{S + O} = 0.172 \pm 0.010 \text{ (PDG)}$$

$S(O)$  = number of true pairs of same (opposite) flavor

$S^{obs} (O^{obs})$  = number of observed pairs of same (opposite) flavor

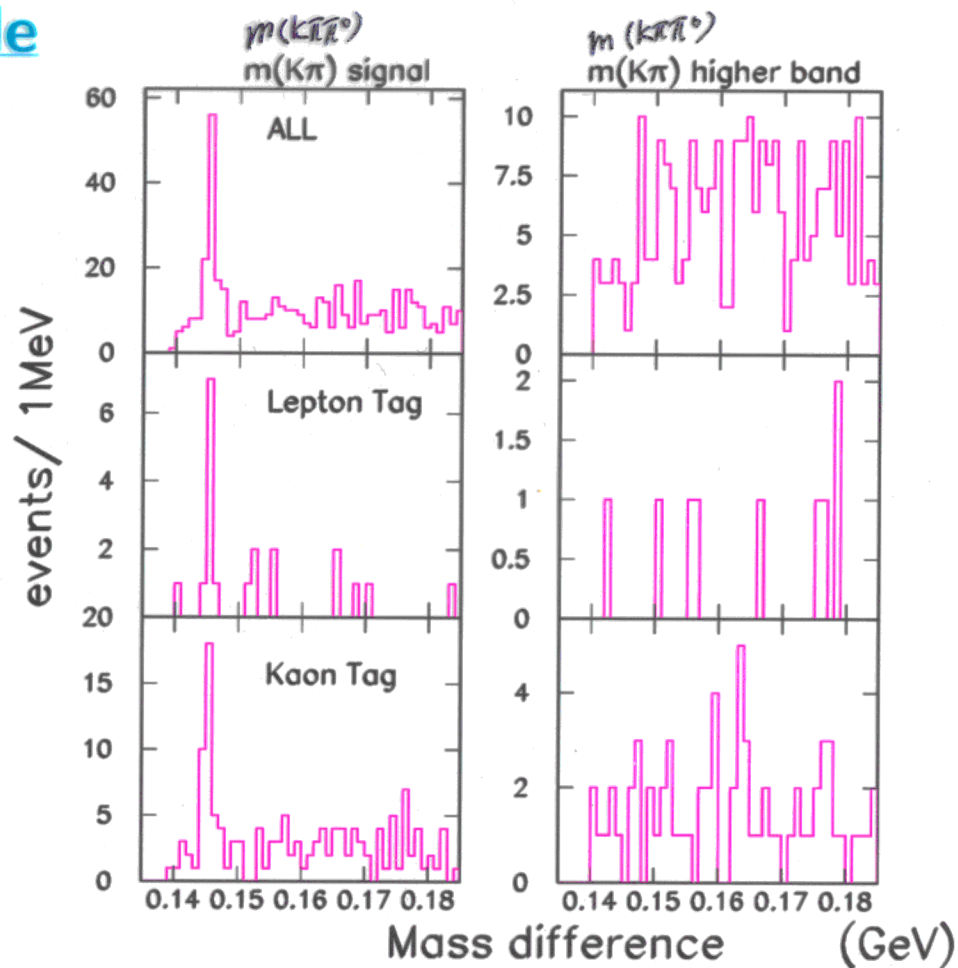
$$\omega = \frac{S^{obs} - \chi_d N}{(1 - 2\chi_d) N}, \quad N = S + O = S^{obs} + O^{obs}$$

- Results based on  $\sim 0.1 \text{ fb}^{-1}$  are consistent with our expectation.

$$B \rightarrow D^* \ell^+ \nu \rightarrow \bar{D}^0 \pi^- \ell^+ \nu$$

$$\bar{D}^0 \rightarrow K\pi \text{ and } K\pi\pi^0 \text{ mode}$$

	# of sig	# of bkg
ALL	122	25
Lepton Tag	9	1
Kaon Tag	40	8



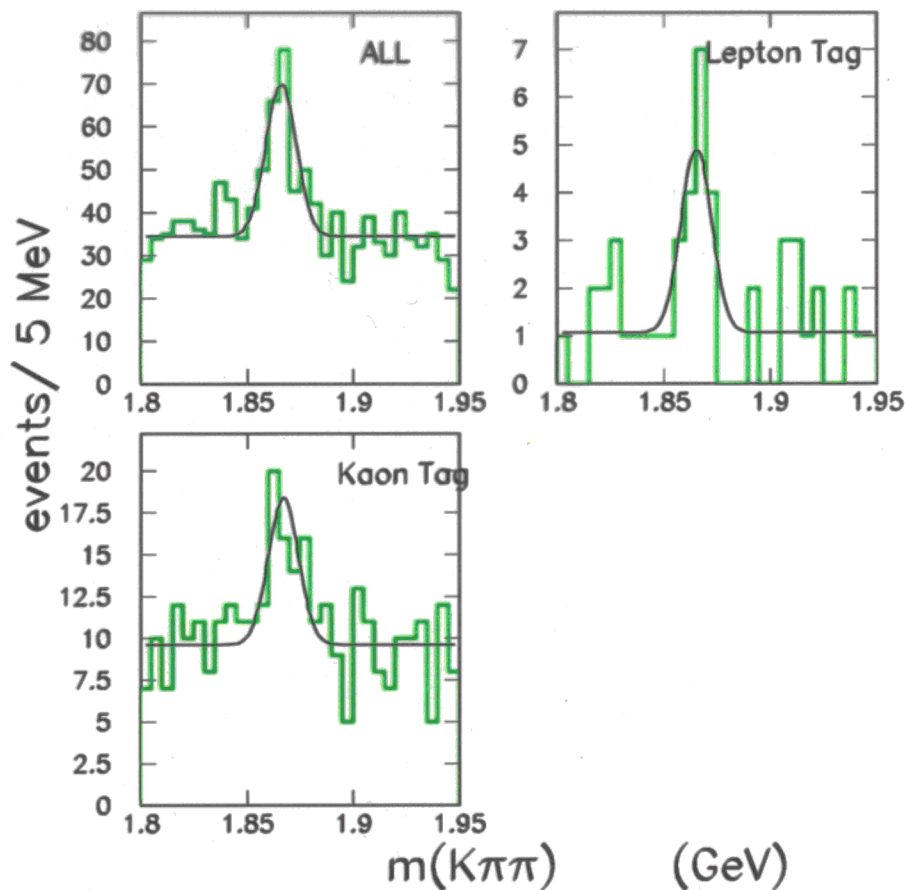
$$\epsilon_{eff} = (1 - 2w)^2 \cdot \epsilon$$

	Right tag		Wrong		$\epsilon$ (%)	$w$ (%)	$\epsilon_{eff}$ (%)
	Opposite Flavor		Same Flavor				
	# of sig	# of bkg	# of sig	# of bkg			
Lepton Tag	6	1	3	0	$8 \pm 3$	$32 \pm 25$	$3 \pm 3$
Kaon Tag	28	5	12	3	$33 \pm 5$	$17 \pm 12$	$14 \pm 10$
Sum	34	6	15	3	$41 \pm 5$	$21 \pm 11$	$14 \pm 10$

$$B^0 \rightarrow D^- \ell^+ \nu$$

→  $K\pi\pi$  mode

	# of sig
ALL	$127.4 \pm 23.6$
Lepton Tag	$13.8 \pm 4.6$
Kaon Tag	$31.3 \pm 9.9$



Right

Wrong

	Opposite Flavor	Same Flavor	$\epsilon$ (%)	$w$ (%)	$\epsilon_{eff}$ (%)
Lepton Tag	$9.9 \pm 3.8$	$3.9 \pm 2.6$	$11 \pm 3$	$18 \pm 5$	$5 \pm 5$
Kaon Tag	$29.2 \pm 8.4$	$6.5 \pm 5.8$	$28 \pm 4$	$2 \pm 10$	$26 \pm 11$
Sum	$39.1 \pm 9.2$	$10.4 \pm 6.3$	$38 \pm 4$	$6 \pm 8$	$30 \pm 13$

## Tagging study based on $\sim 0.1/\text{fb}$ data

- $\sim 122 D^* 1 \nu$  events ( $D \rightarrow K \pi, K \pi \pi^0$ ) and  $\sim 127 D 1 \nu$  events combined: **Very preliminary**

	Efficiency(%)	Wrong tag fraction (%)	Effective efficiency (%)
Lepton	$10 \pm 2(12.2)$	$23 \pm 15(8.2)$	$3 \pm 3(8.5)$
Kaon	$30 \pm 5(29.0)$	$10 \pm 8(16.6)$	$19 \pm 7(13.0)$
Sum	$40 \pm 3(41.2)$	$13 \pm 7$	$22 \pm 8(21.5)$

- Consistent with the expectation (with limited statistics).

Numbers  $i \pm j ( )$  are MC values.



# Belle $\sigma(\sin^2\phi_1)$ errors for 100 fb<sup>-1</sup> (estimates based on GEANT simulation)

CP mode	BR ×10 <sup>-4</sup>	CP mode Rec. EFF	Signal+tag events	Bkgd/Signal	$\sigma$ (Z) $\mu\text{m}$	CP reach Stat. Error	Analytical estimate
J/Ψ (l+l-) K <sub>s</sub> (π+π-)	3.3	0.43	668	0.01	100	0.10	0.09
Ψ (2S) (l+l- / Ψ π π) K <sub>s</sub> (π+	1.6	0.32	160	0.14	100	0.22	0.19
χ c1 (Ψ γ) K <sub>s</sub> (π+π-)	0.9	0.29	106	0.17	100	0.28	0.23
η c (KK π π, 4 π, 4K) K <sub>s</sub> (π+π	3.1	0.22	200	0.39	100	0.19	0.18
combined						0.08	0.07
J/Ψ (l+l-) KL	4	0.23	590	0.62	100	na	0.12
J/Ψ (l+l-) K* (π+π- π 0)	13.2	0.13	100	0.72	100	na	0.27
D*+D*-	9.7	0.03	50	na	100	na	
J/Ψ (l+l-) K <sub>s</sub> (π 0 π 0) ¶	1.2	0.15	120	0.12	100		0.20

Note: Total effective tagging efficiency =  $(1-2w)^2 \text{eff} \sim 0.22$  with leptons and Kaons (GEANT results)  
 Note: For analytical estimation on stat errors, we used 0.54 as dilution due to vertex resolutions.  
 Note ¶ : J/Ψ (l+l-) K<sub>s</sub> (π 0 π 0) is done by parametrized simulation only.

## Belle $\sigma(\sin^2\phi_2)$ errors for 100 fb<sup>-1</sup> (estimates based on parameterized simulation)

CP mode	BR ×10 <sup>-4</sup>	CP mode Rec. EFF	Signal events	N/S	CP reach Stat. Error (No penguins)
π+π-	0.13	0.43	283	0.14	0.15
ρ+π- / ρ+π-	0.60	0.33	1000	na	na

# Conclusion

- Physics analysis is on the way with the initial 0.1/fb data.
- $\sim 1J/\psi$  (ee/ $\mu\mu$ ) event per  $\overset{1\text{ pb}^{-1}}{\cancel{0.01/\text{fb}}}$  data
- Statistical sensitivity of  $\delta \sin(2\phi_1) = \frac{0.08}{\sqrt{\frac{\int Ldt}{100 \text{ fb}^{-1}}}}$  is expected from charmonium + Ks events.
- Efficiency/wrong tag fraction from the initial data are consistent with our expectation.