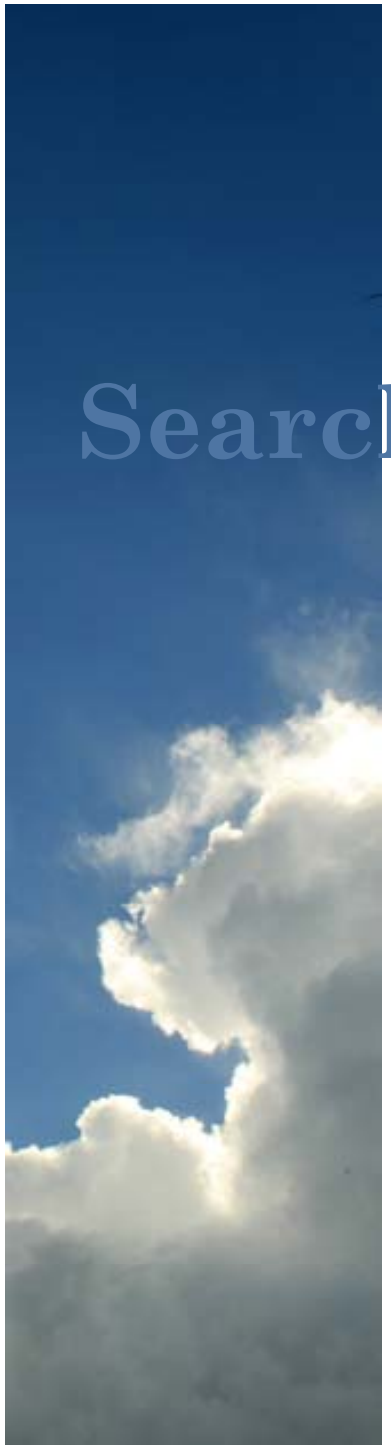

Lake Louise Winter Institute 2010

Search for an exotic light particle at Belle

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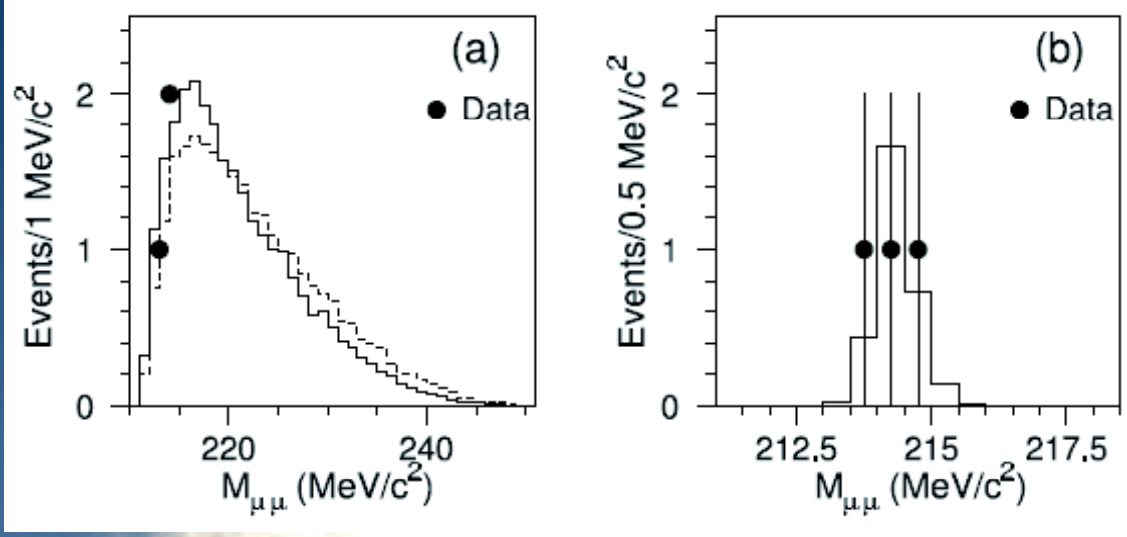
(For the Belle Collaboration)

Contents

- Motivation : HyperCP exotic events
- KEK-B factory and Belle detector
- Search for an exotic light particle at Belle
  - Signal MC study
    - Decay modes, Event selection, and Signal efficiency
  - Background MC study
  - Systematic uncertainty
  - Results
- Summary and Conclusion

HyperCP exotic event

H.K.Park et al. (HyperCP Collaboration), PRL 94, 021801 (2005)



(a) solid : MC events with a form-factor decay
dashed : MC events with a uniform phase-space decay

(b) MC events normalized to match the data

- Observation of 3 events for $\Sigma^+ \rightarrow p\,\mu^+\mu^-$ decays
- Mass of $X^0(214)$: (214.3 ± 0.5) MeV/c^2
- Possible interpretations
  - Pseudo-scalar Sgoldstino D.S.Gorbunov and V.A.Rubakov, PRD 73, 035002 (2006)
  - Light Pseudo-scalar Higgs Boson X.-G.He, J.Tandean and G.Valencia, PRL 98, 081802 (2007)
  - Vector U-boson M. Reece and L.-T. Wang JHEP 0907, 51 (2009), M. Pospelov, arXiv:0811.1030 [hep-ph], C.-H. Chen, C.-Q. Geng and C.-W. Kao, Phys. Lett. B 663, 100 (2008)

Possible Decay Modes for Search at B-Factory

- Possible decay modes to search for sgoldstinos in SUSY models
  - Pseudo-scalar B and D meson decays to pseudo-scalar meson and X^0
    - $D \rightarrow \pi\ \pi\ X^0$, $X^0 \rightarrow \mu^+\mu^-, \gamma\gamma$
    - $B \rightarrow K\ \pi\ X^0$, $X^0 \rightarrow \mu^+\mu^-, \gamma\gamma$
  - Pseudo-scalar B and D meson decays to vector meson and X^0

    S.V.Demidov and D.S.Gorbunov, JETP Letters, 2006, vol. 84, No. 9, pp479-484
    - $B(D \rightarrow \rho\ X^0, X^0 \rightarrow \mu^+\mu^-) = 10^{-9} \sim 10^{-6}$
    - **$B(B \rightarrow K^{*0}\ X^0, X^0 \rightarrow \mu^+\mu^-) = 10^{-9} \sim 10^{-6}$**
    - **$B(B \rightarrow \rho^0\ X^0, X^0 \rightarrow \mu^+\mu^-) = 10^{-9} \sim 10^{-7}$**
- The channels listed above are possible for a low mass Higgs in NMSSM (Next-to-Minimal SUSY SM)
- In this talk, we will show results on $B \rightarrow K^{*0}\ X^0$, $X^0 \rightarrow \mu^+\mu^-$ and $B \rightarrow \rho^0\ X^0$, $X^0 \rightarrow \mu^+\mu^-$

Expected B.F as Pseudo-scalar Sgoldstino

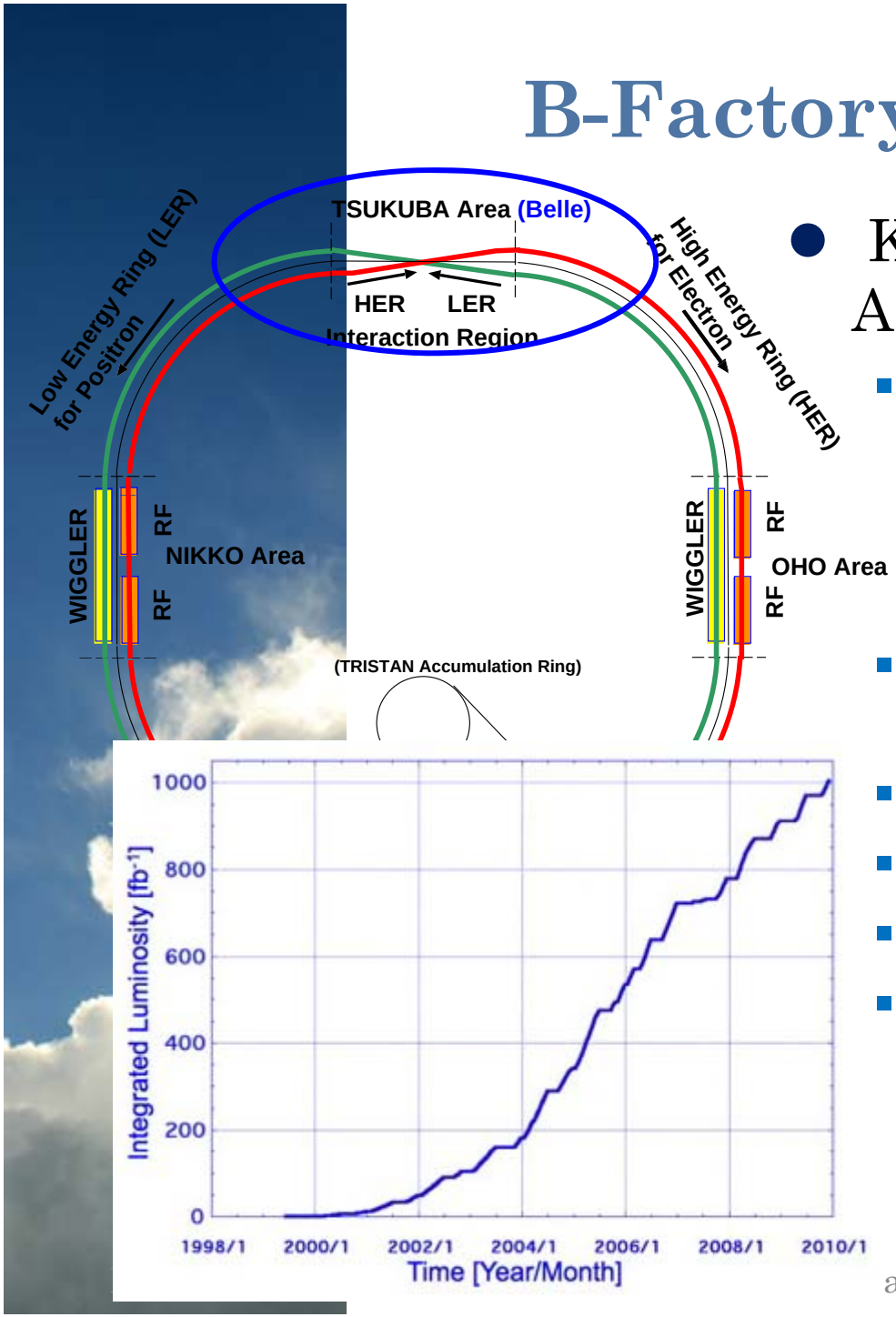
Branching ratios of decays $P_{B,D} \longrightarrow VP(P \longrightarrow \mu^+\mu^-)$ in the models I, II, and III. Branching ratios of decays $P_{B,D} \longrightarrow VP(P \longrightarrow \gamma\gamma)$ are given by the same numbers multiplied by $\Gamma(P \longrightarrow \gamma\gamma)/\Gamma(P \longrightarrow \mu^+\mu^-)$

Decay	h_{jl}	$A_0^{(P_{B,D}, V)}$	$\mathrm{Br}_{(\text{model I})}$	$\mathrm{Br}_{(\text{model II})}$	$\mathrm{Br}_{(\text{model III})}$
$B_s \longrightarrow \phi P(P \longrightarrow \mu^+\mu^-)$	$h_{23}^{(D)}$	0.42 [18]	6.5×10^{-9}	8.8×10^{-6}	8.7×10^{-6}
$B_s \longrightarrow K^{*0} P(P \longrightarrow \mu^+\mu^-)$	$h_{13}^{(D)}$	0.37 [18]	5.3×10^{-9}	7.2×10^{-6}	2.3×10^{-7}
$B_c^+ \longrightarrow D^{*+} P(P \longrightarrow \mu^+\mu^-)$	$h_{13}^{(D)}$	0.14 [19]	3.2×10^{-10}	4.4×10^{-7}	1.4×10^{-8}
$B_c^+ \longrightarrow D_s^{*+} P(P \longrightarrow \mu^+\mu^-)$	$h_{23}^{(D)}$	0.14[a]	3.0×10^{-10}	4.0×10^{-7}	4.0×10^{-7}
$B_c^+ \longrightarrow B^{*+} P(P \longrightarrow \mu^+\mu^-)$	$h_{12}^{(U)}$	0.23 [20]	4.1×10^{-10}	4.4×10^{-8}	8.2×10^{-7}
$B^+ \longrightarrow K^{*+} P(P \longrightarrow \mu^+\mu^-)$	$h_{23}^{(D)}$	0.31 [17]	3.8×10^{-9}	5.2×10^{-6}	5.1×10^{-6}
$B^0 \longrightarrow K^{*0} P(P \longrightarrow \mu^+\mu^-)$			3.5×10^{-9}	4.8×10^{-6}	4.7×10^{-6}
$B^0 \longrightarrow \rho P(P \longrightarrow \mu^+\mu^-)$	$h_{13}^{(D)}$	0.28 [17]	3.1×10^{-9}	4.2×10^{-6}	1.4×10^{-7}
$B^+ \longrightarrow \rho^+ P(P \longrightarrow \mu^+\mu^-)$			3.3×10^{-9}	4.6×10^{-6}	1.3×10^{-7}
$D^0 \longrightarrow \rho P(P \longrightarrow \mu^+\mu^-)$	$h_{12}^{(U)}$	0.64 [17]	1.4×10^{-9}	1.5×10^{-7}	2.8×10^{-6}
$D^+ \longrightarrow \rho^+ P(P \longrightarrow \mu^+\mu^-)$			3.5×10^{-9}	3.7×10^{-7}	7.0×10^{-6}

[a] We did not find any estimate of this form factor in literature and use this value as an order-of-magnitude estimate, which is sufficient for our study.

S.V.Demidov and D.S.Gorbunov, JETP Letters, 2006, vol. 84, No. 9, pp479-484

B-Factory at KEK

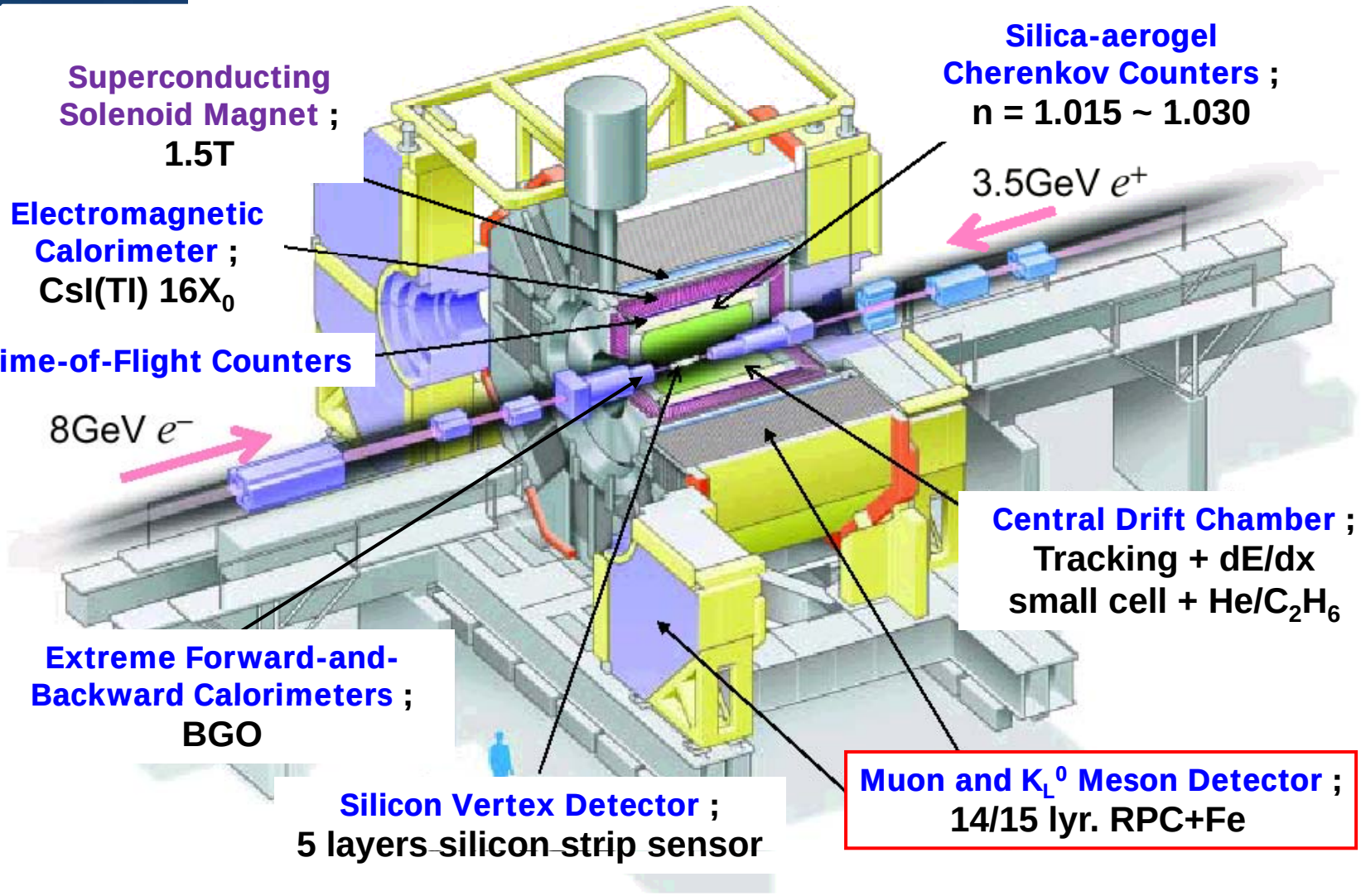


- KEKB :
  Asymmetric e^+e^- collider
  - Two separate rings
    - e^+ (LER) : 3.5 GeV
    - e^- (HER) : 8.0 GeV

    (3.1 GeV/9 GeV for PEPII)
  - CM energy : 10.58 GeV at $\Upsilon(4S)$
    $\Upsilon(4S) \rightarrow$ BB-bar
  - ±11 mrad finite crossing angle at IP
  - Operation since June, 1999
  - $L_{peak} = 2.11 \times 10^{34}\ cm^{-2}s^{-1}$
  - Accumulated total integrated L
    ~ 1000 fb^{-1}

New World Record Luminosity

Belle Detector



Decay modes and Event selection

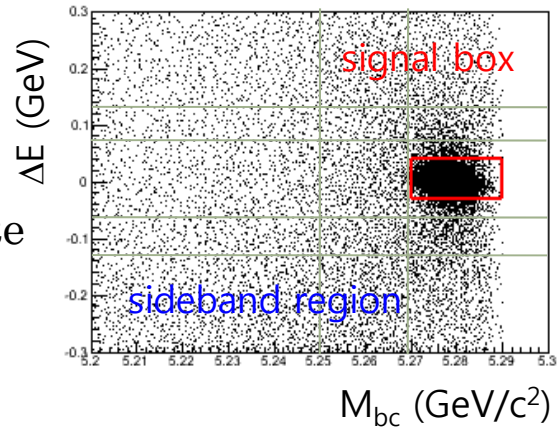
$B^0 \rightarrow K^{*0}X^0$, $K^{*0} \rightarrow K^+\pi^-$, $X^0(214) \rightarrow \mu^+\mu^-$

$B^0 \rightarrow \rho^0X^0$, $\rho^0 \rightarrow \pi^+\pi^-$, $X^0(214) \rightarrow \mu^+\mu^-$

- Large sample of Y(4S) → BB-bar : 657M BB-bar pairs
- $X^0(214)$ as a scalar particle

- Invariant masses of K^{*0} and ρ^0 : within $\pm 1.5\sigma$ and $\pm 1\sigma$ from a central value, respectively
- Kinematic variables, ΔE and M_{bc}
  - $\Delta E = E_B^* - E_{beam}^*$
  - $(M_{bc})^2 = (E_{beam}^*)^2 - |p_B^*|^2$

  E_{beam}^* : beam energy,
  p_B^* and E_B^* : momentum and energy of B candidate



Signal efficiency

Decay modes	$B^0 \rightarrow K^{*0}X^0(214)$	$B^0 \rightarrow \rho^0 X^0(214)$
Dimuon mass resolution [keV/c^2]	427 ± 14	428 ± 15
signal efficiency (ε)	$(26.3 \pm 0.1)\%$	$(23.5 \pm 0.1)\%$

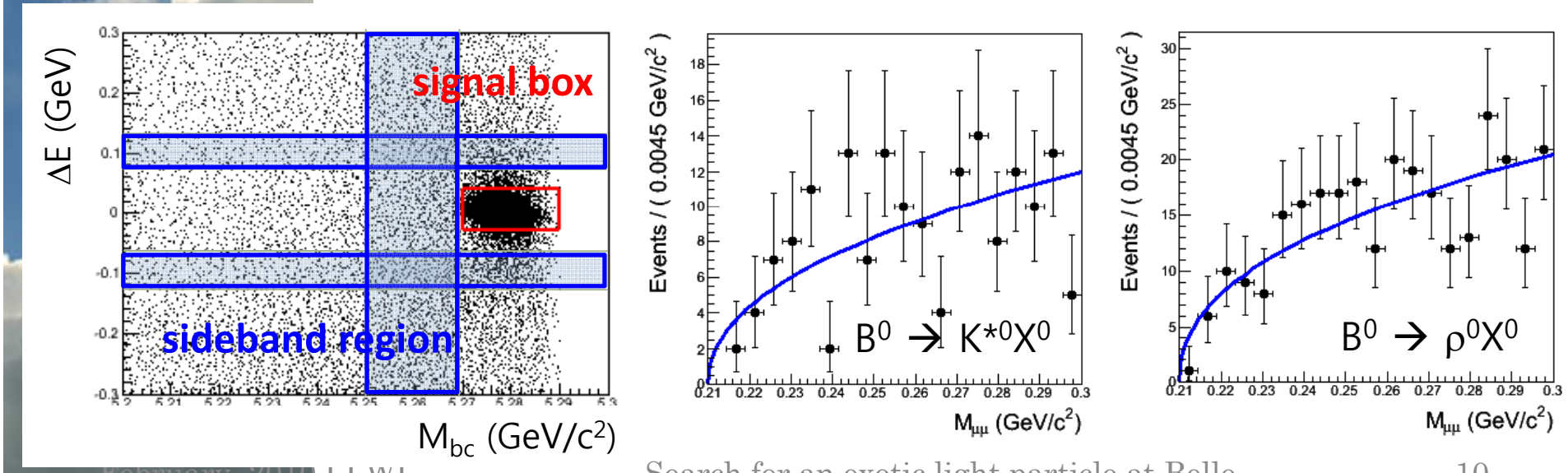
- X^0 search window is defined in terms of the dimuon mass resolution

  $214.3 \pm 3 \times [0.5\ (\text{HyperCP}) + \text{resol.}\ (\text{Belle})]\ \text{MeV}/c^2$

  ➡ **$211.5\ \text{MeV}/c^2 < M_{\mu^+\mu^-} < 217.1\ \text{MeV}/c^2$**

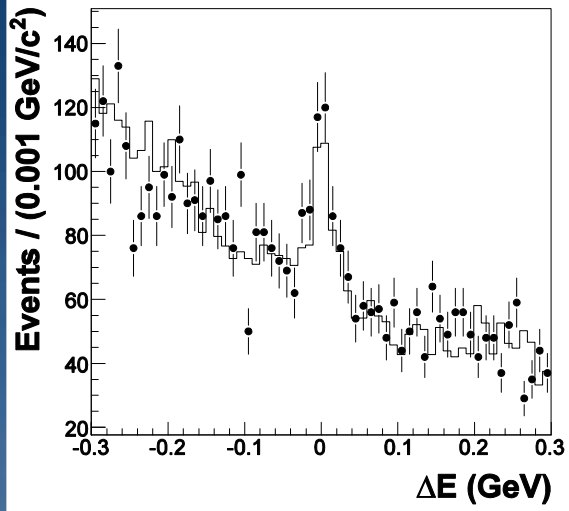
Background Study

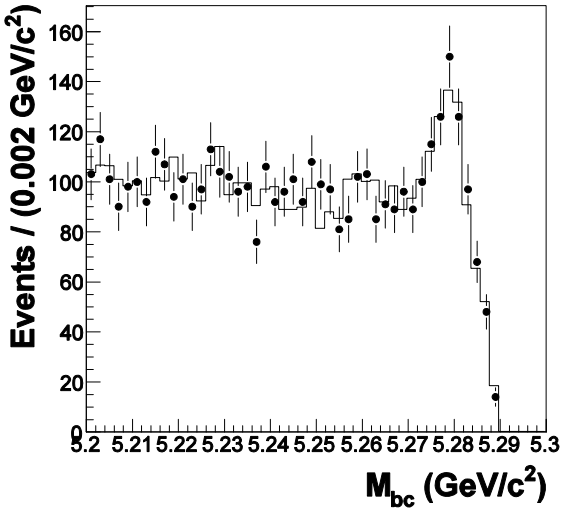
- Fitting method
  - Use MC samples of continuum and BB-bar, which are about 3 times larger than data sample
  - Fit MC data with threshold function at sideband region
    - sideband is defined as 5σ ~ 10σ in ΔE-M_{bc} :
      0.06 GeV < |ΔE| < 0.12 GeV and 5.25 GeV/c^2 < M_{bc} < 5.27 GeV/c^2
- Background estimation : **$0.13^{+0.04}_{-0.03}$ and $0.12^{+0.03}_{-0.02}$** for $B^0 \rightarrow K^{*0}X^0$ and $B^0 \rightarrow \rho^0 X^0$, respectively

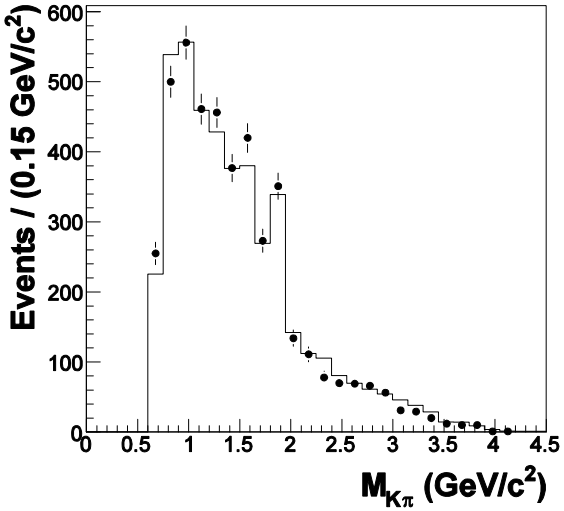


Comparisons between MC and data

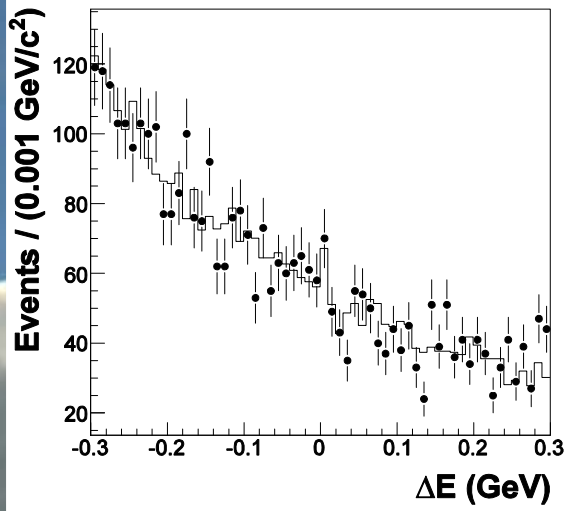
$B^0 \rightarrow K^{*0}X^0$

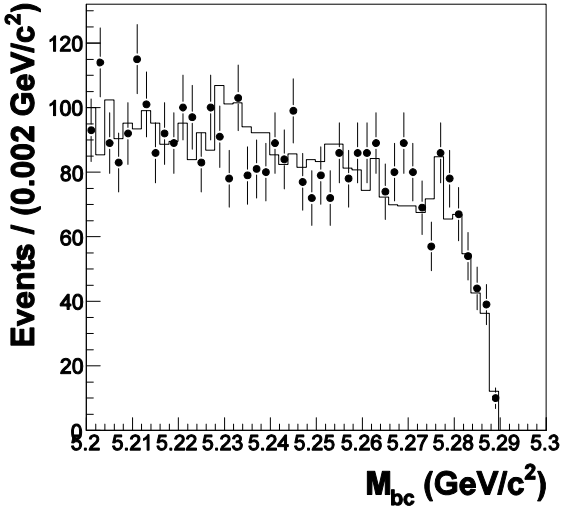


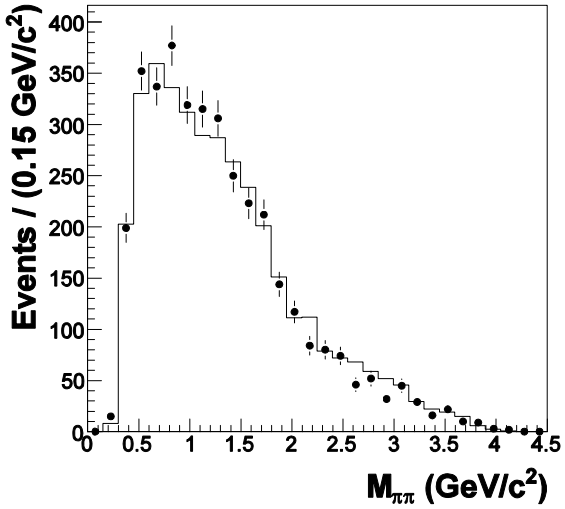




$B^0 \rightarrow \rho^0X^0$

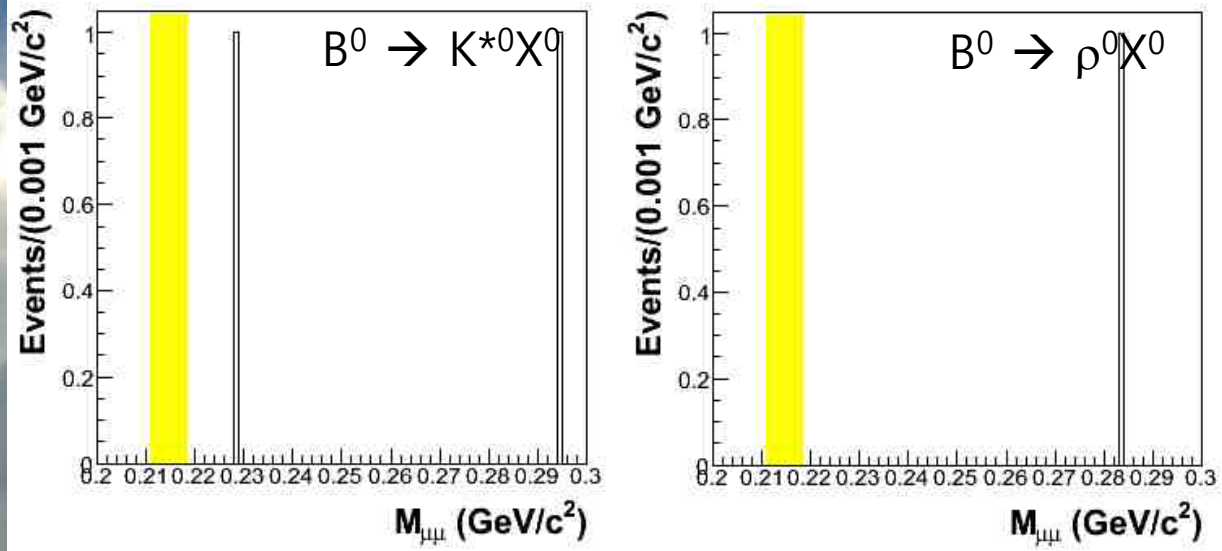






Systematic uncertainties and N_{obs}

- Total systematic uncertainties are 5.2% and 5.7% for $B \rightarrow K^{*0}X^0$ and $B \rightarrow \rho^0 X^0$, respectively
- Dominant systematic uncertainties come from tracking efficiency (~ 4%) and muon identification (~ 3%)



- **No events** are observed in the signal region for any of the modes with 657M BB-bar data sample

Upper limits @ 90% C.L.

$$B(B^0 \to V X^0, X^0 \to \mu^+\mu^-) < \frac{S_{90}}{\varepsilon \times N_{B\bar{B}} \times B.R.}$$

V : K^{*0} or ρ^0
S_{90} : Signal yield
ε : signal efficiency with corrections of charged particle identification
$N_{BB\text{-bar}}$: the number of BB-bar pairs
B.R. : $B(K^{*0} \to K^+\pi^-)$ or $B(\rho^0 \to \pi^+\pi^-)$

$B(K^{*0} \to K^+\pi^-)$	**0.6651**
$B(K^{*0} \to K^0\pi^0)$	0.3326
$B(K^{*0} \to K^0\gamma)$	0.0023

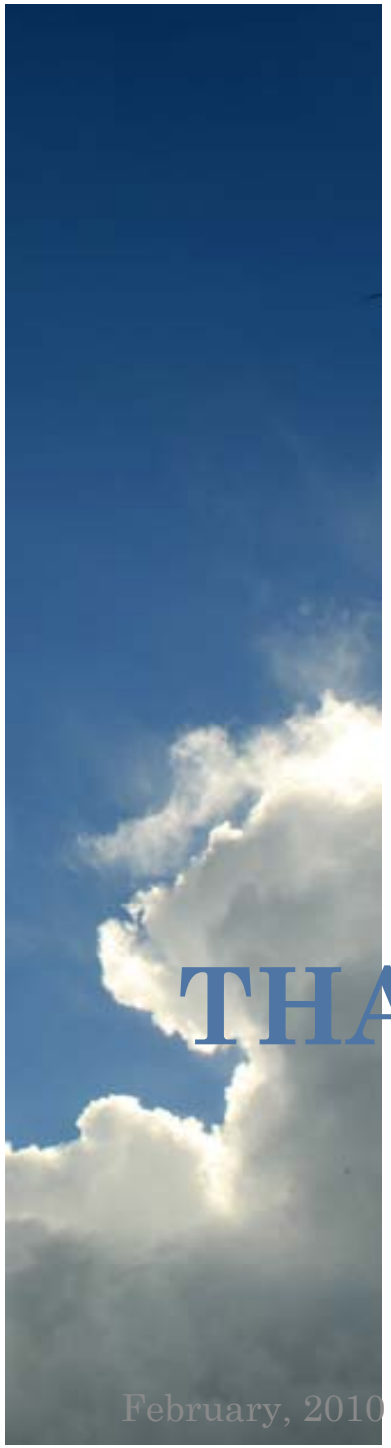
$B(\rho^0 \to \pi^+\pi^-)$	**0.9894**
$B(\rho^0 \to \pi^+\pi^-\gamma)$	0.0099

- The upper limits @ 90% C.L. are calculated
  - **$B(B^0 \to K^{*0} X^0, K^{*0} \to K^+ \pi^-$ and $X^0 \to \mu^+ \mu^-) < 2.01 \times 10^{-8}$**
  - **$B(B^0 \to \rho^0 X^0, \rho^0 \to \pi^- \pi^+$ and $X^0 \to \mu^+ \mu^-) < 1.51 \times 10^{-8}$**
- Our result rules out most of allowed B.F for sgoldstino interpretation

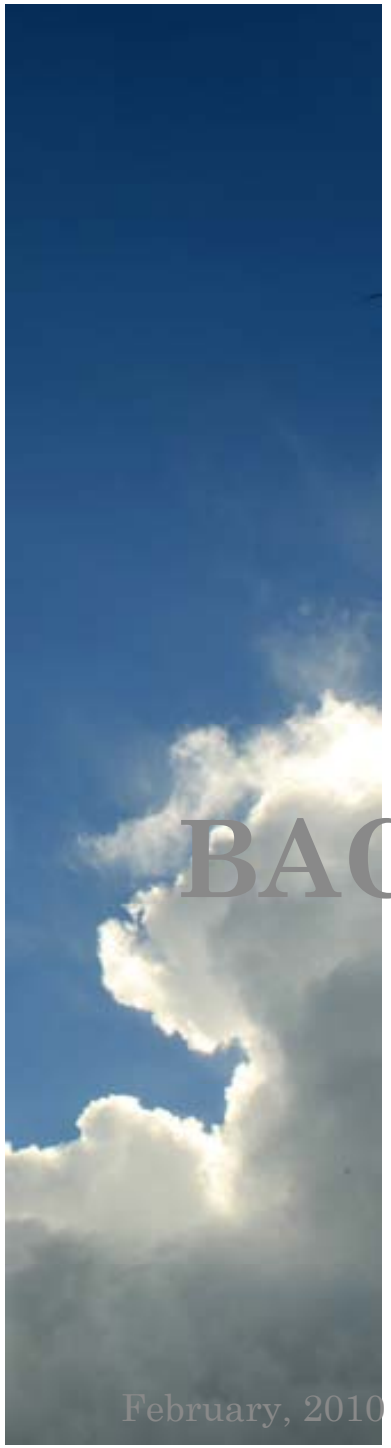
Summary and Conclusion

- We have searched for the HyperCP particle in B decay
  - No signals are observed in 211.5 MeV/c^2 < $M_{\mu^+\mu^-}$ < 217.1 MeV/c^2
  - The obtained upper limits @ 90% C.L. are as follows :
    - **$B(B^0 \to K^{*0} X^0) \times B(X^0 \to \mu^+\mu^-) < 2.01 \times 10^{-8}$**
    - **$B(B^0 \to \rho^0 X^0) \times B(X^0 \to \mu^+\mu^-) < 1.51 \times 10^{-8}$**
  - Our results rule out models II and III in the pseudo-scalar sgoldstino interpretation

- Other results such as a vector particle X^0, lifetime study, and extended search are in progress



THANK YOU



BACK UP SLIDES

$X^0(214)$ Search in Other Experiments

- hadron collider:
  - D0 Experiment (PRL 103, 061801 (2009))
- e+ e- collider
  - BaBar (PRL 103, 081803 (2009))
  - CLEO (PRL 101, 151802 (2008))
- Fixed Target
  - E391@KEK (PRL 102, 051802(2009))
  - E949@BNL (PRD 79, 092004(2009))
  - KTeV@FNAL (PoS(KAON09)039)

$X^0(214)$ Search in Other Experiments

David G. Phillips II "Search for a New Pseudoscalar Particle in the Rare Decay $K_L \rightarrow \pi^0\pi^0\mu^+\mu^-$" at Rencontres de Moriond EW 2009

- Using $N_{K,1997} = 3.24 \times 10^{11}$, $N_{K,1999} = 4.11 \times 10^{11}$ and σ_r^2, one finds the following upper limits at 90% CL:

$$Br(K_L \rightarrow \pi^0\pi^0\mu^+\mu^-) < 8.60 \times 10^{-11}$$

Preliminary!!!
(Systematic Error from P_z still under study)

$$Br(K_L \rightarrow \pi^0\pi^0 X^0 \rightarrow \pi^0\pi^0\mu^+\mu^-) < 9.41 \times 10^{-11}$$

Compare with:

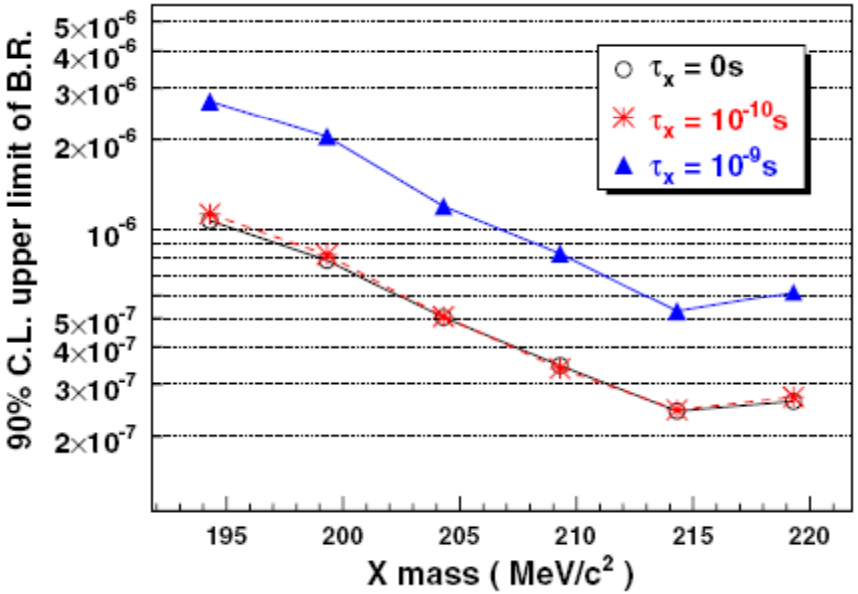
$$Br(K_L \rightarrow \pi^0\pi^0 X^0{}_P \rightarrow \pi^0\pi^0\mu^+\mu^-) = (8.3^{+7.5}_{-6.6}) \times 10^{-9}$$

$$Br(K_L \rightarrow \pi^0\pi^0 X^0{}_A \rightarrow \pi^0\pi^0\mu^+\mu^-) = (1.0^{+0.9}_{-0.8}) \times 10^{-10}$$

KTeV experiment at Fermilab.

$X^0(214)$ Search in Other Experiments

- at KEK E391a experiment E391a collaboration, Y. C. Tung, et al., Phys. Rev. Lett. 102, 051802 (2009)
  - $B(K_L^0 \rightarrow \pi^0\pi^0 X, X \rightarrow \gamma\gamma) < 2.5 \times 10^{-7}$ @ 90% C.L. ($m_X = 214.3$ MeV/c^2)



- at Babar experiment BaBar collaboration, B. Aubert, et al., Phys. Rev. Lett. 103, 081803 (2009)
  - $B(\Upsilon(3S) \rightarrow \gamma A^0, A^0 \rightarrow \mu^+\mu^-) < 0.8 \times 10^{-6}$ @ 90% C.L. ($m_{A0} = 214$ MeV/c^2)

Data set and Monte Carlo

- The X(214) search is based on 605 fb^{-1} data sample (Exp.7 ~ Exp.55) which contains 657 million B meson pairs collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB accelerator.

- Summary of Monte Carlo samples

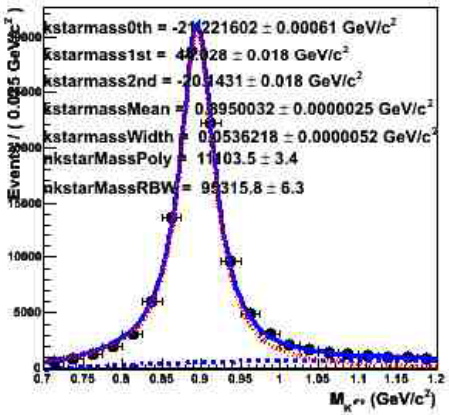
Data samples		Number of event
Signal MC	$B^0 \to K^{*0} X^0$, $K^{*0} \to K^- \pi^+$ and $X^0 \to \mu^+ \mu^-$	300,000
	$B^0 \to \rho^0 X^0$, $\rho^0 \to \pi^- \pi^+$ and $X^0 \to \mu^+ \mu^-$	300,000
Background MC	continuum qq-bar	1750 fb^{-1}
	B^0B^0-bar	
	B^+B^-	

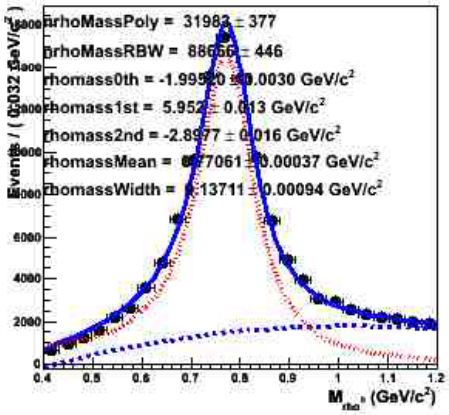
Dilepton skim

- The MC data are skimmed by using the following requirements on leptons. The selection criteria in the dilepton skim are as follows,
  - eid(3, -1, 5) > 0.05
  - electron momentum at lab frame > 0.395 GeV/c
  - μid > 0.6
  - muon momentum at lab frame > 0.69 GeV/c
  - at least one opposite or same sign charged lepton pair (ee, μμ, eμ)
  - E(ll) at CM frame > 1.3 GeV

Event Selection

Charged track	Selection requirement
Good charged track	dr < 1.0 cm |dz| < 5.0 cm
electron	eid > 0.9 P_{lab} > 0.395 GeV/c
muon	μid > 0.95 P_{lab} > 0.690 GeV/c
Kaon	kid > 0.6
pion	remaining tracks after selecting the lepton and K tracks
K^{*0}	0.815 GeV/c^2 < $M_{K^{*0}}$ < 0.975 GeV/c^2
ρ^0	0.633 GeV/c^2 < $M_{\rho 0}$ < 0.908 GeV/c^2
best B	minimum χ2 value of four charged tracks





Definition of Signal Region

- Signal candidates are selected by the following two kinematic variables defined in the $\Upsilon(4S)$ c.m. frame.
  - Energy difference (ΔE) = $E_B - E_{beam}$
  - Beam-energy constrained mass (M_{bc}) = $\sqrt{(E_{beam}^2 - \sum p_B^2)}$

  E_{beam} : the beam energy, E_B : the energy of the B candidate
  p_B : the momentum of the B candidate

$B^0 \rightarrow K^{*0}X^0$