A Search for an exotic light particle at Belle experiment

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Seminar @ KISTI

HyoJung Hyun

Kyungpook National University

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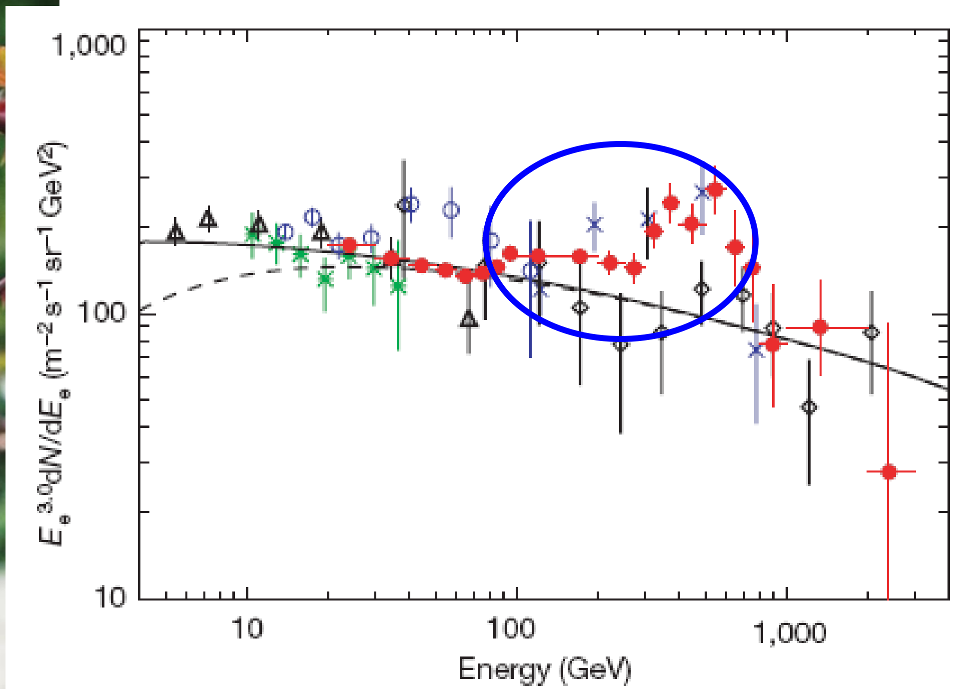
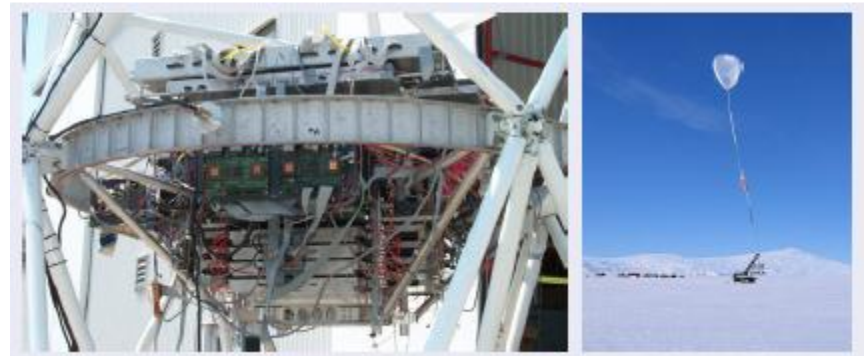
Astro-particle Observations : ATIC exp.

J. Chang et al., (ATIC collaboration), Nature **456**, 362 (2008)



The electron differential energy spectrum (scaled by E^3) :

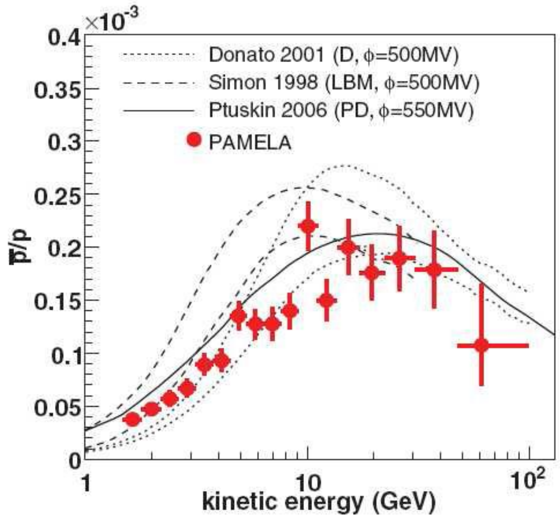
Red filled circles : ATIC
Green stars : AMS
Open black triangles : HEAT
Open blue circles : BETS
Blue crosses : PPB-BETS
Black open diamonds : emulsion chambers

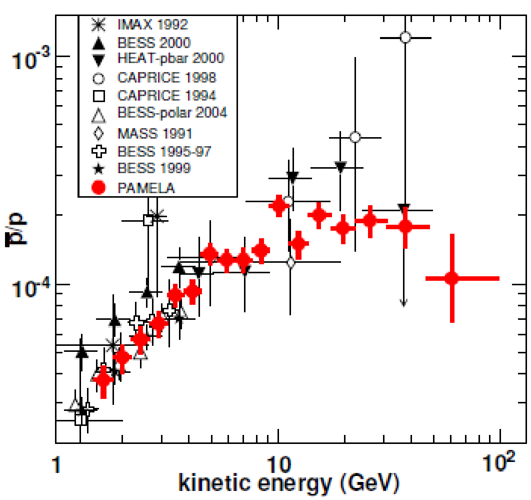


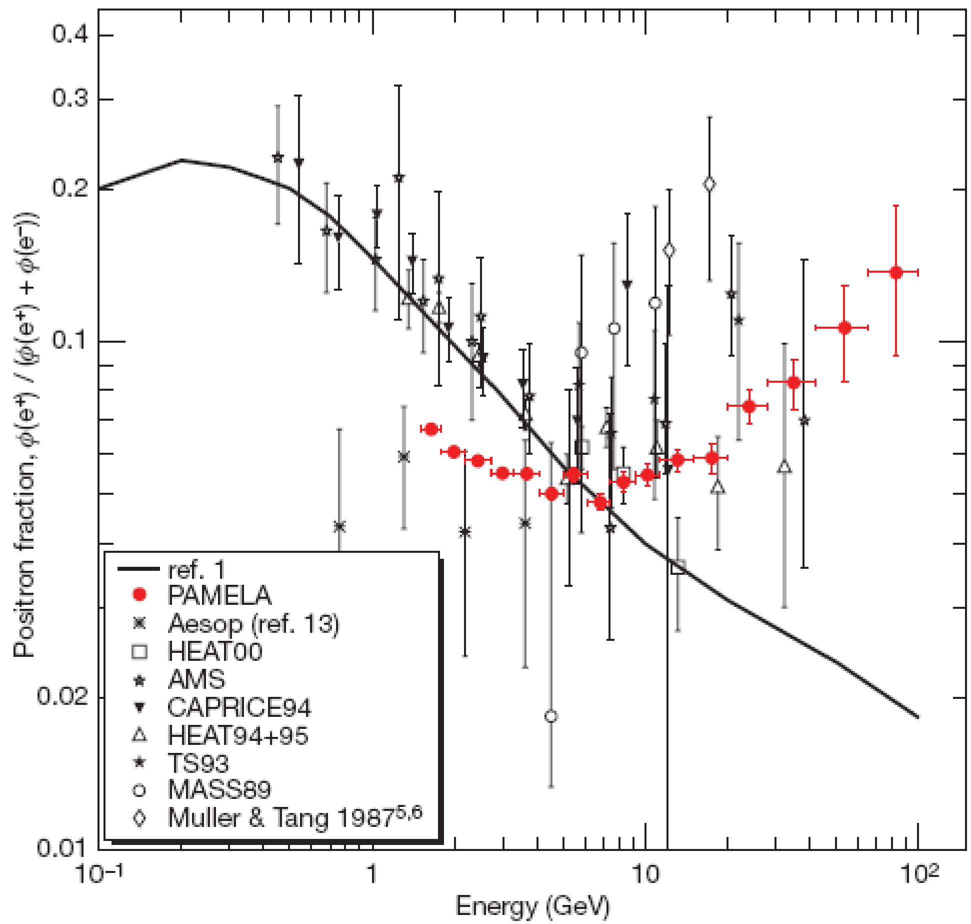
- ATIC results showing agreement with previous data at lower energy and with the PPB-BETS at higher energy
- ATIC observes an 'enhancement' in the electron intensity over the GALPROP (interstellar propagation code) curve.

Astro-particle Observations : PAMELA exp.

O. Adriani et al., (PAMELA collaboration), Nature **458**, 607 (2009)







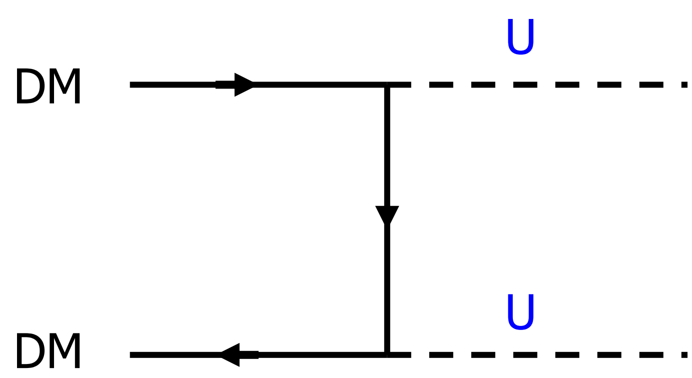
Positron fraction with other experimental data and with secondary production model.

Astro-particle Observations

- ATIC : excess in $e^+ + e^-$ spectrum between 300 GeV and 800 GeV.
- PAMELA : excess in e^+ spectrum from 10 GeV to 100 GeV.

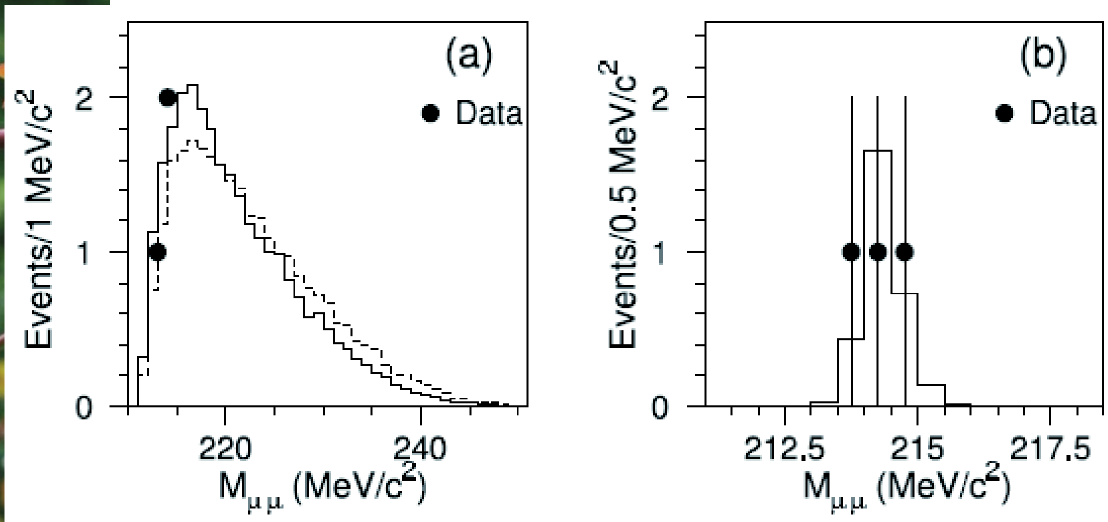
  No excess in proton and anti-proton spectrum
- Dark matter annihilation mediated by a extra gauge boson (U-boson), mass < ~1 GeV.

  U-boson → $e^+ e^-$, $\mu^+ \mu^-$



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
  - Pseudoscalar Sgoldstino D.S.Gorbunov and V.A.Rubakov, PRD 73, 035002 (2006)
  - Light Pseudoscalar 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
  - Pseudoscalar B and D meson decays to pseudoscalar meson and X^0
    - $D \rightarrow \pi \pi X^0$, $X^0 \rightarrow \mu^+\mu^-, \gamma\gamma$
    - $B \rightarrow K \pi X^0$, $X^0 \rightarrow \mu^+\mu^-, \gamma\gamma$
  - Pseudoscalar 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 Pseudoscalar Sgoldstino

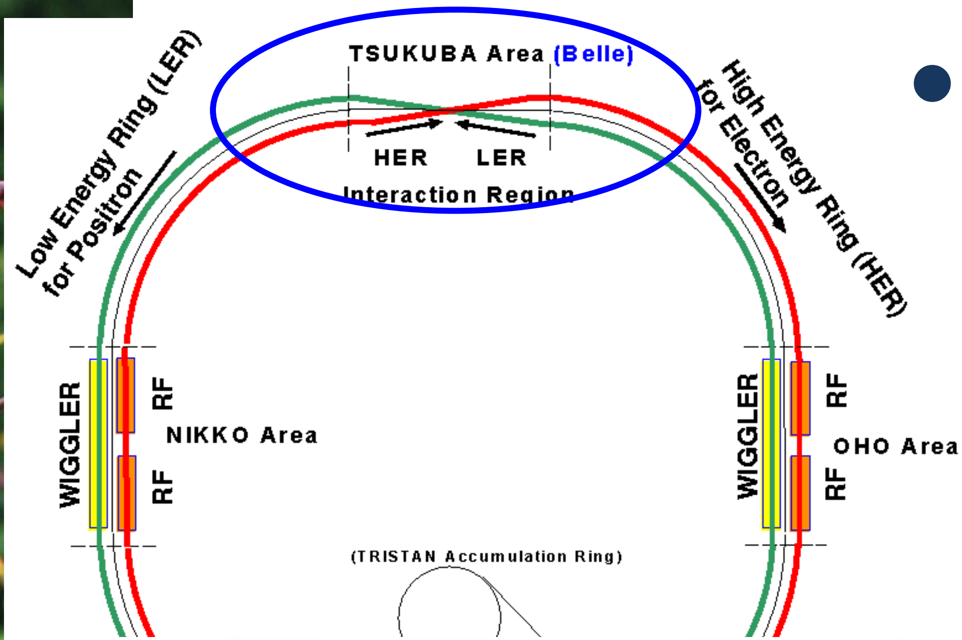
Branching ratios of decays $P_{B,D} \longrightarrow VP(P \longrightarrow \mu^+\mu^-)$ in the models I, II, and III. Branching ratios of decays $P_{B,D} \longrightarrow VP(P \longrightarrow \gamma\gamma)$ are given by the same numbers multiplied by $\Gamma(P \longrightarrow \gamma\gamma)/\Gamma(P \longrightarrow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

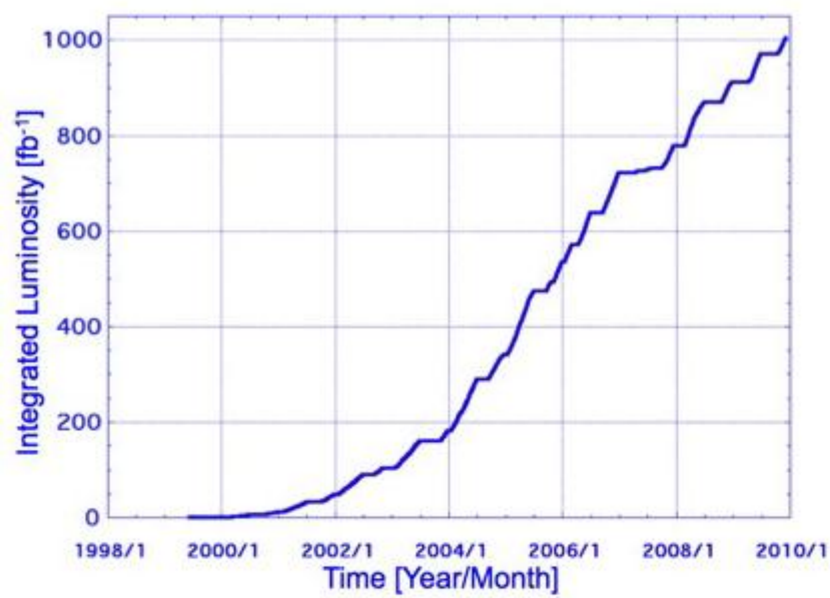
Decay	h_{jl}	$A_0^{(P_{B,D}, V)}$	$\mathrm{Br}_{(\mathrm{model\ I})}$	$\mathrm{Br}_{(\mathrm{model\ II})}$	$\mathrm{Br}_{(\mathrm{model\ III})}$
$B_s \longrightarrow \phi P(P \longrightarrow \mu^+\mu^-)$	$h_{23}^{(D)}$	0.42 [18]	6.5×10^{-9}	8.8×10^{-6}	8.7×10^{-6}
$B_s \longrightarrow K^{*0} P(P \longrightarrow \mu^+\mu^-)$	$h_{13}^{(D)}$	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



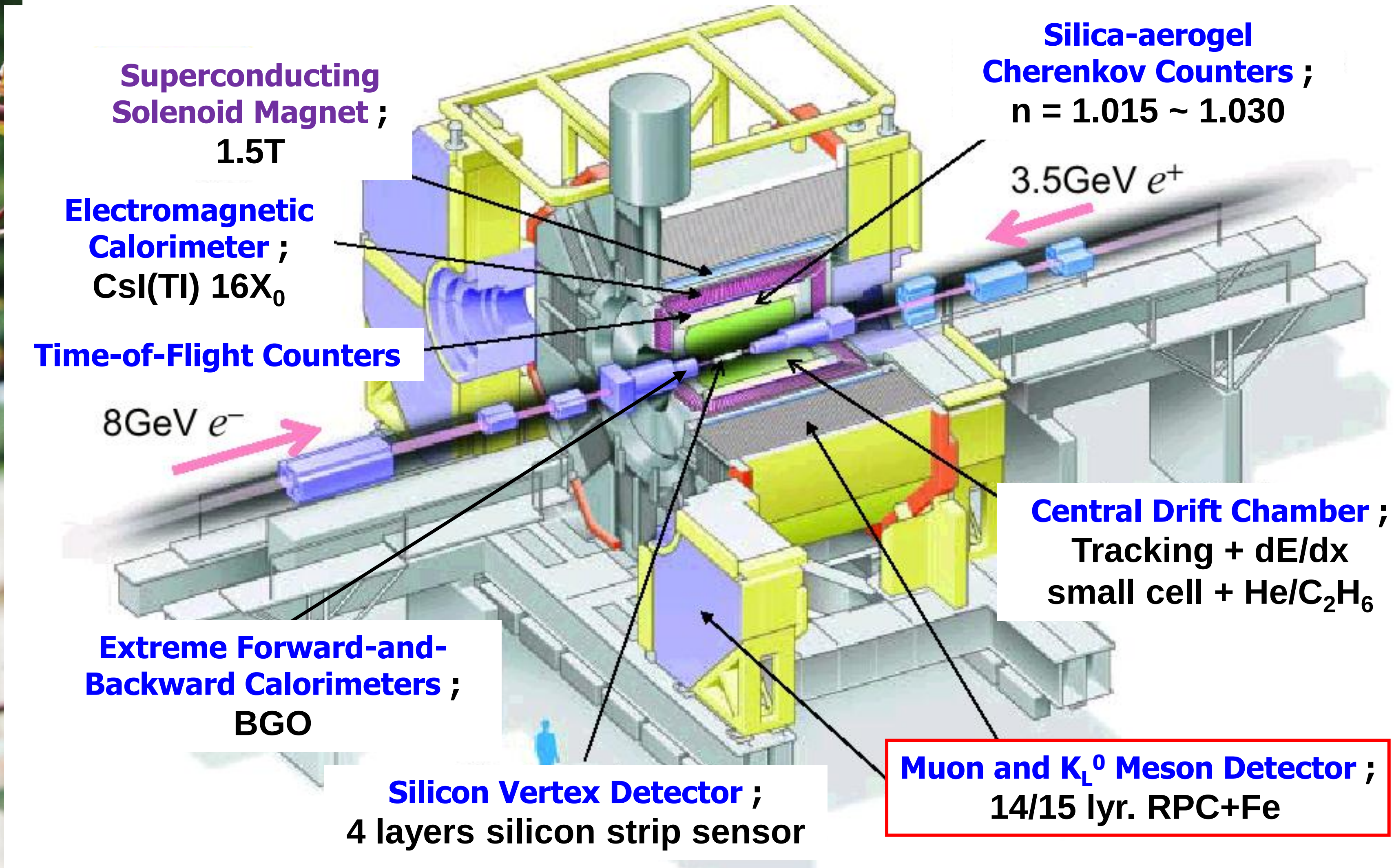


- KEKB : Asymmetric e^+e^- collider
  - Two separate rings
    - e^+ (LER) : 3.5 GeV
    - e^- (HER) : 8.0 GeV

    (3.1 GeV/9 GeV for PEPII)
  - CM energy : 10.58 GeV at $\Upsilon(4S)$
    $\Upsilon(4S) \rightarrow$ BB-bar
  - $\pm$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



Detailed view : slide p29

Decay modes and Event selection

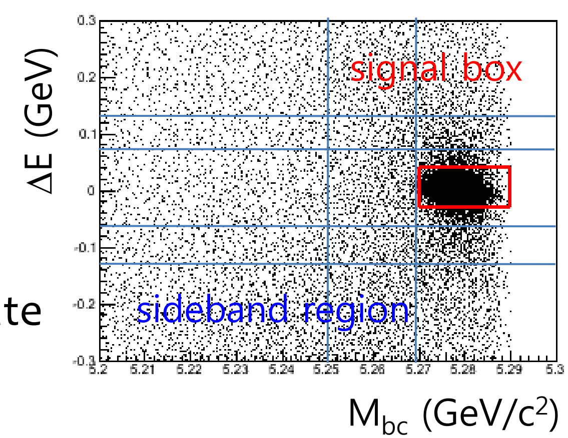
$B^0 \rightarrow K^{*0}X^0$, $K^{*0} \rightarrow K^+\pi^-$, $X^0(214) \rightarrow \mu^+\mu^-$

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

- Large sample of $\Upsilon(4S) \rightarrow$ BB-bar : 657M BB-bar pairs
- $X^0(214)$ as a scalar particle (spin 0)
  or a vector particle (spin 1)
- Fully longitudinally polarized for a vector particle $X^0(214)$

- Invariant masses of K^{*0} and ρ^0 :
  within $\pm1.5\sigma$ and $\pm1\sigma$ 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



Detailed view : slide p29

Signal efficiency

Decay modes	$B^0 \rightarrow K^{*0}X^0$		$B^0 \rightarrow \rho^0 X^0$	
	scalar	vector	scalar	vector
Dimuon mass resolution [keV/c^2]	427 ± 14	425 ± 14	428 ± 15	425 ± 15
signal efficiency (ε_{cor})	23.5%	23.5%	20.5%	20.5%

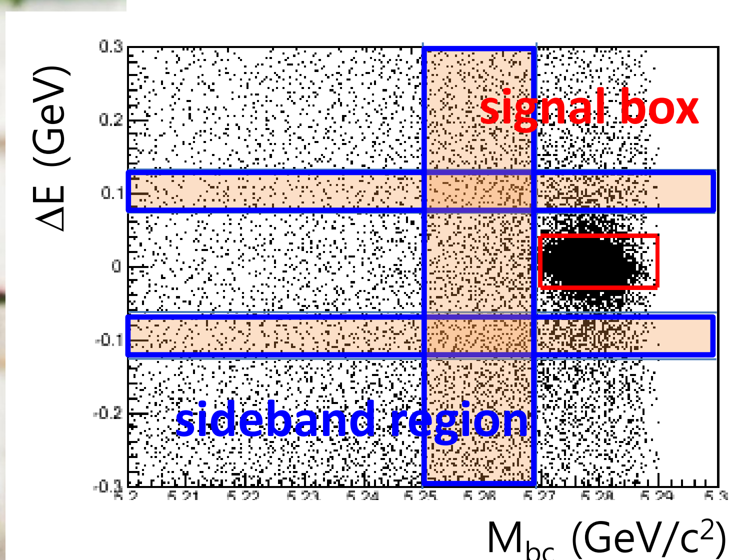
- X^0 search window is defined in terms of the dimuon mass resolution

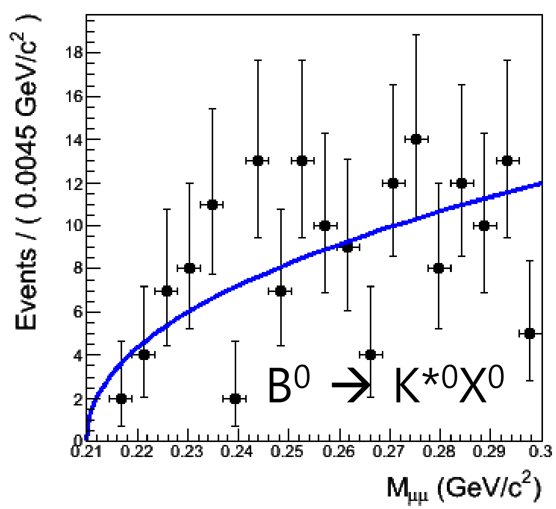
$$214.3 \pm 3 \times [0.5\ (\text{HyperCP}) + \text{resol.}\ (\text{Belle})]\ \text{MeV}/c^2$$

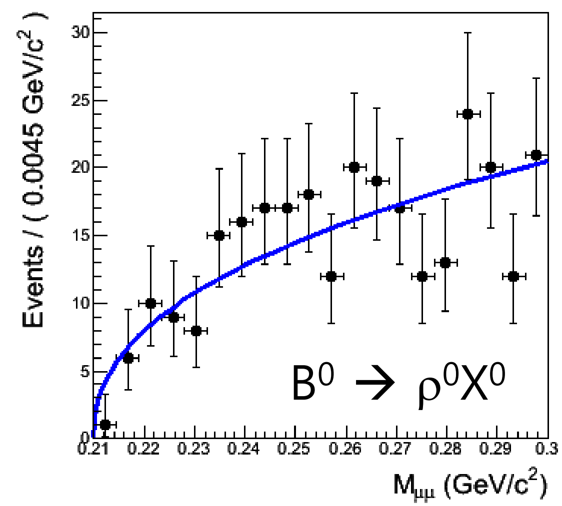
➡ **$211.6\ \text{MeV}/c^2 < M_{\mu+\mu-} < 217.2\ \text{MeV}/c^2$**

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 $5\sigma \sim 10\sigma$ in ΔE-M_{bc} :
      0.06 GeV < $|\Delta E|$ < 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

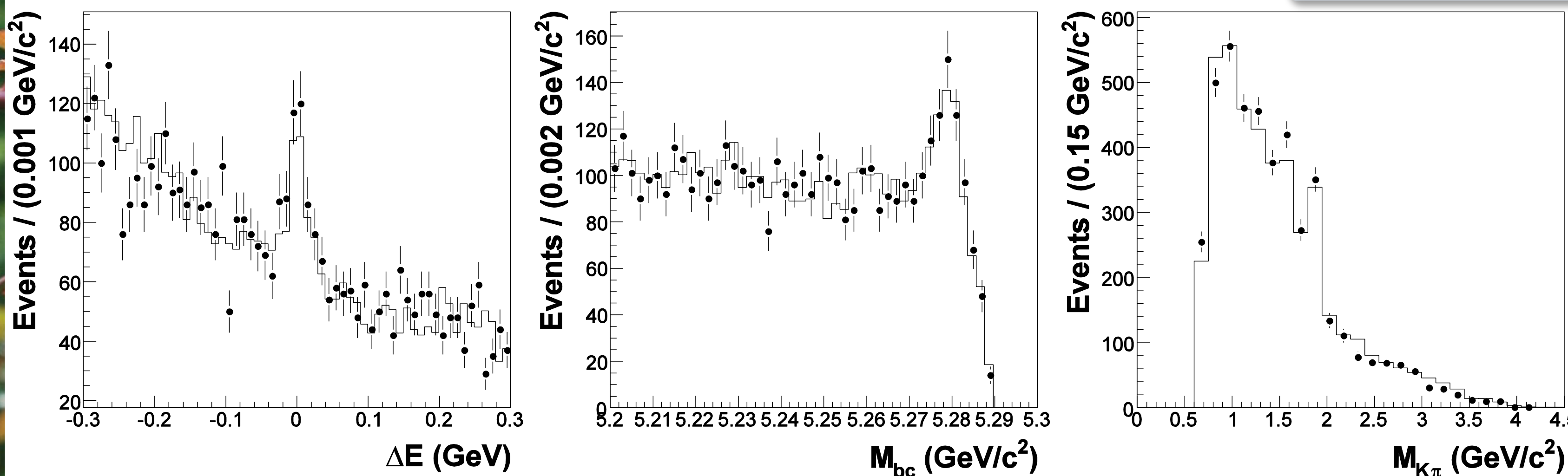




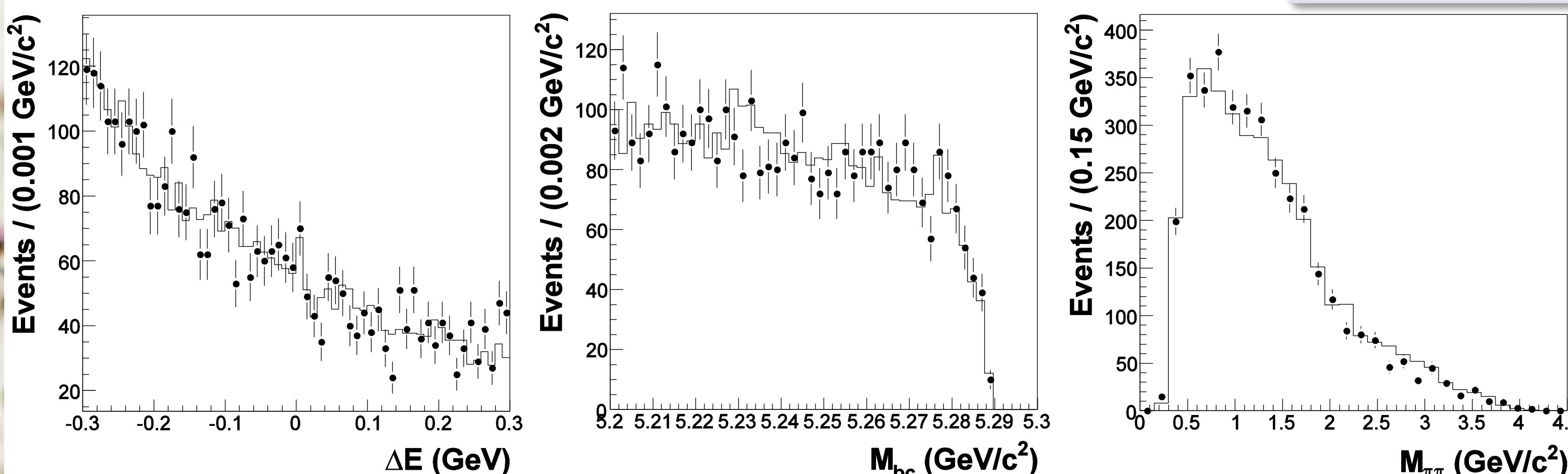


Comparisons between MC and data

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



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

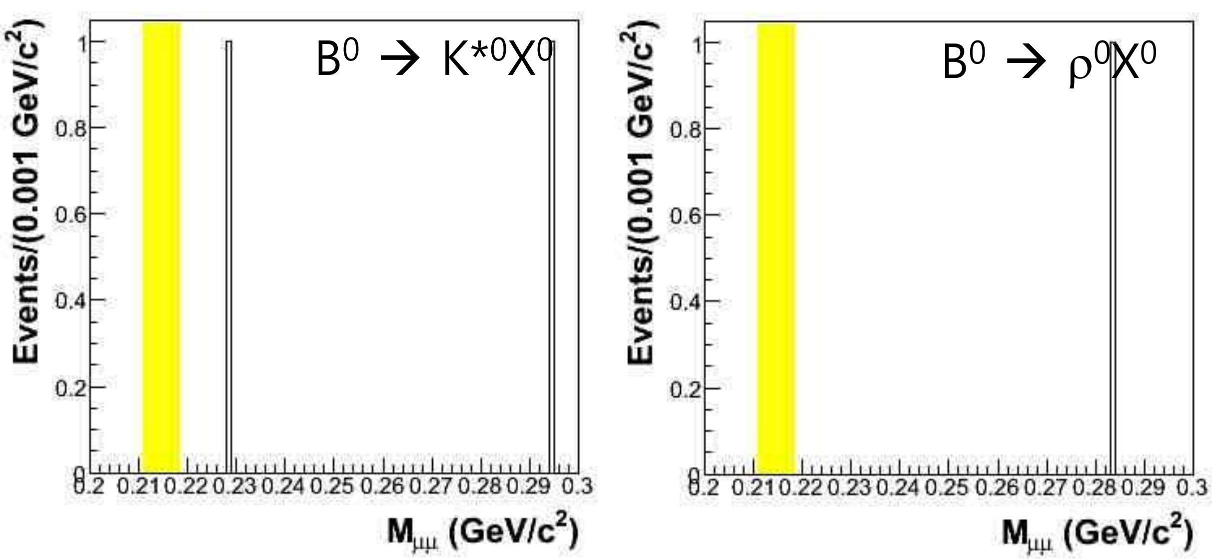


Detailed view : slide p45-46

Systematic uncertainties and N_{obs}

Decay modes	Total systematic uncertainties	
	scalar	vector
$B^0 \rightarrow K^{*0}X^0$	6.3 %	6.3 %
$B^0 \rightarrow \rho^0 X^0$	6.2 %	6.3 %

- Dominant systematic uncertainties come from tracking efficiency (~ 4%) and muon identification (~ 4%)



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

Upper limits @ 90% C.L.

$$\mathcal{B}(\mathrm{B}^0 \to VX^0, X^0 \to \mu^+\mu^-) < \frac{S_{90}}{\varepsilon \times N_{B\bar{B}} \times \mathcal{B}_V}$$

V	: K^{*0} or ρ^0
S_{90}	: signal yield at a 90% C.L.
ε	: signal efficiency with corrections of charged particle identification
$N_{BB\text{-}bar}$	: the number of BB-bar pairs, 657×10^6
B_V	: $\mathcal{B}(K^{*0} \to K^+\pi^-)$ or $\mathcal{B}(\rho^0 \to \pi^+\pi^-)$

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

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

Decay modes	**Upper limits @ 90% C.L.**	
	scalar	vector
$B^0 \to K^{*0}X^0$	2.27×10^{-8}	2.27×10^{-8}
$B^0 \to \rho^0X^0$	1.75×10^{-8}	1.75×10^{-8}

Lifetimes

- Constraints on Lifetime of $X^0(214)$
  - 1.7×10^{-15} s $\leq \tau_{X^0} \leq 4 \times 10^{-14}$ s C.Q. Geng, Y.K. Hsiao, PLB 632, 215-218 (2006)
- We assume the lifetime of the $X^0(214)$ to be in the range **from 10^{-15} s to 10^{-12} s**

Decay modes	$B^0 \to K^{*0}X^0$				$B^0 \to \rho^0 X^0$			
	scalar		vector		scalar		vector	
Lifetimes	10^{-15} s	10^{-12} s	10^{-15} s	10^{-12} s	10^{-15} s	10^{-12} s	10^{-15} s	10^{-12} s
ε_{cor} [%]	23.6	23.3	23.5	23.6	20.7	20.5	20.7	20.5
N_{obs}	0	0	0	0	0	0	0	0
N_{bkg}	0.13	0.14	0.13	0.14	0.12	0.13	0.12	0.13
Syst. [%]	6.2	6.2	6.2	6.3	6.2	6.2	6.3	6.2
S_{90}	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
U.L. at 90% C.L. (10^{-8})	2.26	2.29	2.27	2.26	1.73	1.75	1.73	1.75

A Light Particle Search

TABLE I: Summary of the number of observed events (N_{obs}), estimated number of background events (N_{bg}), efficiencies (ϵ), signal yields (S_{90}) and upper limits ($U.L.$) at 90% C.L. for the decays $B^0_{K^*X}$ and $B^0_{\rho X}$ with the scalar (vector) particle X. The errors on N_{bg} are statistical only.

$M_{\mu\mu}$	$B^0 \to K^{*0}X,\ K^{*0} \to K^+\pi^-,\ X \to \mu^+\mu^-$					$B^0 \to \rho^0 X,\ \rho^0 \to \pi^+\pi^-,\ X \to \mu^+\mu^-$				
(MeV/c^2)	N_{obs}	N_{bg}	ϵ	S_{90}	$U.L.(10^{-8})$	N_{obs}	N_{bg}	ϵ	S_{90}	$U.L.(10^{-8})$
212.0	0	$0.03^{+0.01}_{-0.01}$ ($0.03^{+0.01}_{-0.01}$)	23.8 (23.7)	2.43 (2.43)	2.34 (2.34)	0	$0.02^{+0.01}_{-0.01}$ ($0.02^{+0.01}_{-0.01}$)	21.2 (21.1)	2.44 (2.44)	1.77 (1.78)
214.3	0	$0.13^{+0.04}_{-0.03}$ ($0.13^{+0.04}_{-0.03}$)	23.6 (23.5)	2.33 (2.33)	2.26 (2.27)	0	$0.12^{+0.03}_{-0.02}$ ($0.12^{+0.03}_{-0.02}$)	20.7 (20.7)	2.33 (2.33)	1.73 (1.73)
220.0	0	$0.13^{+0.02}_{-0.02}$ ($0.13^{+0.02}_{-0.02}$)	23.0 (22.9)	2.33 (2.33)	2.31 (2.33)	0	$0.11^{+0.02}_{-0.01}$ ($0.11^{+0.02}_{-0.01}$)	20.2 (20.1)	2.33 (2.33)	1.78 (1.78)
230.0	1	$0.24^{+0.02}_{-0.02}$ ($0.25^{+0.02}_{-0.02}$)	21.4 (21.4)	4.09 (4.12)	4.37 (4.40)	0	$0.21^{+0.01}_{-0.01}$ ($0.21^{+0.01}_{-0.01}$)	18.8 (18.9)	2.27 (2.27)	1.86 (1.85)
240.0	0	$0.38^{+0.02}_{-0.02}$ ($0.39^{+0.02}_{-0.02}$)	20.0 (20.0)	2.09 (2.09)	2.40 (2.39)	0	$0.32^{+0.01}_{-0.01}$ ($0.32^{+0.01}_{-0.01}$)	17.5 (17.5)	2.16 (2.16)	1.90 (1.90)
250.0	0	$0.51^{+0.01}_{-0.01}$ ($0.51^{+0.01}_{-0.01}$)	18.0 (18.4)	1.92 (1.94)	2.43 (2.41)	0	$0.42^{+0.00}_{-0.00}$ ($0.42^{+0.00}_{-0.00}$)	15.9 (16.3)	2.06 (2.06)	1.99 (1.94)
260.0	0	$0.63^{+0.01}_{-0.01}$ ($0.63^{+0.01}_{-0.01}$)	16.5 (17.2)	1.83 (1.83)	2.54 (2.43)	0	$0.60^{+0.01}_{-0.00}$ ($0.70^{+0.01}_{-0.00}$)	14.5 (15.2)	1.84 (1.80)	1.95 (1.82)
270.0	0	$0.75^{+0.02}_{-0.02}$ ($0.75^{+0.02}_{-0.02}$)	15.4 (16.4)	1.76 (1.76)	2.61 (2.45)	0	$0.61^{+0.02}_{-0.01}$ ($0.61^{+0.02}_{-0.01}$)	13.7 (14.4)	1.83 (1.83)	2.06 (1.96)
280.0	0	$0.69^{+0.03}_{-0.03}$ ($0.86^{+0.04}_{-0.04}$)	14.6 (15.8)	1.78 (1.69)	2.78 (2.45)	1	$0.83^{+0.03}_{-0.03}$ ($0.90^{+0.04}_{-0.03}$)	13.0 (13.9)	3.52 (3.45)	4.17 (3.83)
290.0	1	$0.98^{+0.06}_{-0.06}$ ($0.97^{+0.06}_{-0.06}$)	14.0 (15.5)	3.35 (3.37)	5.47 (4.99)	0	$0.80^{+0.04}_{-0.04}$ ($0.78^{+0.04}_{-0.04}$)	12.4 (13.6)	1.74 (1.74)	2.16 (1.97)
300.0	1	$1.08^{+0.08}_{-0.08}$ ($1.08^{+0.08}_{-0.08}$)	13.6 (15.1)	3.28 (3.28)	5.53 (4.97)	1	$0.87^{+0.05}_{-0.05}$ ($0.87^{+0.05}_{-0.05}$)	11.9 (13.3)	3.48 (3.48)	4.51 (4.01)

- 212 MeV/c^2 ~ 300 MeV/c^2 with $\tau_{X^0} = 10^{-15}$ s
- No significant signal is observed
- The efficiencies are little changed as the lifetime of X^0

Summary and Conclusion

- We have search for the HyperCP particle in B decay
  - No signals are observed in 211.6 MeV/c² $< M_{\mu+\mu-} <$ 217.2 MeV/c²
  - The obtained upper limits @ 90% C.L. with $\tau_{X^0} = 10^{-15}$ s are as follows :
    - X^0 as a scalar particle
      - $B(B^0 \to K^{*0} X^0) \times B(X^0 \to \mu^+\mu^-) < 2.26 \times 10^{-8}$
      - $B(B^0 \to \rho^0 X^0) \times B(X^0 \to \mu^+\mu^-) < 1.73 \times 10^{-8}$
    - X^0 as a vector particle
      - $B(B^0 \to K^{*0} X^0) \times B(X^0 \to \mu^+\mu^-) < 2.27 \times 10^{-8}$
      - $B(B^0 \to \rho^0 X^0) \times B(X^0 \to \mu^+\mu^-) < 1.73 \times 10^{-8}$
  - Our results rule out models II and III in the pseudoscalar sgoldstino interpretation
- No significant excess are observed for the X^0 of mass below 300 MeV/c² that covers a broader mass range
- The results are accepted by PRL

Search for a low mass particle decaying into \mu^+ \mu^- in B^0 \rightarrow K\ast^0X and B^0 \rightarrow \rho^0X at Belle

H. J. Hyun et al.

Accepted Thursday Jul 29, 2010

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Search for a low mass particle decaying into \mu^+ \mu^- in B^0 \rightarrow K\ast^0X and B^0 \rightarrow \rho^0X at Belle

H. J. Hyun et al.

Accepted Thursday Jul 29, 2010

We search for dimuon decays of a low mass particle in the decays \bz K*0 X and \bz r0 X using a data sample of 657 ×106 B [`B] events collected with the Belle detector at the KEKB asymmetric-energy e+ e- collider. We find no evidence for such a particle in the mass range from 212 \mmev to 300 \mmev for lifetimes below 10-12 s, and set upper limits on its branching fractions. In particular, we search for a particle with a mass of 214.3 \mmev reported by the HyperCP experiment, and obtain upper limits on the products \BR(\bzkx)×\BR(X m+ m-) < 2.26 (2.27) ×10-8 and \BR(\bzrhox)×\BR(X m+ m-) < 1.73 (1.73) ×10-8 at 90% C.L. for a scalar (vector) X particle.


THANK YOU


BACK UP SLIDES

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

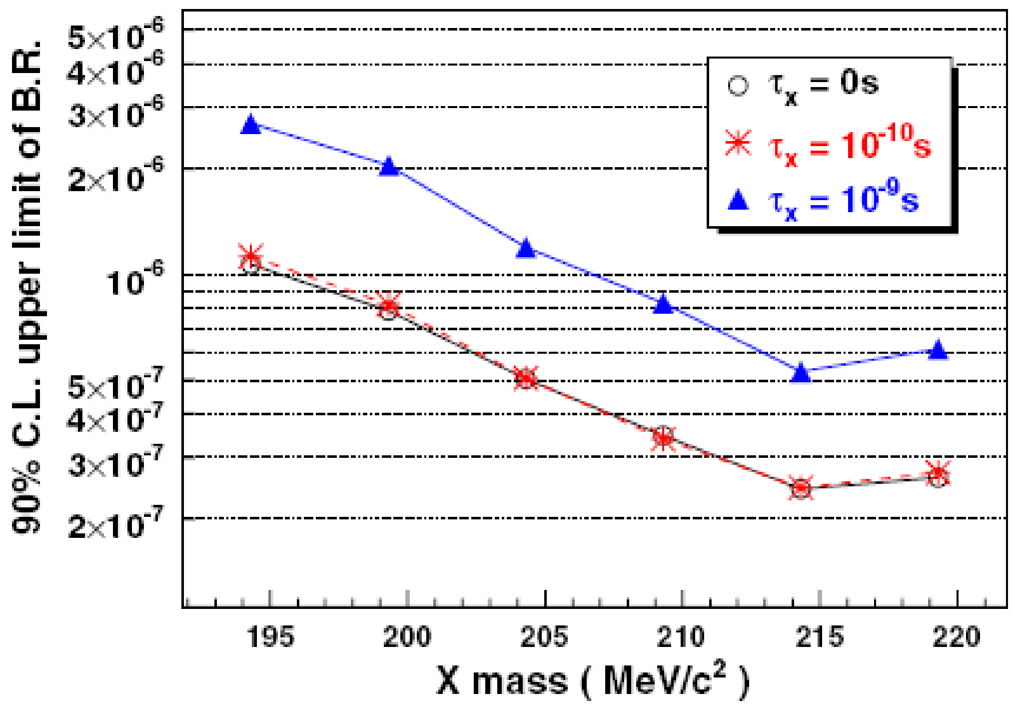
- hadron collider:
  - D0 Experiment (PRL 103, 061801 (2009))

- $e^+ e^-$ collider
  - CLEO (PRL 101, 151802 (2008)) :
    $B(\Upsilon(1S) \to \gamma a_1^0, a_1^0 \to \mu^+\mu^-) < 2.3 \times 10^{-6}$ @ 90% C.L.
    (m_{a0} = 214.3 MeV/c^2)
  - BaBar (PRL 103, 081803 (2009)) :
    $B(\Upsilon(3S) \to \gamma A^0, A^0 \to \mu^+\mu^-) < 0.8 \times 10^{-6}$ @ 90% C.L.
    (m_{A0} = 214 MeV/c^2)

- Fixed Target
  - E391a@KEK (PRL 102, 051802(2009))
  - E949@BNL (PRD 79, 092004(2009))
  - KTeV@FNAL (PoS(KAON09)039)

$X^0(214)$ 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)



$X^0(214)$ 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:

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

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

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

Compare with:

$$Br(K_L \rightarrow \pi^0\pi^0 X^0_P \rightarrow \pi^0\pi^0\mu^+\mu^-) = (8.3^{+7.5}_{-6.6}) x10^{-9}$$

$$Br(K_L \rightarrow \pi^0\pi^0 X^0_A \rightarrow \pi^0\pi^0\mu^+\mu^-) = (1.0^{+0.9}_{-0.8}) x10^{-10}$$

KTeV experiment at Fermilab.

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.

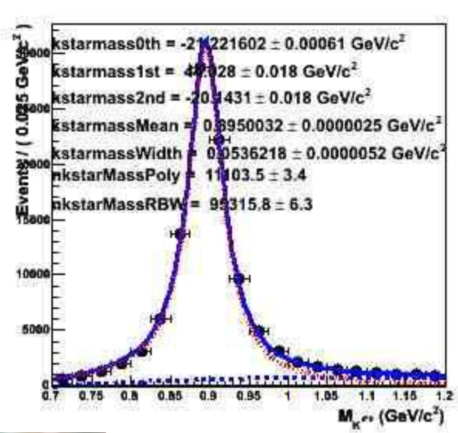
- Summary of Monte Carlo samples

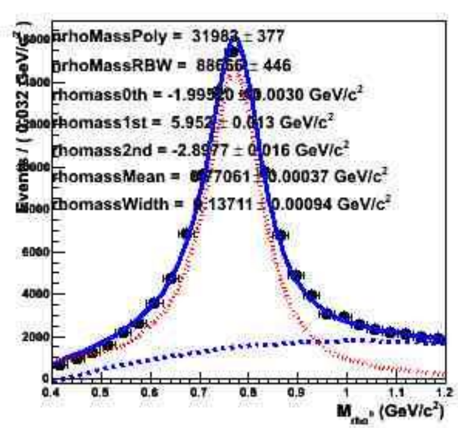
Data samples		Number of event
Signal MC	$B^0 \to K^{*0} X^0$, $K^{*0} \to K^- \pi^+$ and $X^0 \to \mu^+ \mu^-$	300,000
	$B^0 \to \rho^0 X^0$, $\rho^0 \to \pi^- \pi^+$ and $X^0 \to \mu^+ \mu^-$	300,000
Background MC	continuum qq-bar	1750 fb^{-1}
	B^0B^0-bar	
	B^+B^-	

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, $\mu\mu$, 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 $\chi 2$ value of four charged tracks

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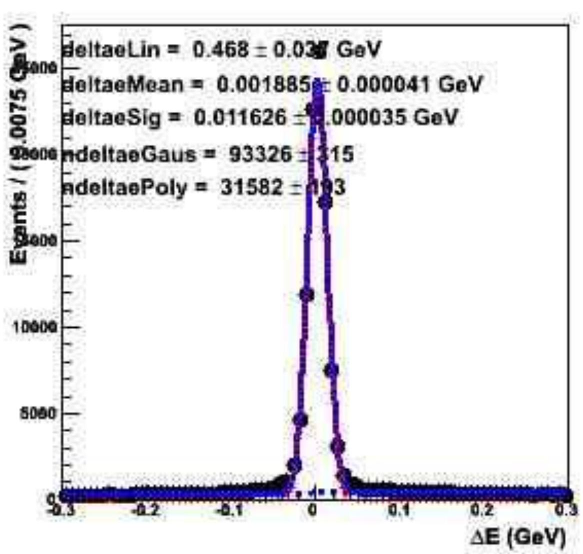
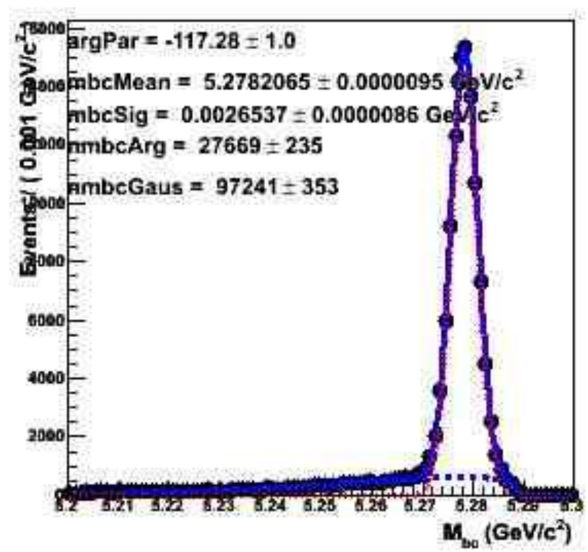
Definition of Signal Region

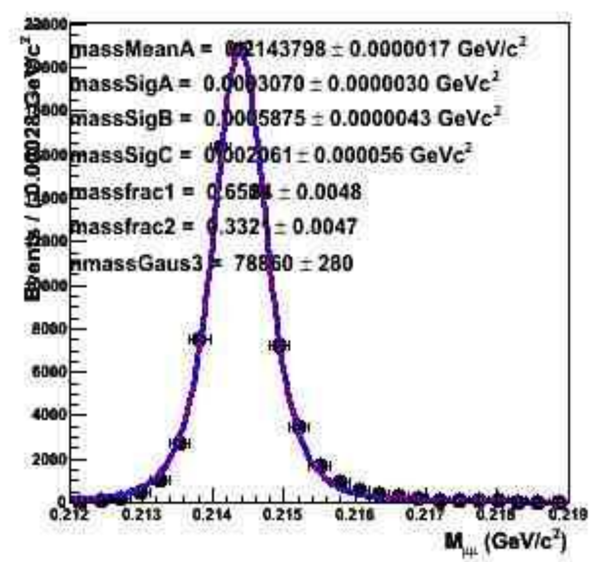
- Signal candidates are selected by the following two kinematic variables defined in the $\Upsilon(4S)$ c.m. frame.
  - Energy difference (ΔE) = $E_B - E_{beam}$
  - Beam-energy constrained mass (M_{bc}) = $\sqrt{(E_{beam}^2 - \sum p_B^2)}$

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

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







$X^0(214)$ as a Vector particle

- $X^0(214)$ can be a vector particle

- SVV decay model (SVV_HELAMP used)
  - fully longitudinal vs. fully transverse
  - 214.3 MeV/c^2 and immediately decays

Decay mode		$B \rightarrow K^{*0}X^0$	$B \rightarrow \rho^0 X^0$
efficiency	longitudinal	(26.3 ± 0.1) %	(23.6 ± 0.1) %
	transverse	(27.9 ± 0.1) %	(30.0 ± 0.1) %

Helicity angle distribution

BN344, R.Itoh, 'Measurement of Polarization of J/ψ in $B^0 \rightarrow J/\psi + K^{*0}$ and $B^+ \rightarrow J/\psi + K^{*+}$ decays

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_\psi d\cos\theta_{K^*}} =$$

$$\frac{9}{32}(1+\cos^2\theta_\psi)\sin^2\theta_{K^*}(1-\frac{\Gamma_L}{\Gamma}) + \frac{9}{8}\sin^2\theta_\psi\cos^2\theta_{K^*}\frac{\Gamma_L}{\Gamma}$$

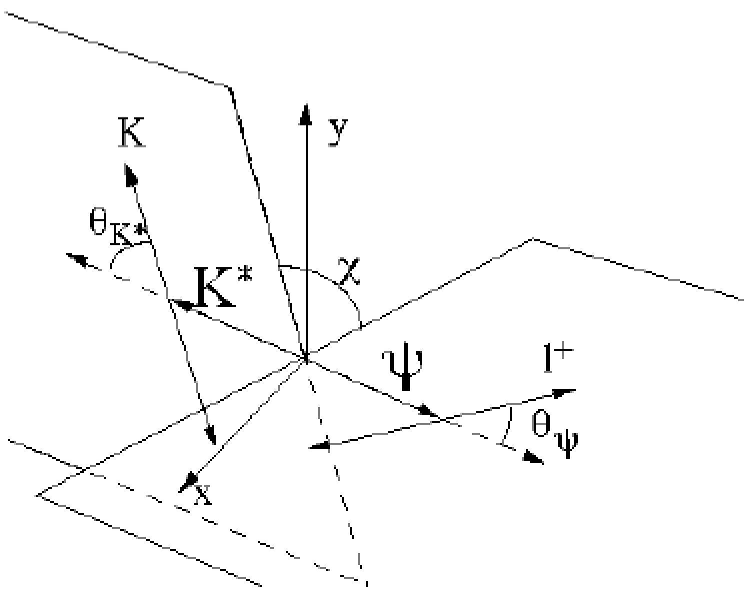


Figure 5: The definition of angles used in the helicity analysis

- $B^0 \rightarrow K^{*0} X^0$
  $K^{*0} \rightarrow K^+ \pi^-$
  $X^0 \rightarrow \mu^+\mu^-$

$$\cos\theta_X = \frac{\vec{P_X}\cdot\vec{P_\mu}}{|\vec{P_X}||\vec{P_\mu}|}$$

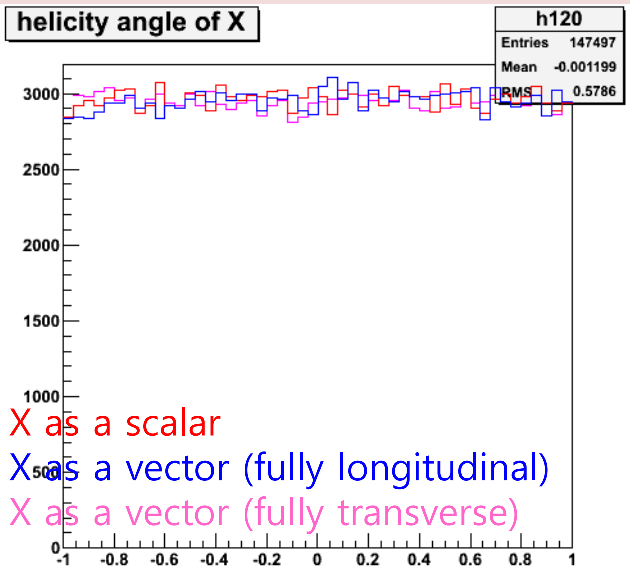
Px : momentum of X^0 at B^0 rest frame
$P\mu^+$: momentum of μ+ at X^0 rest frame

$$\cos\theta_{K^*} = \frac{\vec{P_{K^*}}\cdot\vec{P_K}}{|\vec{P_{K^*}}||\vec{P_K}|}$$

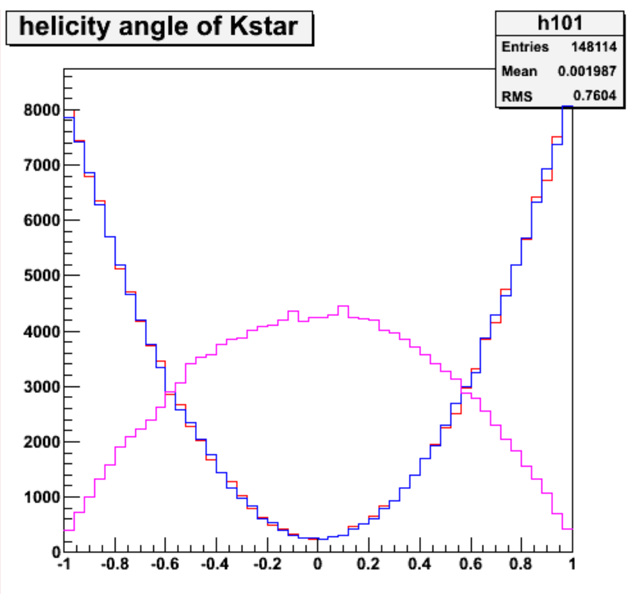
$P_{K^{*0}}$: momentum of K^{*0} at B^0 rest frame
P_{K+} : momentum of K^+ at K^{*0} rest frame

Helicity Angle for $K^{*0}X^0$

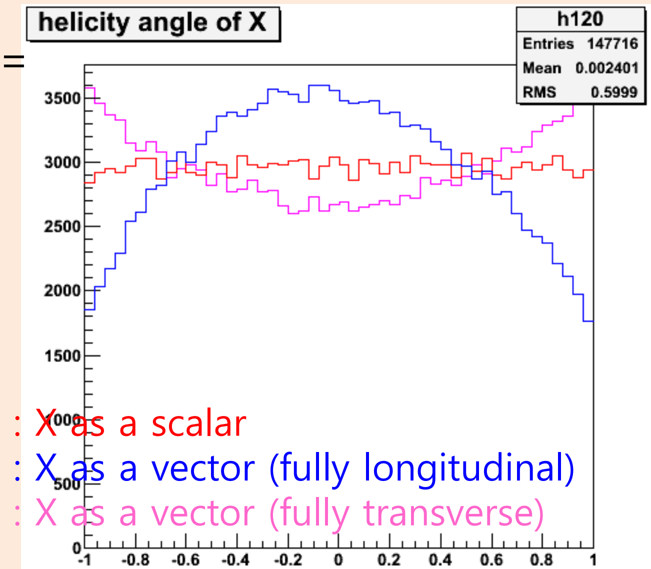
Mass of X^0 = 0.214 GeV



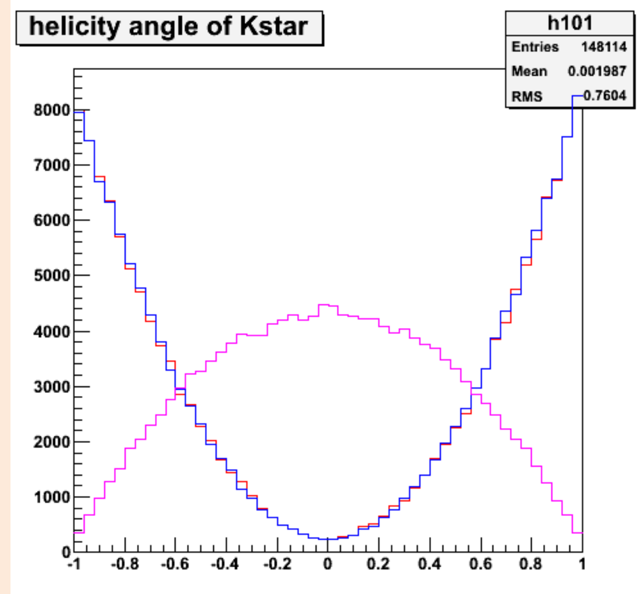
red : X as a scalar
blue : X as a vector (fully longitudinal)
pink : X as a vector (fully transverse)



Mass of X^0 = 3.09 GeV



red : X as a scalar
blue : X as a vector (fully longitudinal)
pink : X as a vector (fully transverse)



Decay model study (1)

- B to $K^{*0} X^0$ by PHSP

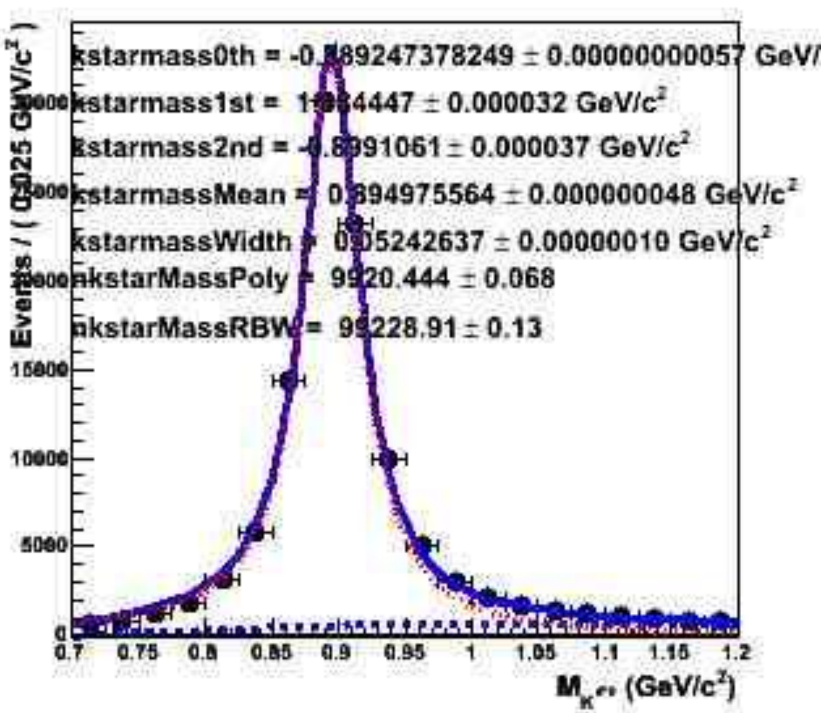
  $5.27 < M_{bc} < 5.29$, $-0.03 < \Delta E < 0.04$, and

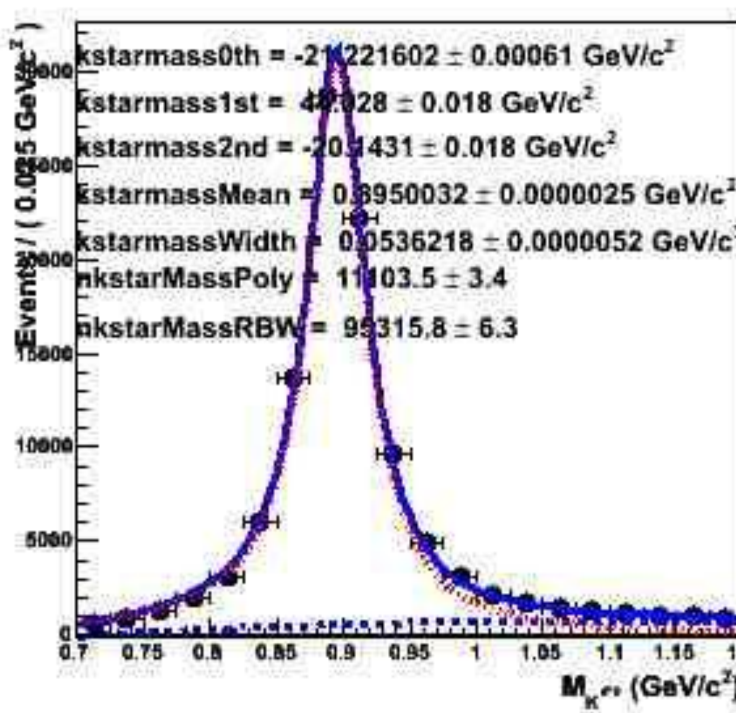
  $0.816 < M_{K^{*0}} < 0.974$

- B to $K^{*0} X^0$ by SVS

  $5.27 < M_{bc} < 5.29$, $-0.03 < \Delta E < 0.04$, and

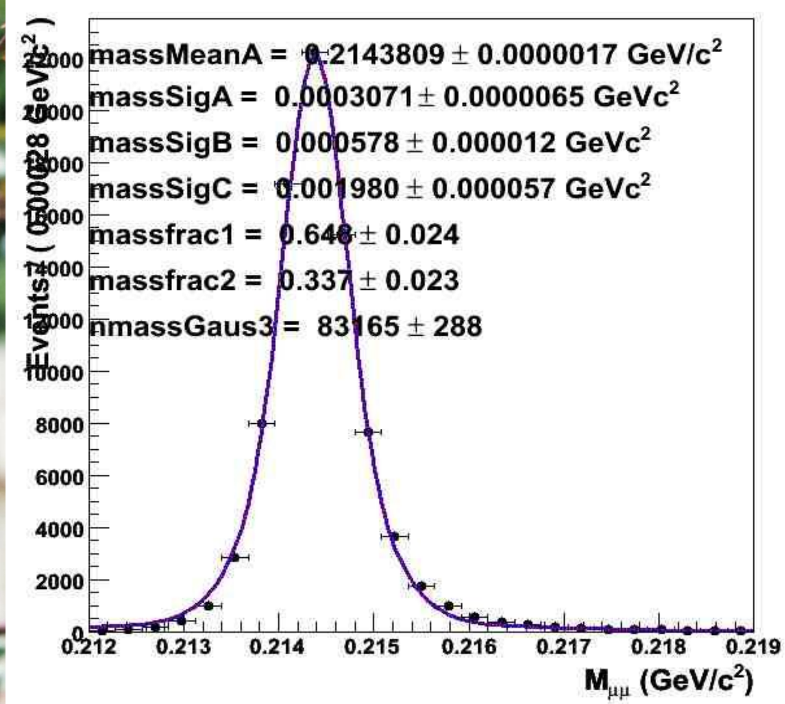
  $0.815 < M_{K^{*0}} < 0.975$



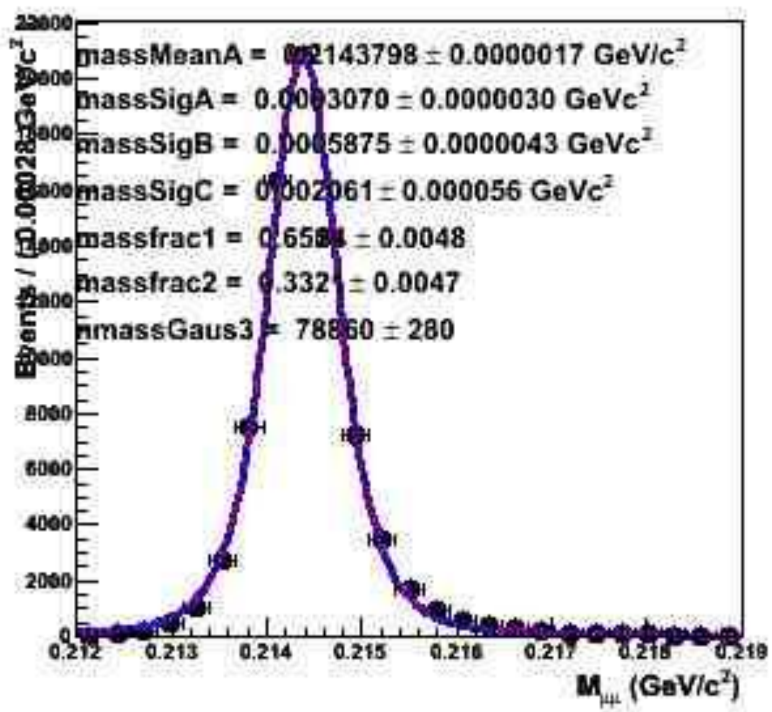


Decay model study (2)

- B to K^{*0} X^0 by PHSP
  signal efficiency : **27.7 ± 0.1 %**

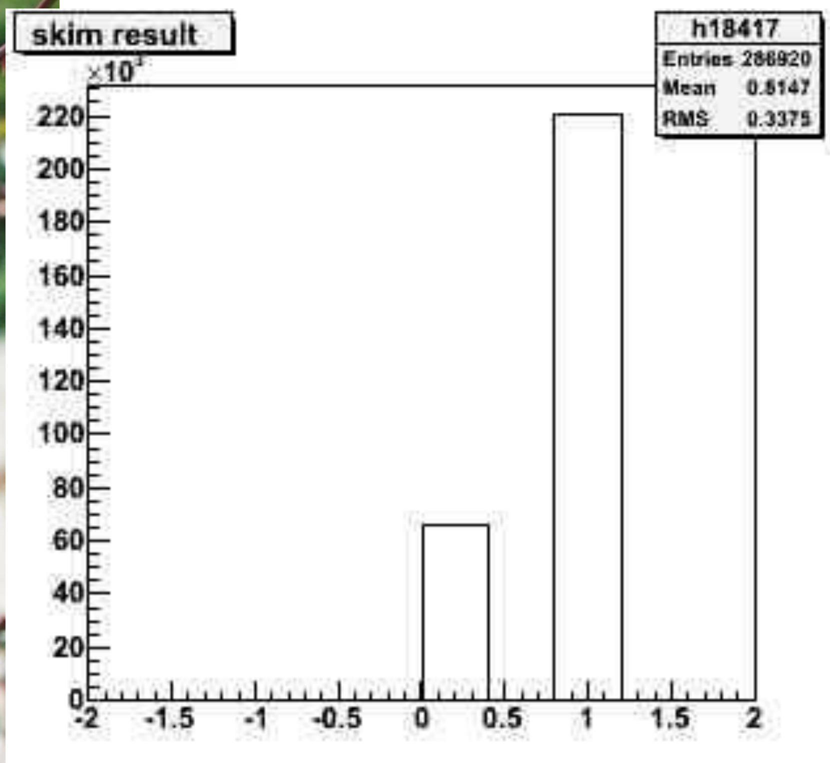


- B to K^{*0} X^0 by SVS
  signal efficiency : **26.3 ± 0.1 %**

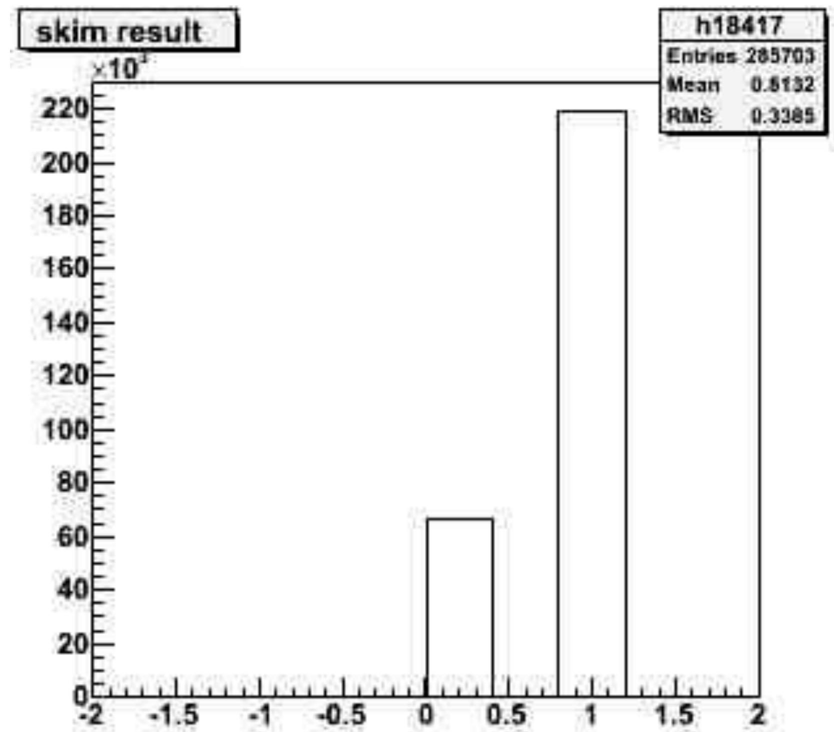


Decay model study (3)

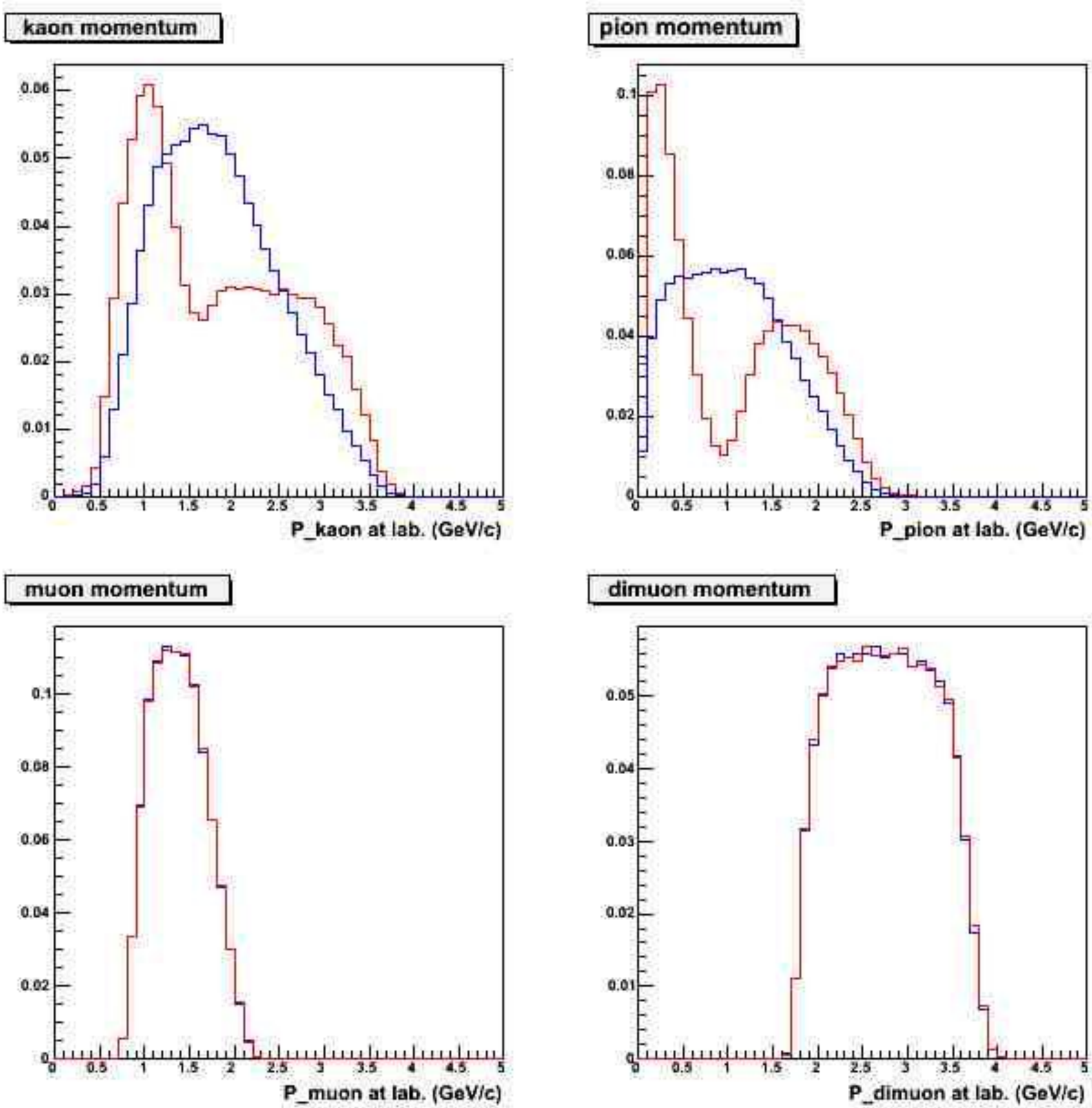
- B to K^{*0} X^0 by PHSP
  skim ratio : **73.5 %**



- B to K^{*0} X^0 by SVS
  skim ratio : **73.0 %**

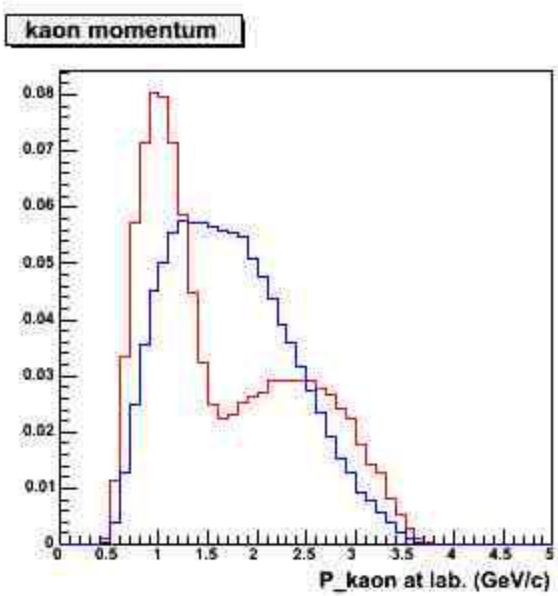


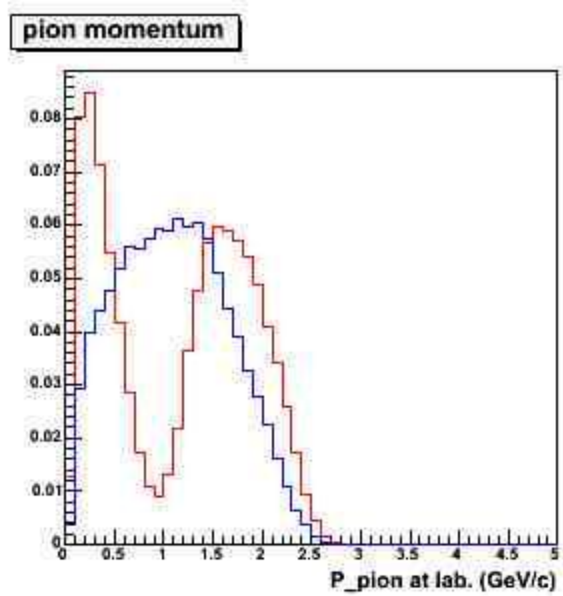
Decay model study (4)

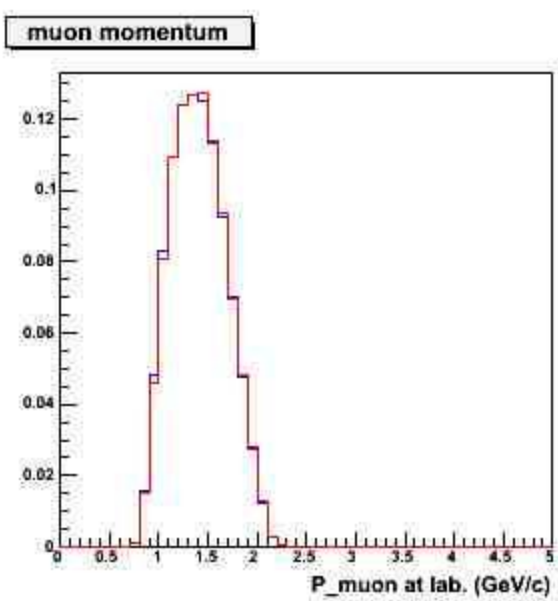


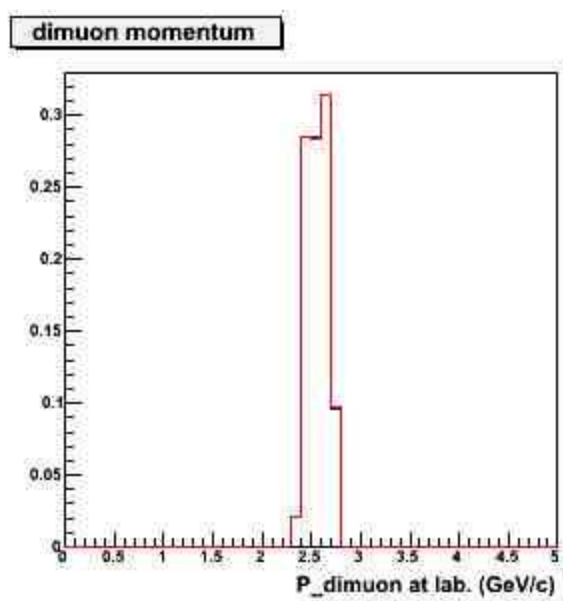
At Generator level
blue : PHSP model
red : SVS model

Decay model study (5)



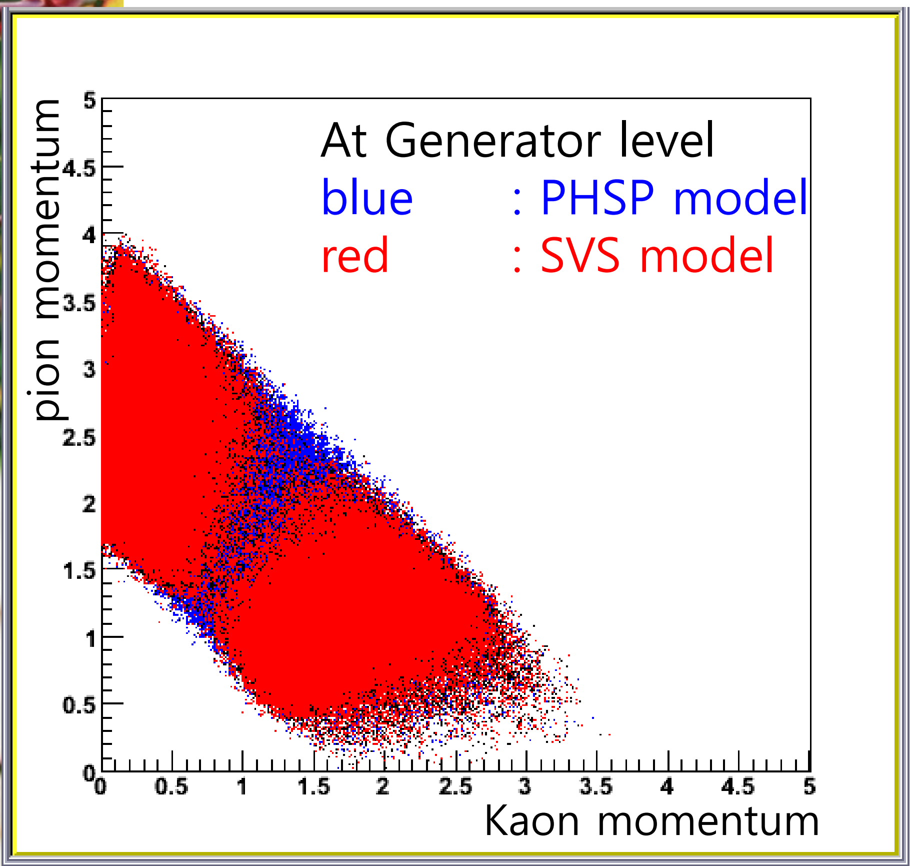


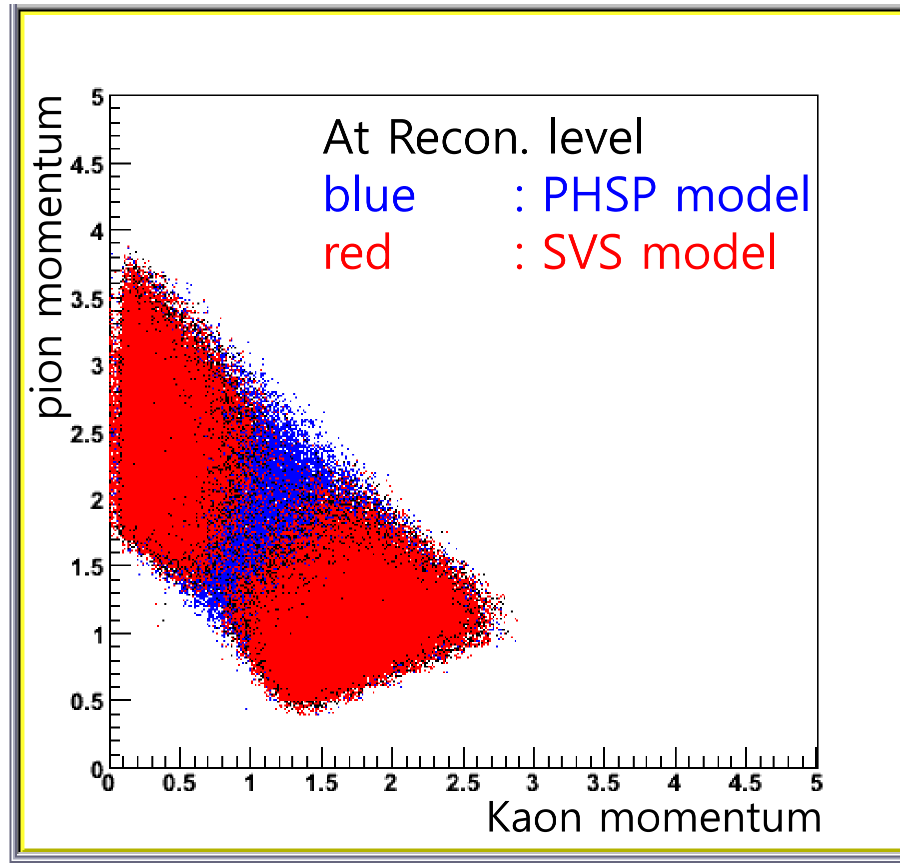




At Recon. level
blue : PHSP model
red : SVS model

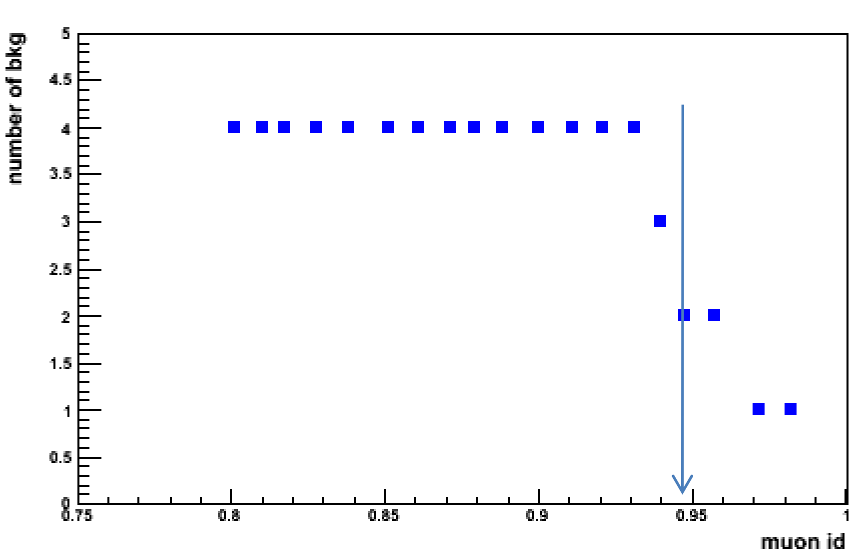
Decay model study (6)

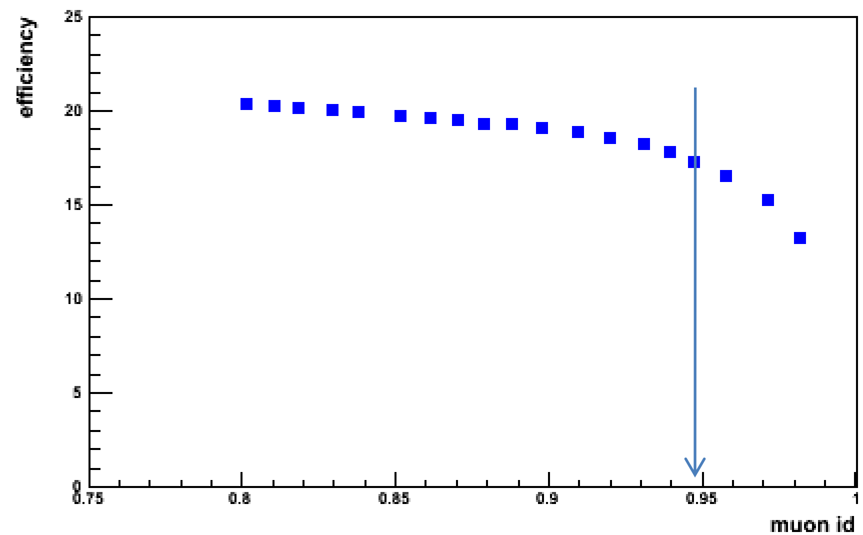




Muon identification study (1)

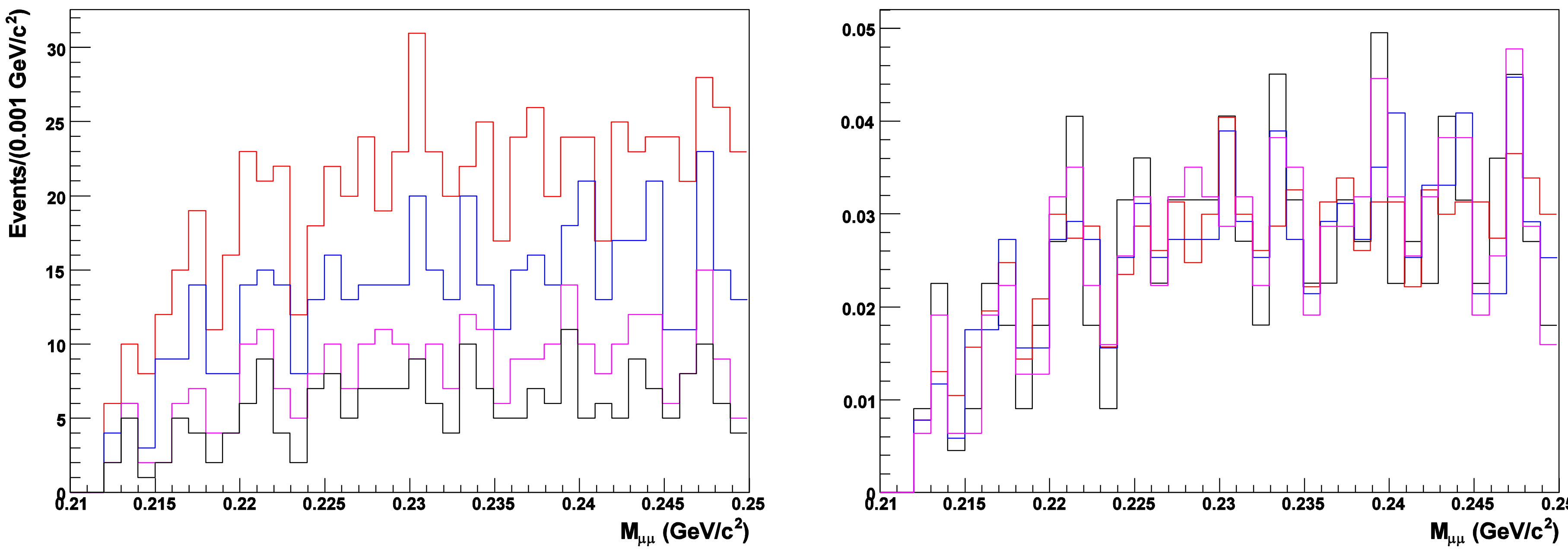
- Bkg. MC exp41 ~ exp55 and kpix signal MC are used.





* common applied cut : bestb, $\Delta E - M_{bc}$ signal region, $M_{\mu\mu}$ <0.2170 GeV/c^2

Muon identification study (2)



red : muid>0.6 blue: muid>0.8 pink : muid>0.9 black : muid >0.95

- From the upper plots, the bkg. shape looks like independent of likelihood on muon identification.

V-shape event study (1)

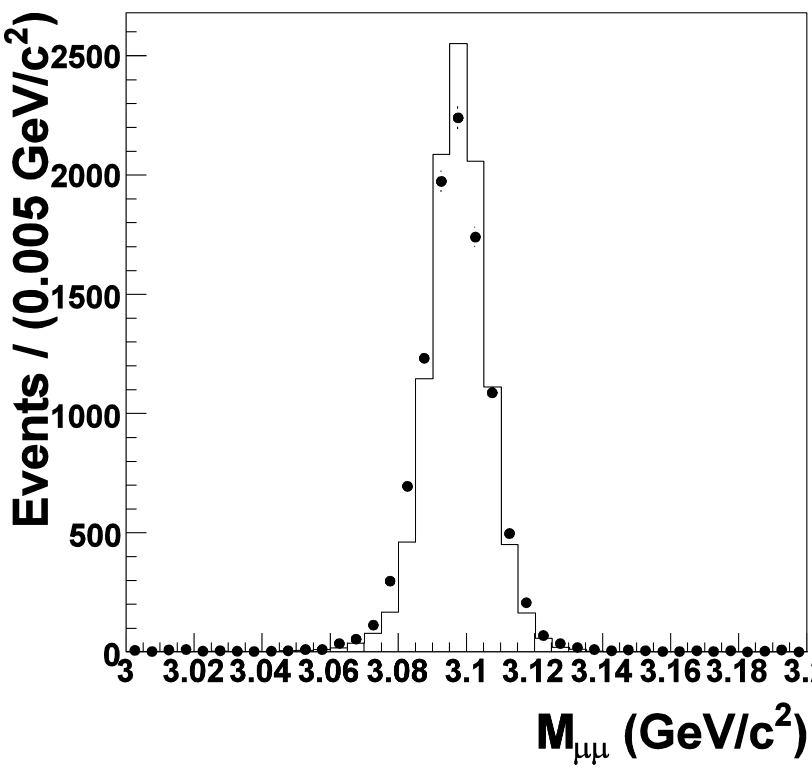
- Since dimuon mass of $X^0(214)$ is just 3 MeV above of two muon masses, tracking efficiency for small opening angle of two tracks is checked using real data sample

- **$B(B^0 \rightarrow J/\psi(1S)K^+\pi^-) = (1.2 \pm 0.6) \times 10^{-3}$**
  - Use control sample, $B^0 \rightarrow J/\psi$ K pi, $J/\psi \rightarrow \mu^+\mu^-$
  - Check invariant mass of K and pi for the control sample

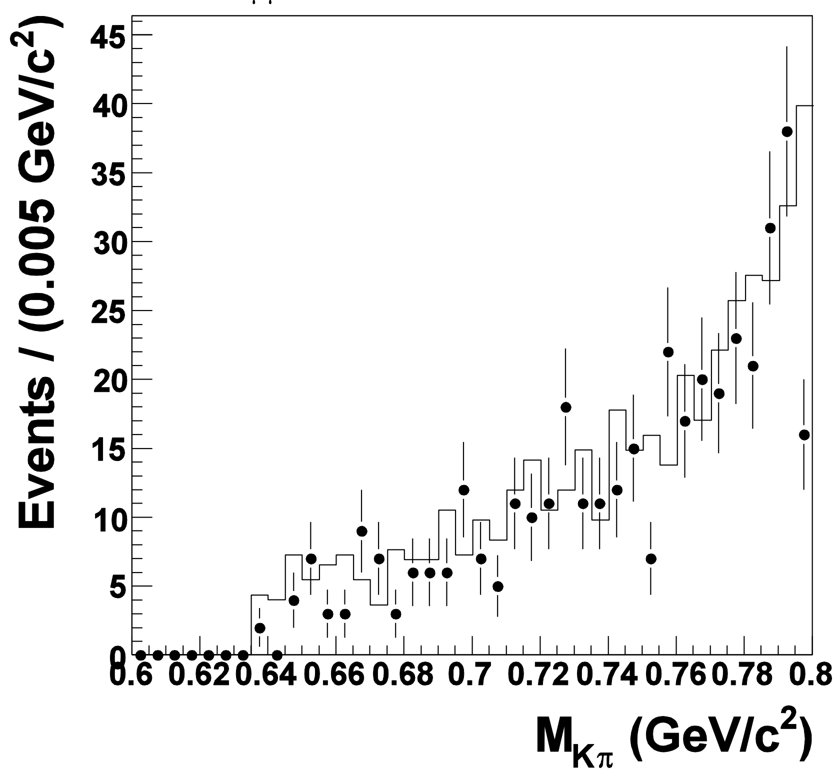
- B^0/B^0-bar bkg. MC exp7 ~ exp55 and real data exp7 ~ exp55 are used
  - bestb, $5.27 < M_{bc} < 5.29$, $-0.03 < \Delta E < 0.04$
  - $3.0 < M_{\mu\mu} < 3.2$ for $J/\psi(1S)$ selection
  - $0.6 < M_{kpi} < 0.8$ for low mass kaon-pion region

V-shape event study (2)

bestb, 5.27 < M_{bc} < 5.29, -0.03 < ΔE < 0.04, and 0.6 < M_{kpi} < 0.8



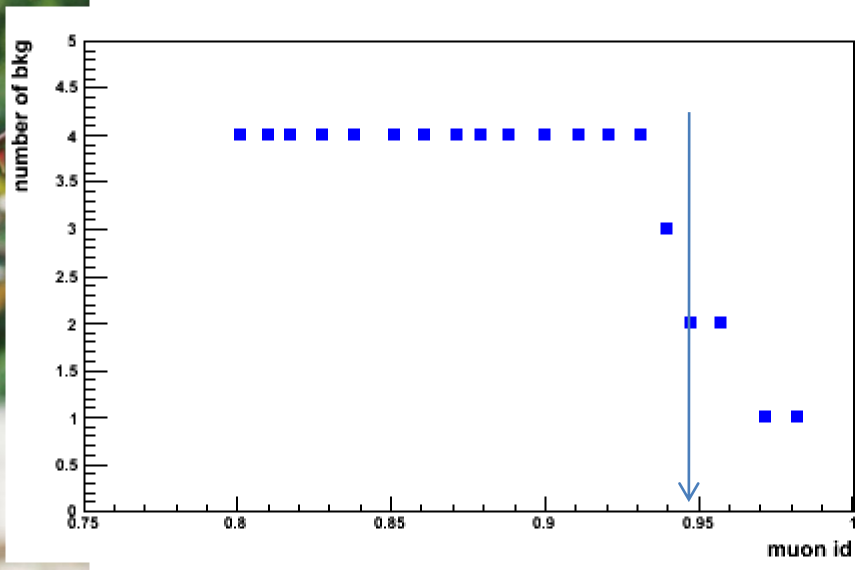
bestb, 5.27 < M_{bc} < 5.29, -0.03 < ΔE < 0.04, and 3.0 < $M_{\mu\mu}$ < 3.2

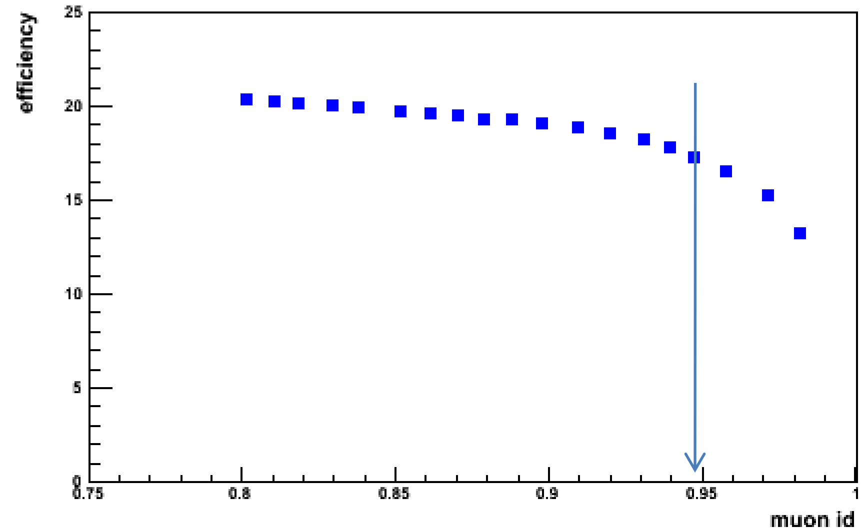


- There is no significant discrepancy between Data and MC for invariant masses of K and pi tracks, specially a few MeV above of threshold of those tracks

Muon identification study (1)

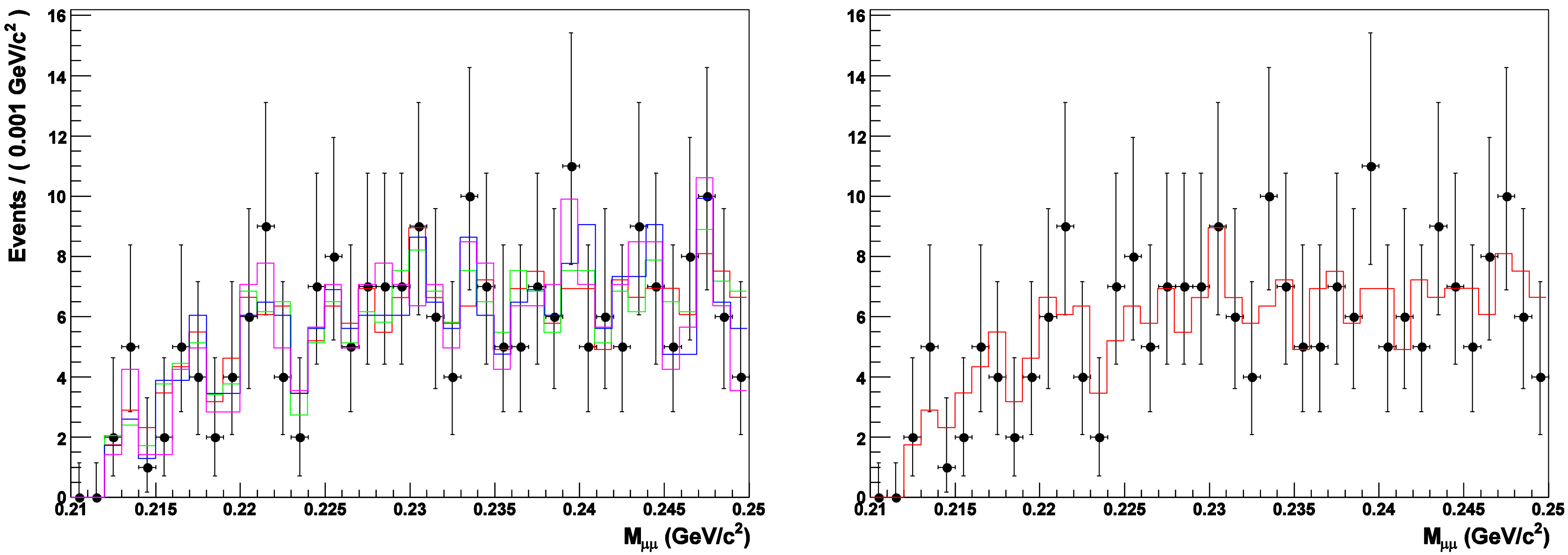
- Bkg. MC exp41 ~ exp55 and kpix signal MC are used.





* common applied cut : bestb, $\Delta E - M_{bc}$ signal region, $M_{\mu\mu}$ <0.2170 GeV/c^2

Muon identification study (2)



red : muid>0.6   green : muid>0.7   blue: muid>0.8   pink : muid>0.9   black : muid >0.95

- From the upper plots, the bkg. shape is independent of likelihood on muon identification.

Go back to slide p15

Systematics : scalar and 214.3 MeV/c²

Decay mode		$K^{*0}X^0$			ρ^0X^0		
Source \ lifetime		0 s	10^{-15} s	10^{-12} s	0 s	10^{-15} s	10^{-12} s
Integrated Luminosity ($N_{BB\text{-}bar}$)		1.4 %	1.4 %	1.4 %	1.4 %	1.4 %	1.4 %
Signal efficiency	**Muon ID**	**4.2 %**	**4.2 %**	**4.2 %**	**4.1 %**	**4.1 %**	**4.1 %**
	charged kaon ID	0.8 %	0.8 %	0.8 %	-	-	-
	charged pion ID	0.5 %	0.5 %	0.5 %	1.0 %	1.0 %	1.0 %
	Tracking	**4.2 %**	**4.2 %**	**4.2 %**	**4.2 %**	**4.3 %**	**4.3 %**
	MC statistics	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %
Cut variables	M_{bc}	0.6 %	0.5 %	0.3 %	0.7 %	0.3 %	0.4 %
	ΔE	0.6 %	0.5 %	0.4 %	0.7 %	0.3 %	0.4%
	K^{*0} mass	0.6 %	0.5 %	0.4 %	-	-	-
	ρ^0 mass	-	-	-	0.7 %	0.3 %	0.5%
	Total	**6.3 %**	**6.2 %**	**6.2 %**	**6.2 %**	**6.2 %**	**6.2 %**

Go back to slide p15

Systematics : vector and 214.3 MeV/c^2

Decay mode		$K^{*0}X^0$			ρ^0X^0		
Source \ lifetime		**0 s**	**10^{-15} s**	**10^{-12} s**	**0 s**	**10^{-15} s**	**10^{-12} s**
Integrated Luminosity ($N_{BB\text{-}bar}$)		1.4 %	1.4 %	1.4 %	1.4 %	1.4 %	1.4 %
Signal efficiency	**Muon ID**	**4.2 %**	**4.2 %**	**4.2 %**	**4.1 %**	**4.1 %**	**4.1 %**
	charged kaon ID	0.8 %	0.8 %	0.8 %	-	-	-
	charged pion ID	0.5 %	0.5 %	0.5 %	1.0 %	1.0 %	1.0 %
	Tracking	**4.2 %**	**4.2 %**	**4.2 %**	**4.3 %**	**4.3 %**	**4.3 %**
	MC statistics	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %
Cut variables	M_{bc}	0.6 %	0.3 %	0.7%	0.6 %	0.6 %	0.5 %
	ΔE	0.6 %	0.3 %	0.7 %	0.6 %	0.6 %	0.5 %
	K^{*0} mass	0.6 %	0.3 %	0.7 %	-	-	-
	ρ^0 mass	-	-	-	0.6 %	0.6 %	0.5 %
	Total	**6.3 %**	**6.2 %**	**6.3 %**	**6.3 %**	**6.3 %**	**6.2%**