Search for Light Dark Matter in Upsilon(3S) Decays at Belle

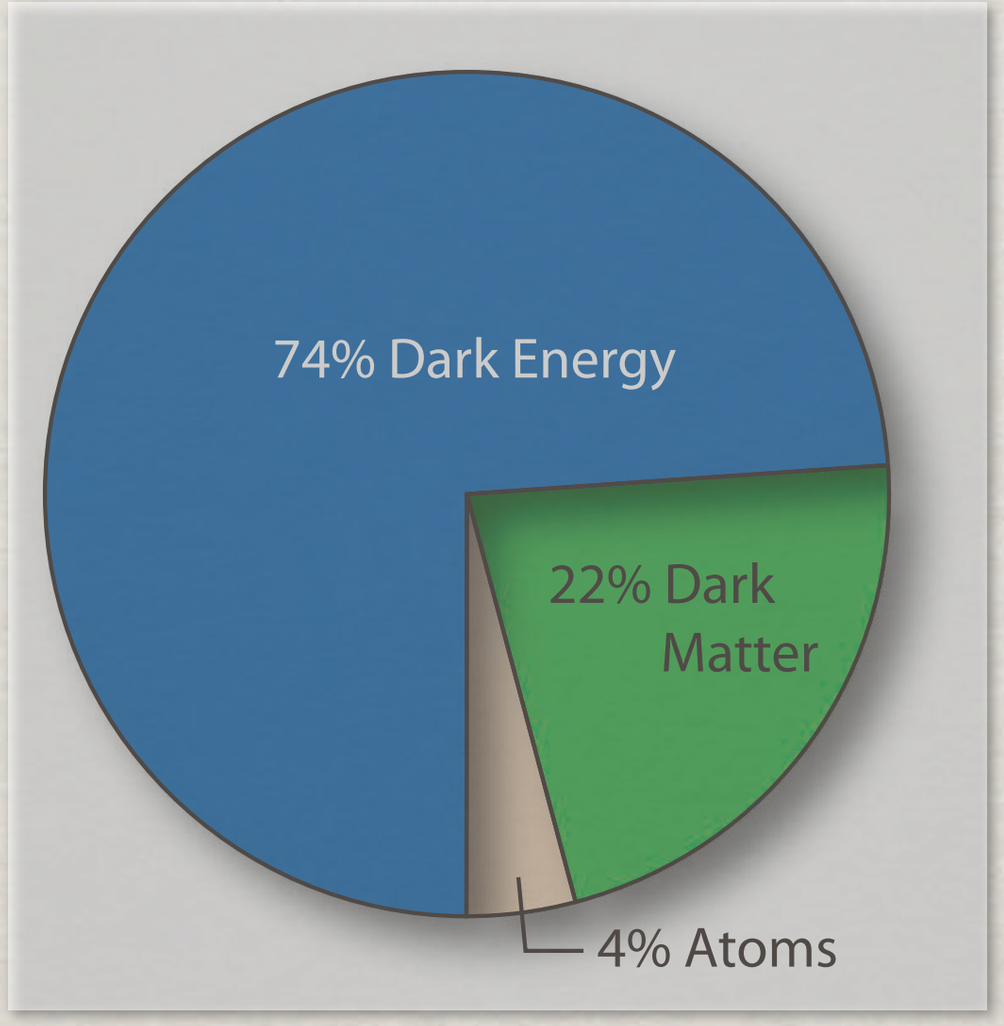
Y. Iwasaki (KEK)
Belle Collaboration

2007/05/10 @ FNAL

yoshihito.iwasaki@kek.jp

Dark Matter ?

Contents of the Universe

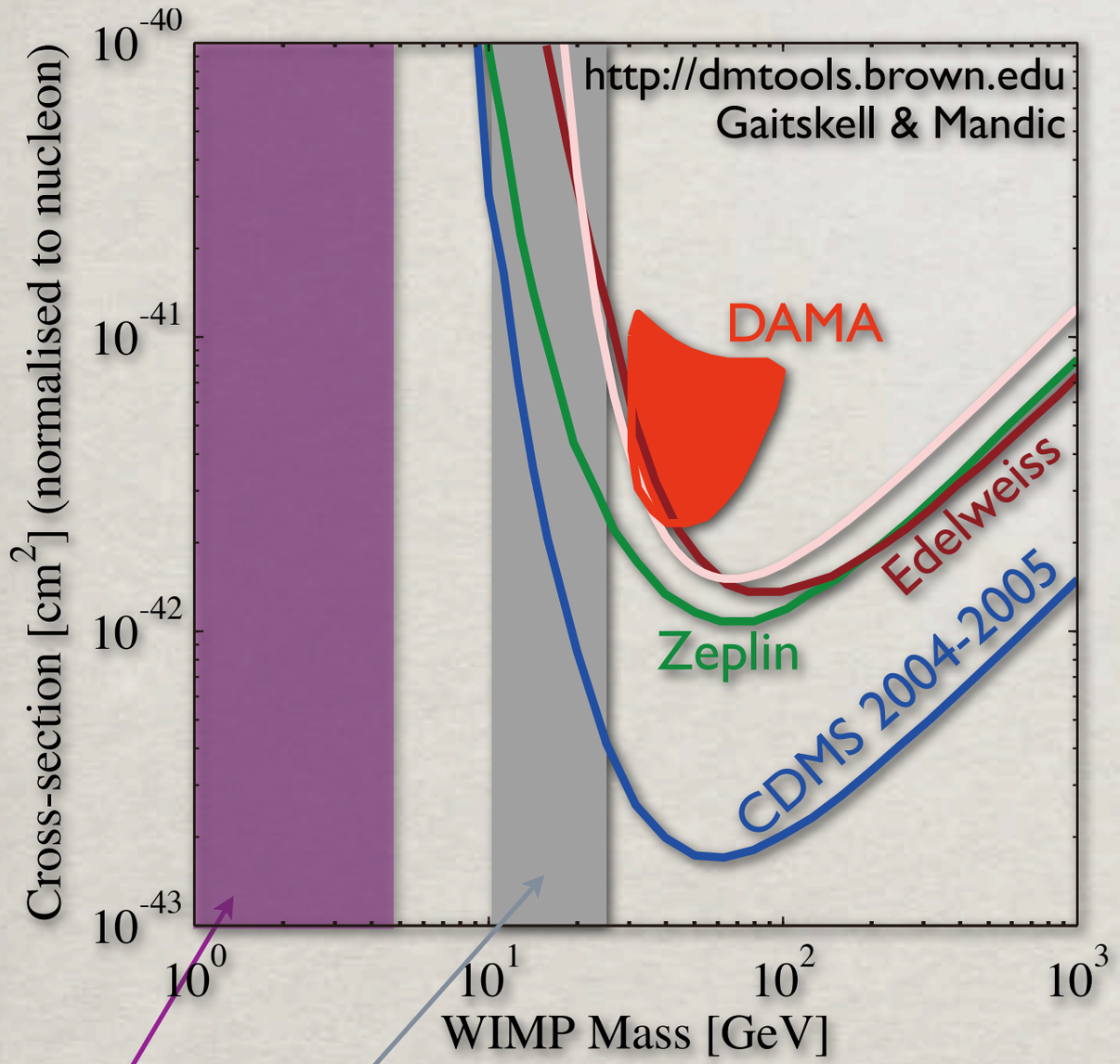


WMAP result

http://map.gsfc.nasa.gov/m_mm.html

yoshihito.iwasaki@kek.jp

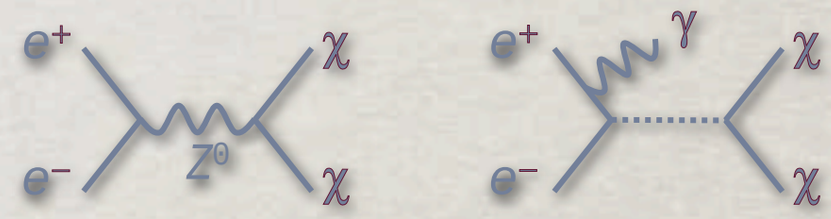
DM Searches (Collider Exp.)



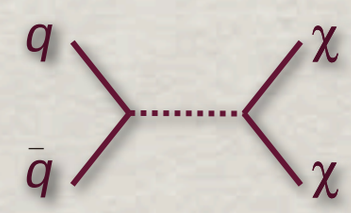
LEP limits

Belle search

- Searches in LEP
  - DM coupling with Z
  - DM coupling with e^+e^-



- A search in Belle
  - DM coupling with quarkonium



yoshihito.iwasaki@kek.jp

Y(1S) to DM

- $\Omega_\chi h^2 = \mathbf{0.113 \pm 0.009}$ (WMAP)

$$\simeq \frac{0.1\text{pb} \cdot c}{\langle \sigma(\chi\chi \to \text{SM}) \cdot v \rangle}$$

Ω_χ: Relic density
h: Hubble constant
v = $c/20$

- $\sigma(\chi\chi \to \text{SM}) \underset{\text{reversal}}{\overset{\text{time}}{\rightleftharpoons}} \sigma(\text{SM} \to \chi\chi) \sim 18\,\text{pb}$

$$Br\left(\Upsilon(1S) \to \chi\chi\right) = f_\Upsilon^2 M_\Upsilon \sigma(b\bar{b} \to \chi\chi)$$

$$= \mathbf{6 \times 10^{-3}} \text{ (prediction)}$$

McElrath, Phys. Rev. D 72, 103508 (2005)

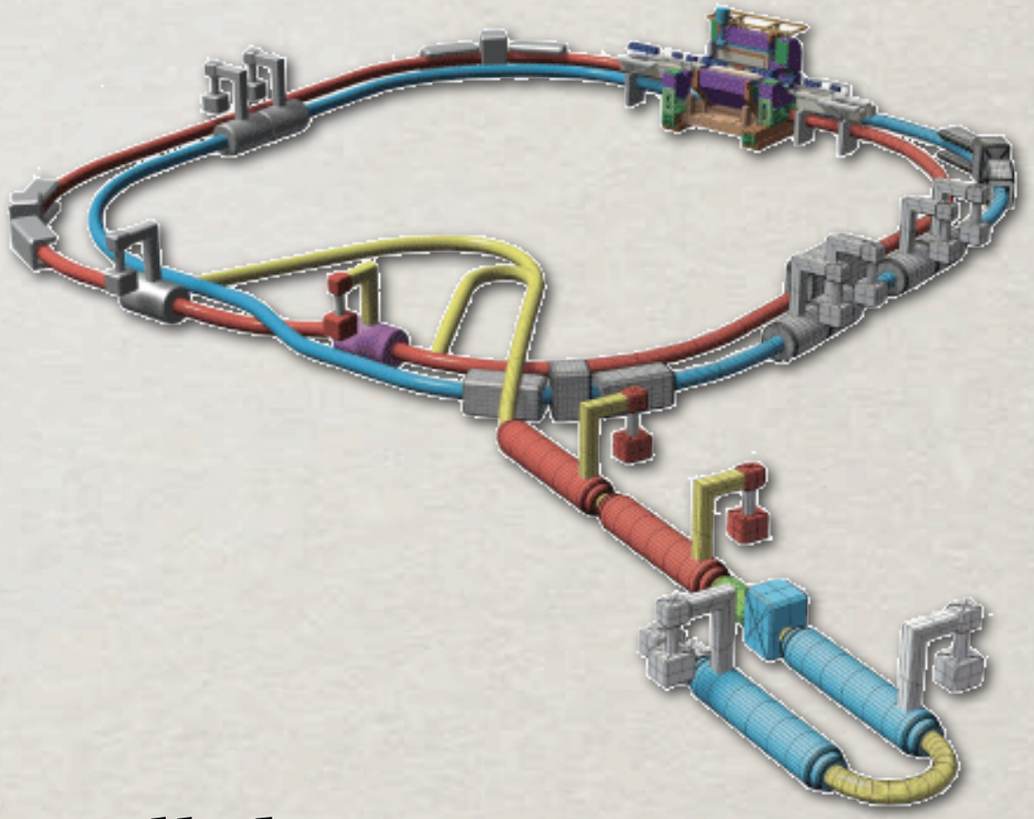
- Measurements ever done

$Br(\Upsilon(1S) \to invisible) < 50 \times 10^{-3}$ (90%C.L.) CLEO, Phys. Rev. D 30, 1433 (1984)

$Br(\Upsilon(1S) \to invisible) < 23 \times 10^{-3}$ (90%C.L.) ARGUS, Phys. Lett. B 179, 403 (1986)

yoshihito.iwasaki@kek.jp

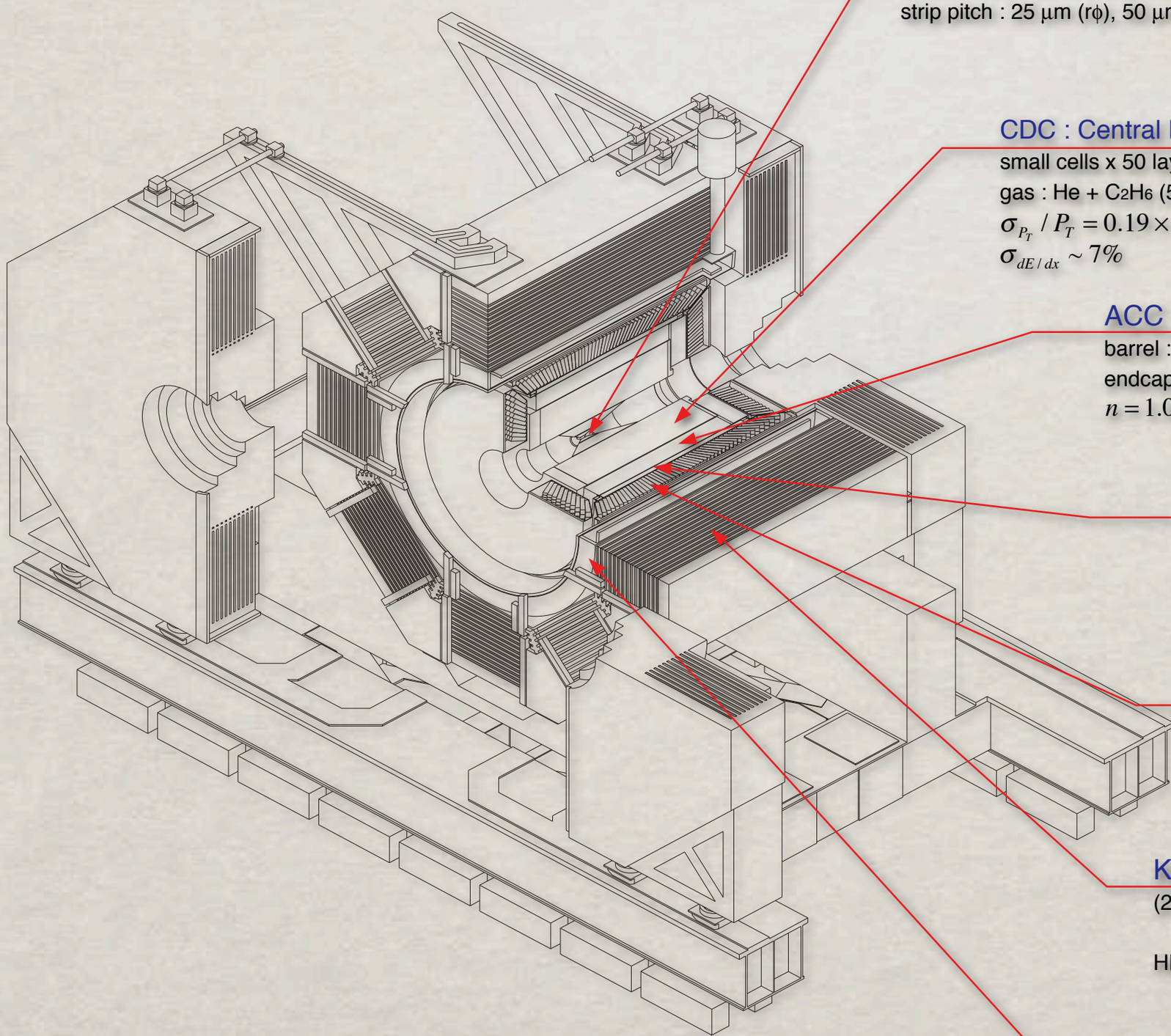
KEKB Accelerator



- An e^+e^- asymmetric energy collider
  - To produce two B mesons via Y(4S)
  - 8.0 GeV e^- and 3.5 GeV e^+ : Ecm=10.58 GeV (Y(4S) mass)
- Peak luminosity = 1.71 $\times 10^{34}$ cm^2/s
- Integrated luminosity since 1999 ~ 700fb^{-1}

yoshihito.iwasaki@kek.jp

Belle Detector



SVD : Silicon Vertex Detector
double-sided silicon strip x 3 layers
strip pitch : 25 μm (rϕ), 50 μm (z)

CDC : Central Drift Chamber
small cells x 50 layers
gas : He + C_2H_6 (50:50)
$\sigma_{P_T} / P_T = 0.19 \times P_T \oplus 0.30 / \beta \quad (\%)$
$\sigma_{dE/dx} \sim 7\%$

ACC : Aerogel Cerenkov Counter
barrel : 960 aerogel boxes x 2 FM-PMT's
endcap : 228 boxes x 1 FM-PMT's
$n = 1.01 \sim 1.03$

TOF : Time Of Flight counter
4cm x 6cm x 2600cm x 128 scint. counters
x 2 FM-PMT's
$\sigma_{TOF} \sim 95 ps$

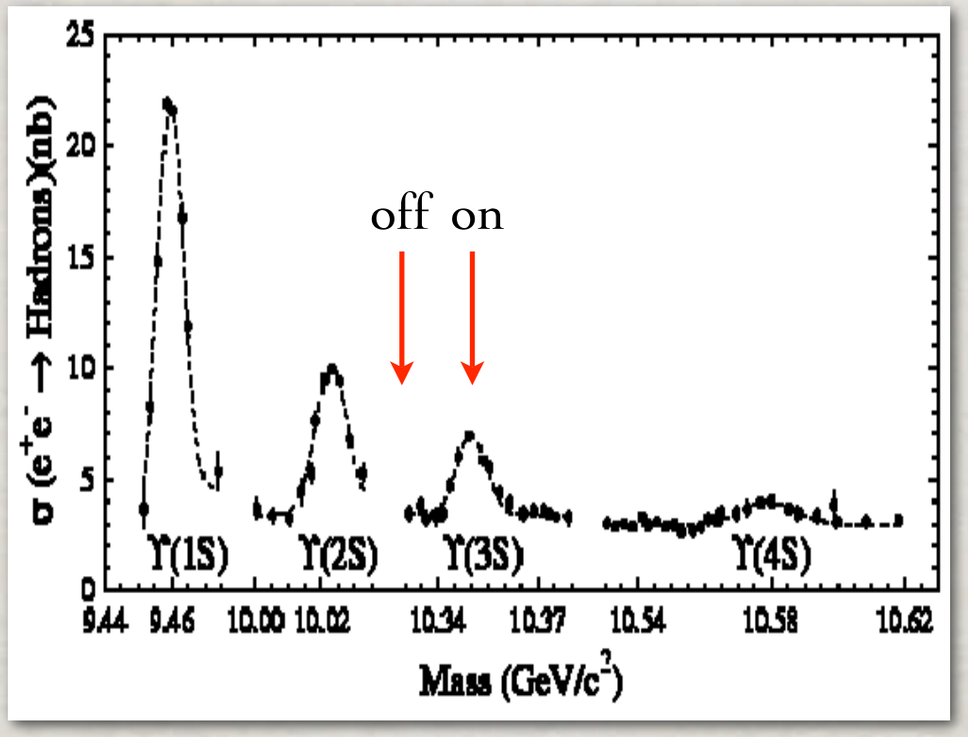
ECL : Electromagnetic Calorimeter
barrel : 6624 CsI crystals
endcap : 1152 + 960 CsI crystals
16.2 X_0
$\sigma_E / E = 1.3 \oplus 0.7 / E \oplus 0.8 / E^{1/4} (\%)$

KLM : KL and Muon detector
(2 resistive plate counters(θ and ϕ) + 5cm Fe)
x 14 layers
HFC-134a : Ar : Butane = 62 : 30 : 8

Superconducting Solenoid

yoshihito.iwasaki@kek.jp

Production of Υ(1S)



e+e– → Υ(1S)	nothing left, can't trigger
e+e– → Υ(2S) → Υ(1S)π+π–	high σ, but pions so slow
e+e– → Υ(3S) → Υ(1S)π+π–	pions detectable
e+e– → Υ(4S) → Υ(1S)π+π–	very low σ, low S/N

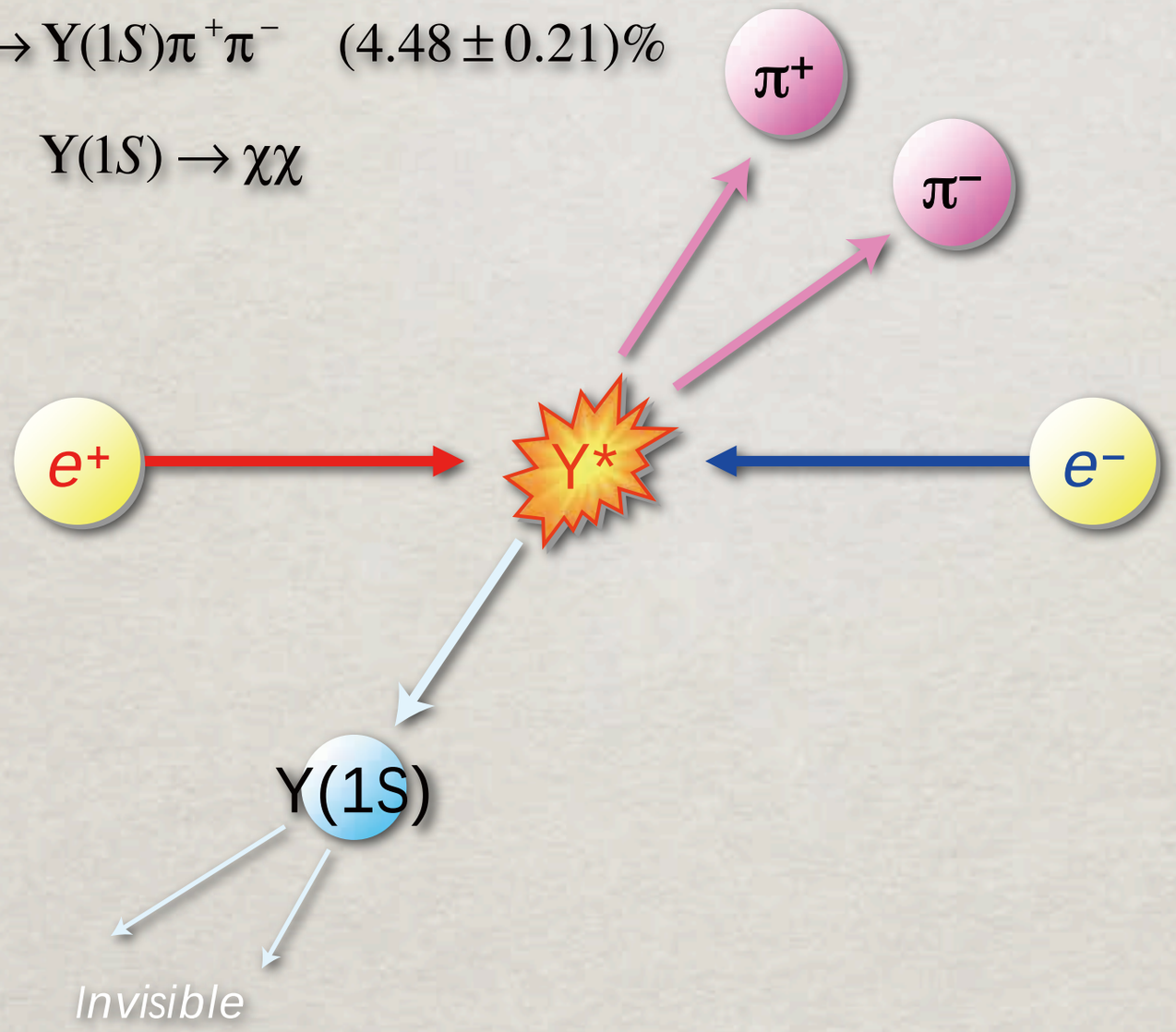
- We took special runs on Υ(3S) for this study
  - Int. L = 2.9 fb^{-1} (on-resonance, 4 days), Int. L = 0.25 fb^{-1} (off-resonance, 16 hours)

yoshihito.iwasaki@kek.jp

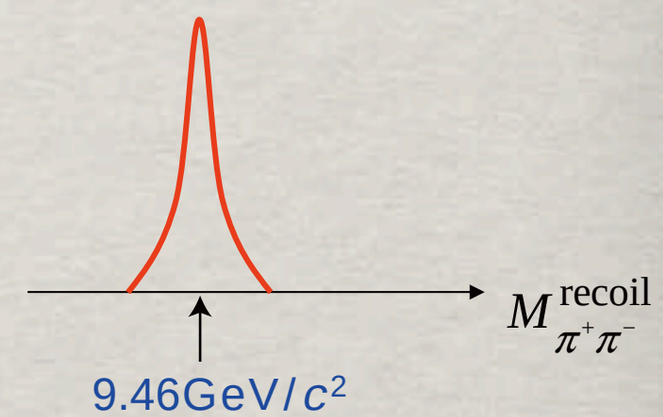
Signal Events

$e^+e^- \to \Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$ $(4.48 \pm 0.21)\%$

$\Upsilon(1S) \to \chi\chi$



Signature

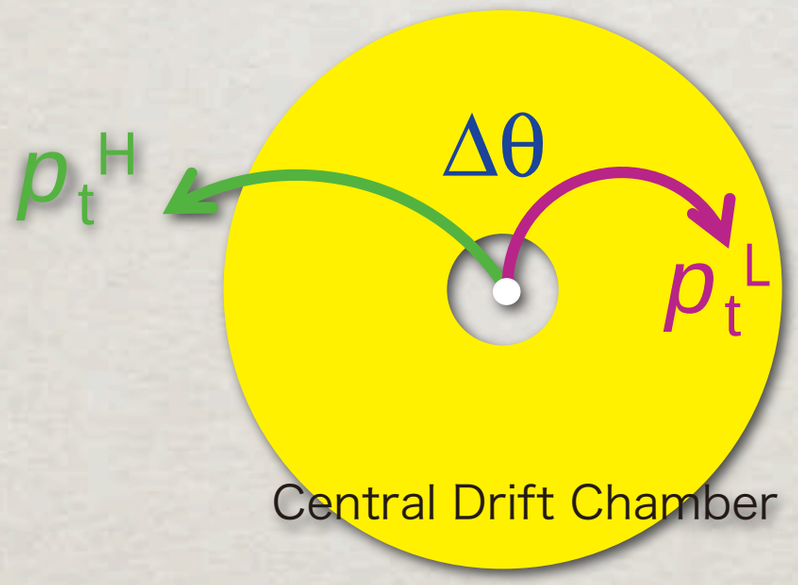


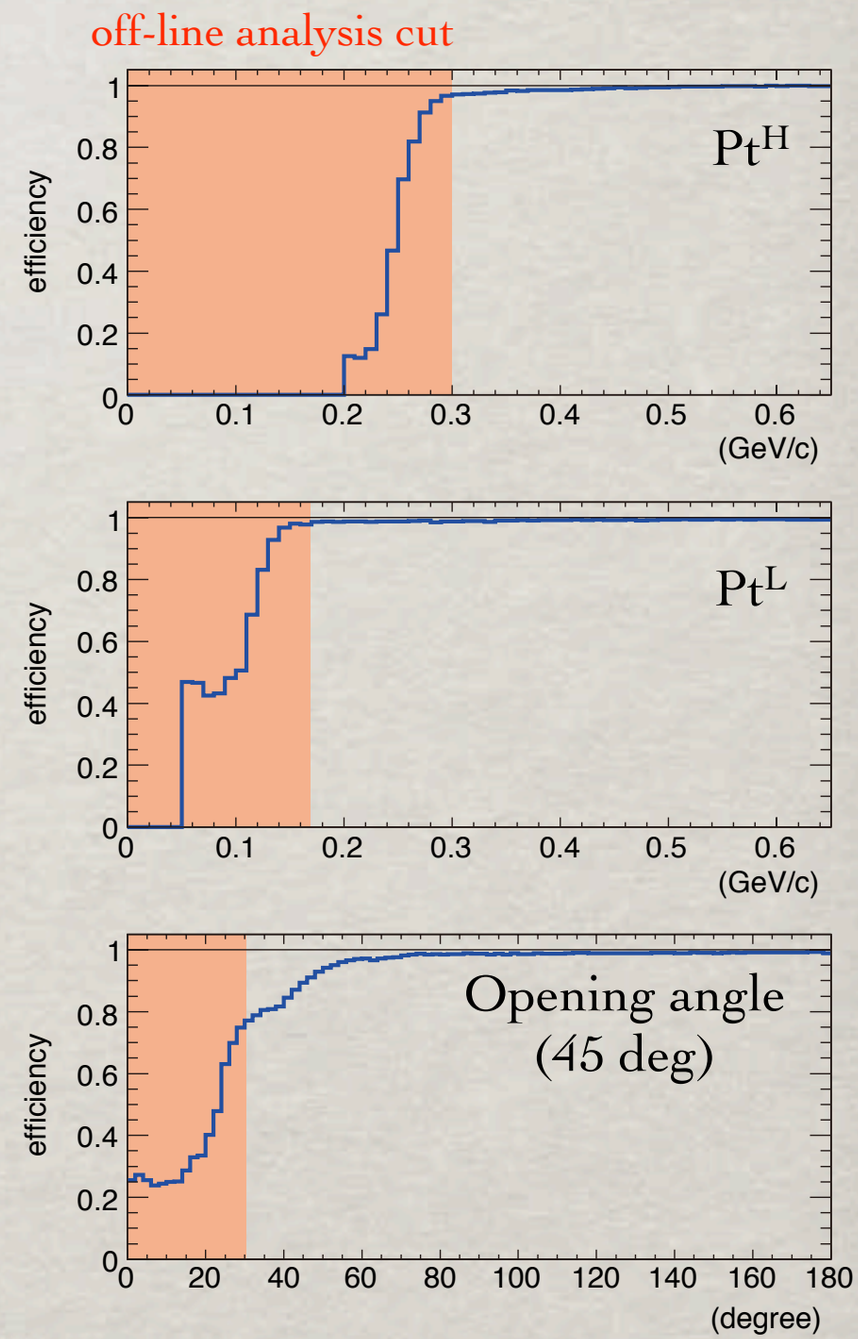
- Final state : two soft pions only
  - Events should be triggered by two pions
- Recoil mass of two pions is Y(1S) mass

yoshihito.iwasaki@kek.jp

Trigger Set-up

- Charged track trigger
  - Two Pt thresholds
    - Pt^H > 300 MeV/c
    - Pt^L > 200 MeV/c
  - Opening angle
    - 45, 90, 135 deg





Target	Pt	Opening
B Phys.	Pt^H+Pt^H	135 deg.
Y(3S)	Pt^H+Pt^L	45 deg.

The trigger efficiency is 89.8%.

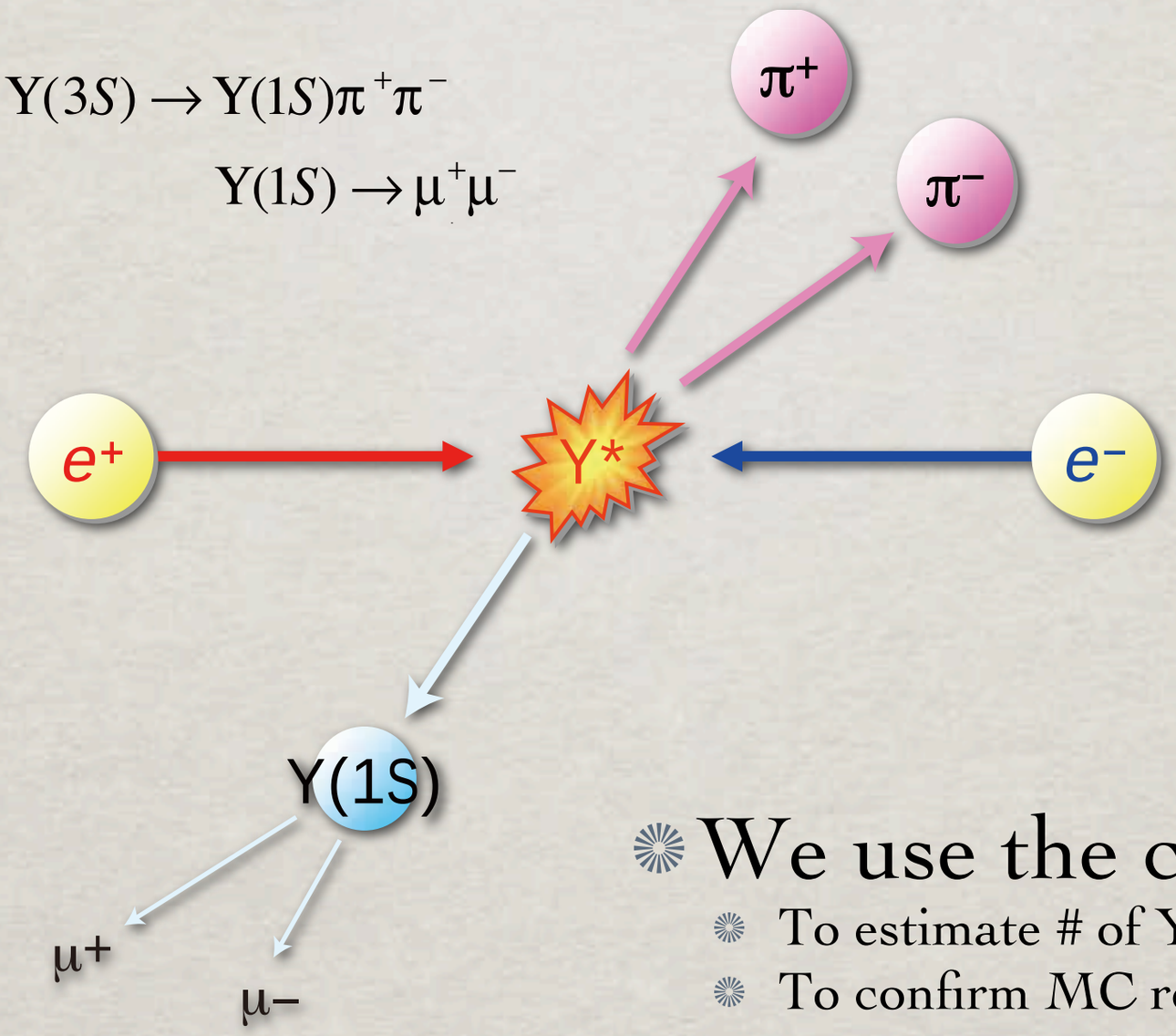
Monitored with pre-scaled (1/500) Pt^H triggered events

yoshihito.iwasaki@kek.jp

Control Sample

$$e^+e^- \to \Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$$

$$\Upsilon(1S) \to \mu^+\mu^-$$



- We use the control sample
  - To estimate # of Y(3S) in our data,
  - To confirm MC reproducibility,
  - To optimize selection criteria,
  - To determine a shape of the recoil mass distribution

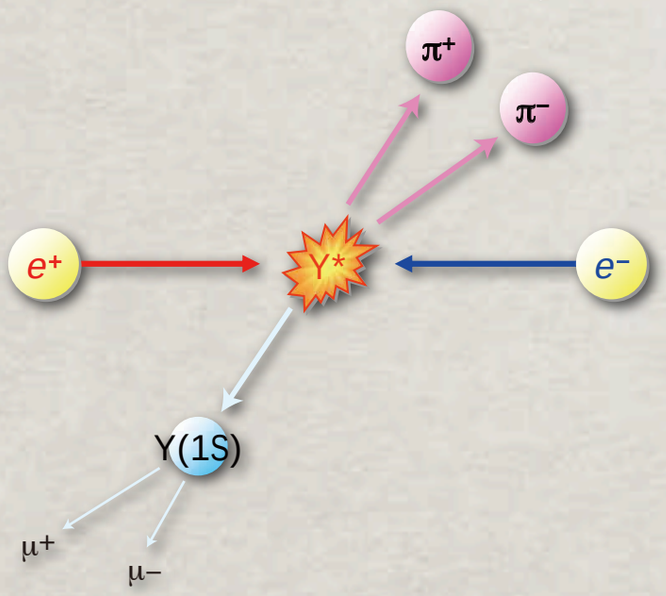
yoshihito.iwasaki@kek.jp

Number of Υ(3S)

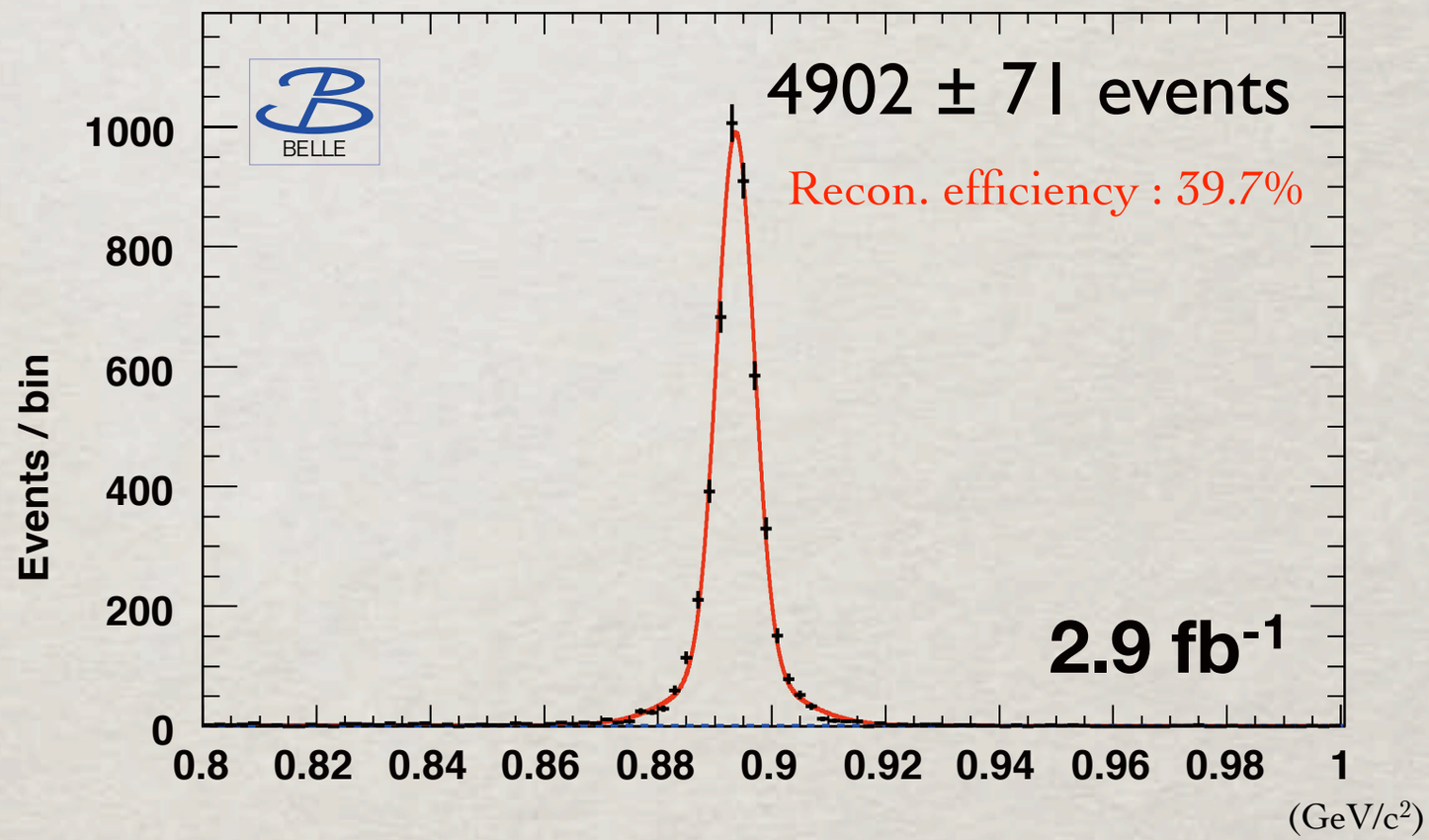
Control sample

$e^+e^- \to \Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$

$\Upsilon(1S) \to \mu^+\mu^-$



Mass difference of Υ(1S)ππ and Υ(1S)



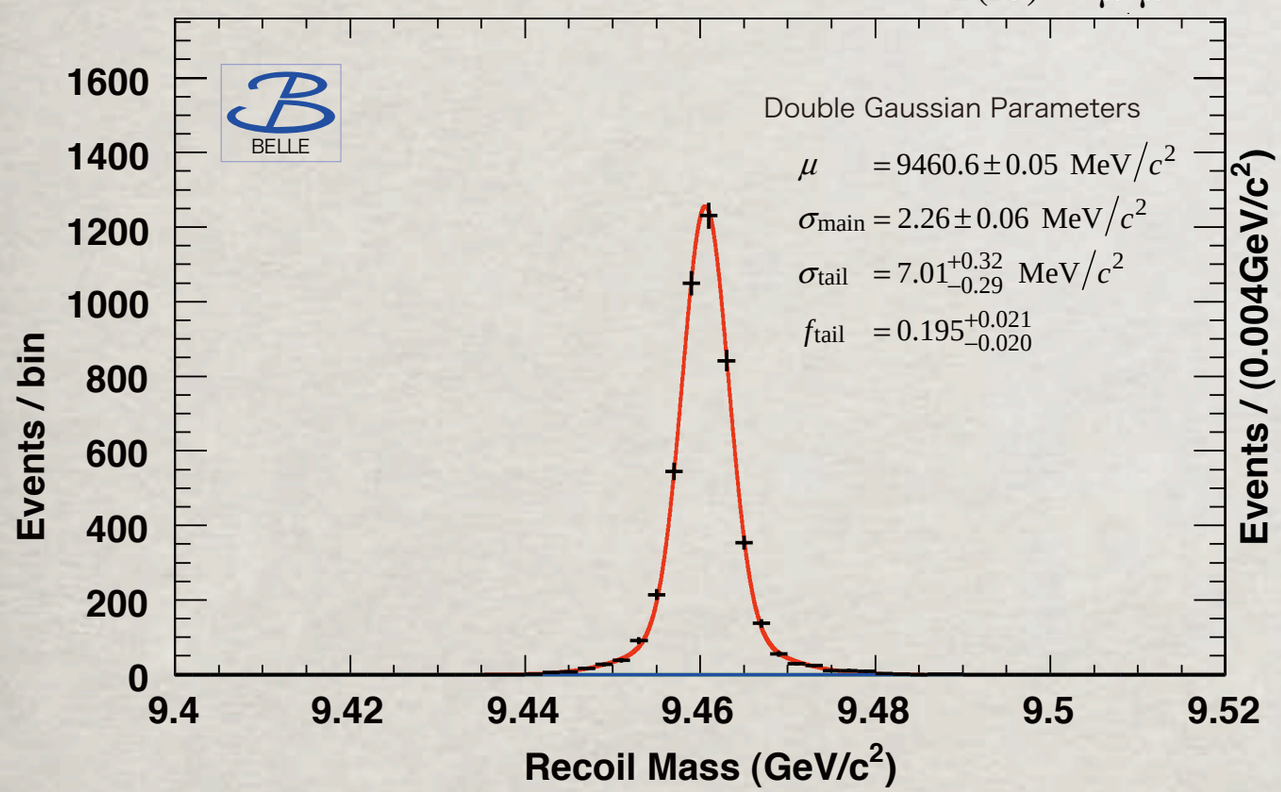
Control sample	$e^+e^- \to \Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$ $\Upsilon(1S) \to \mu^+\mu^-$	4902±71
Υ(3S)	$e^+e^- \to \Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	4.98×10^5
Υ(3S)	$e^+e^- \to \Upsilon(3S)$	11×10^6

yoshihito.iwasaki@kek.jp

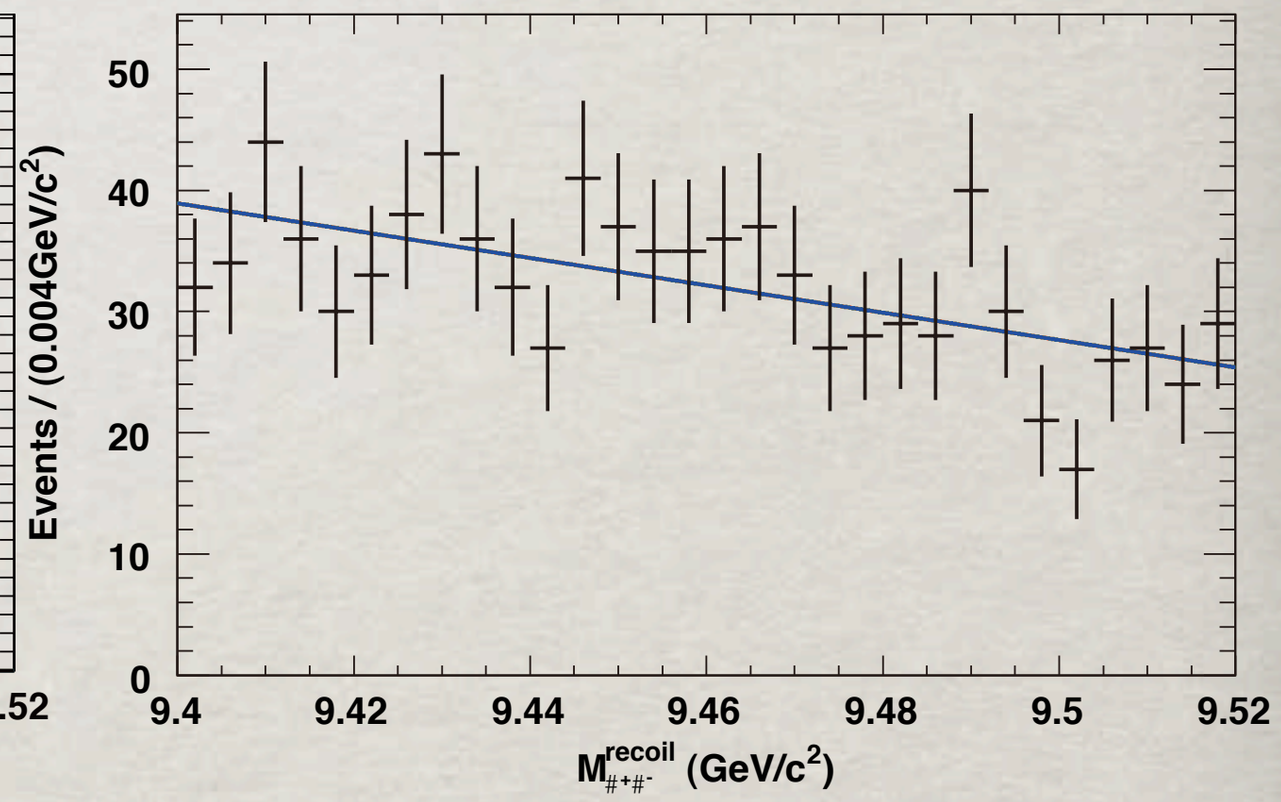
Recoil Mass

Control sample $e^+e^- \to \Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$

$\Upsilon(1S) \to \mu^+\mu^-$



Off-resonance data

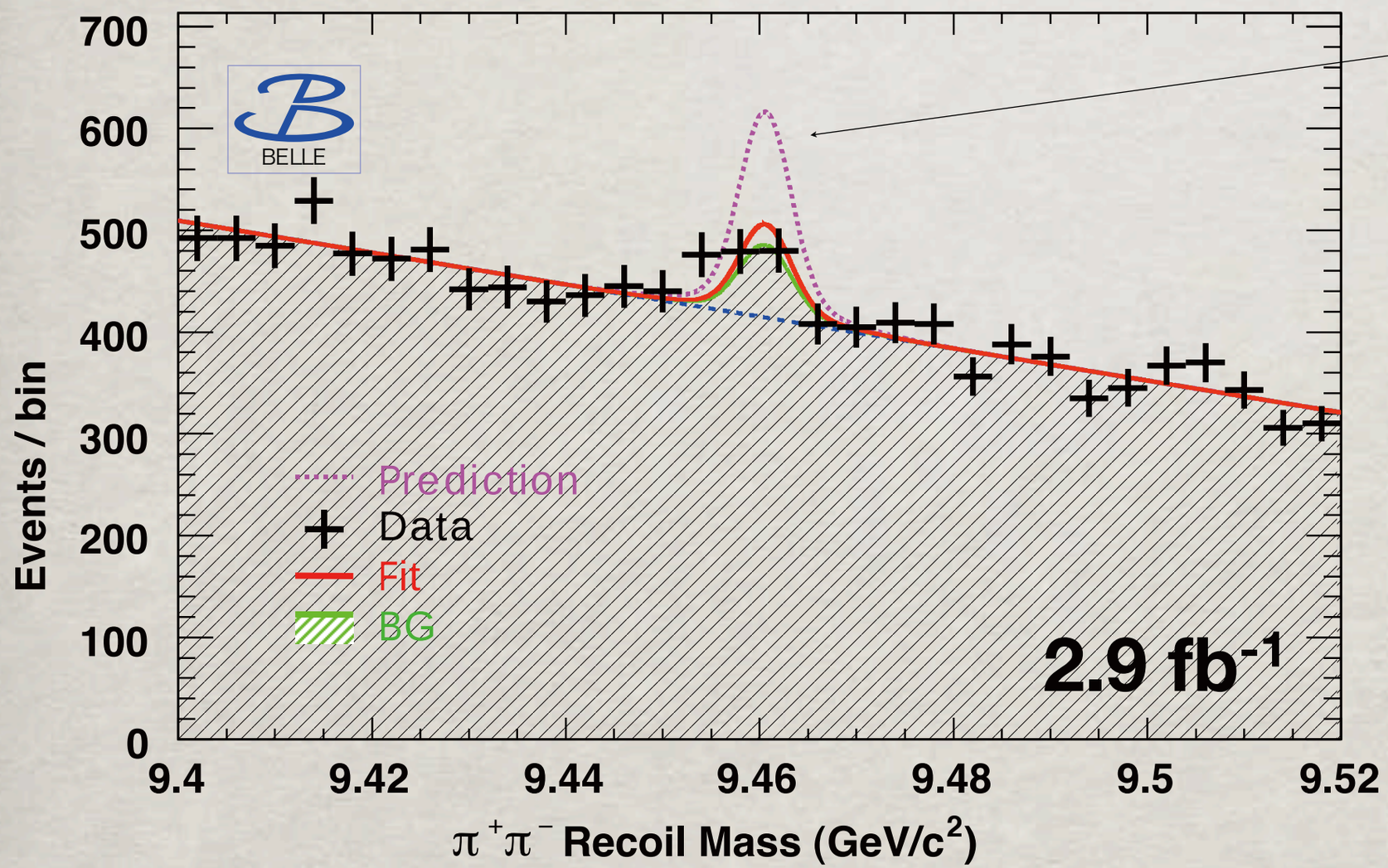


- Signal shape of the recoil mass is determined by the control sample
- Background shape is determined by the off-resonance data

yoshihito.iwasaki@kek.jp

Result

$N_{sig}=38\pm39$



The prediction is disfavoured
$Br(\Upsilon(1S) \to \chi\chi) = 6\times10^{-3}$

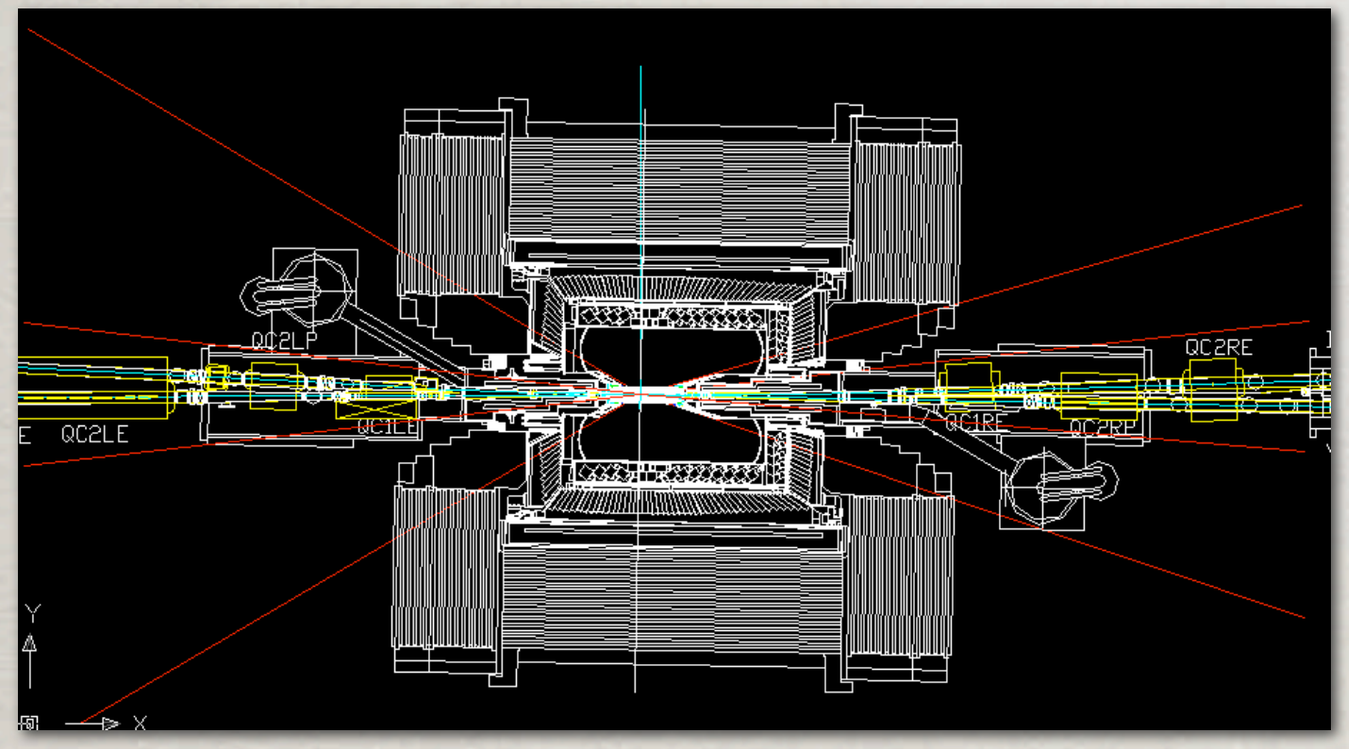
Peaking B.G.

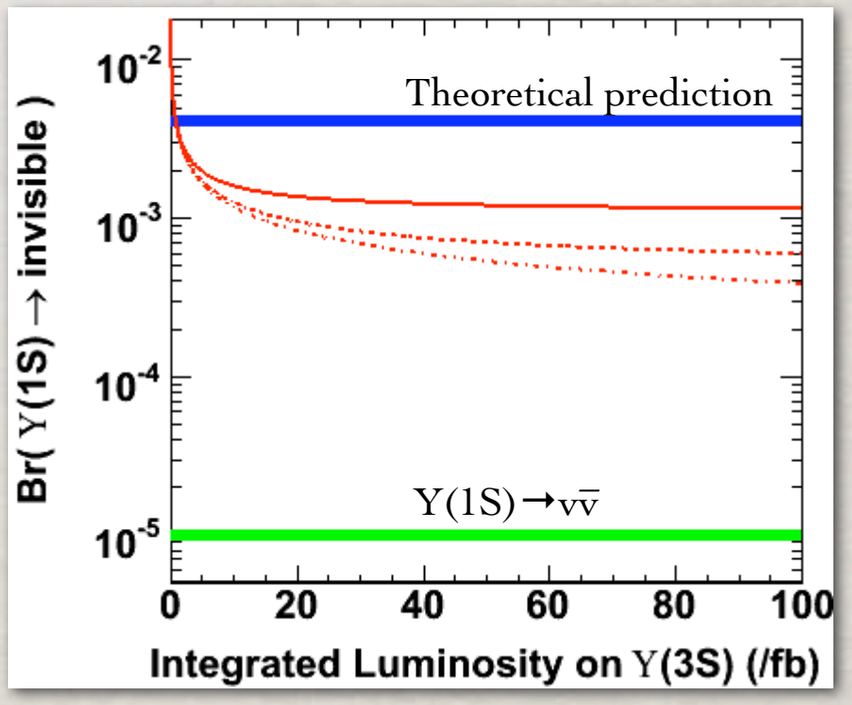
$\Upsilon(1S) \to \mu^+\mu^-$	77.3	±12.0
$\Upsilon(1S) \to e^+e^-$	50.3	±8.0
$\Upsilon(1S) \to \tau^+\tau^-$	5.2	±1.0
$\Upsilon(1S) \to \nu\bar{\nu}$	0.4	±0.1
$\Upsilon(1S) \to$ other modes	0.0	$+2.8$
Others	0.0	$+12.9$
Total	133.2	$^{+19.7}_{-14.6}$

$$Br(\Upsilon(1S) \to invisible) < 2.5\times10^{-3} \quad (90\%\text{C.L.})$$

yoshihito.iwasaki@kek.jp

Prospects





- By increasing Y(3S) data, we can reach to $\sim 1\times10^{-3}$
  - Sensitivity saturated because of the peaking backgrounds
- To get higher sensitivity, we have to veto $Y(1S)\to l^+l^-$
  - With forward-backward μ veto detector, 6×10^{-4}
  - With forward-backward calorimeter, 4×10^{-4}

yoshihito.iwasaki@kek.jp

Summary

- We see no evidence for Dark Matter in Y(1S) decays
  - We took special runs on Y(3S) for this study with looser trigger condition
  - We found 0 consistent result in 11M Y(3S) decays
  - We set the upper limit in Y(1S) decay

$$Br(\Upsilon(1S) \rightarrow invisible) < 2.5 \times 10^{-3} \quad (90\%\text{C.L.})$$

- To get a sensitivity of 4×10^{-4}, we need
  - 100fb^{-1} of Y(3S) data,
  - more hermeticity to veto Y(1S)->l^+l^- background

yoshihito.iwasaki@kek.jp

Back-up

yoshihito.iwasaki@kek.jp

Selection Criteria

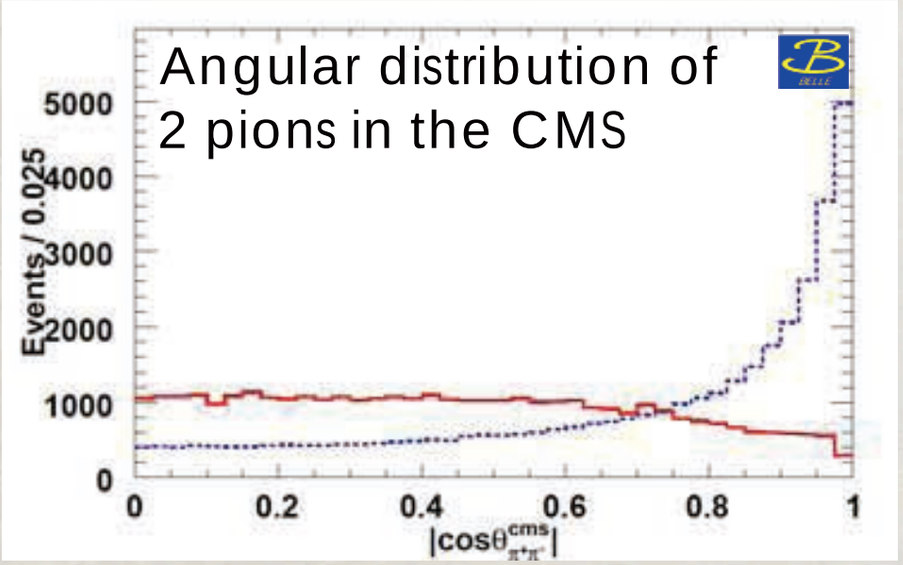
- Event selection criteria
  - 2 charged tracks in the event.
  - Total energy deposit in the calorimeter < 3 GeV.
  - No π^0 candidates in the event; no 2 γ pair with E_γ>20MeV that forms π^0 mass within 16 MeV/c^2.
- Pion selection criteria
  - Track's polar angle within the detector acceptance.
  - Track is close to interaction point (|dr|<1cm, |dz|<3cm).
  - Not positively identified as one of $e/\mu/K$.
  - Not forms K_S^0 mass.
- Background suppression
  - See the next slide.

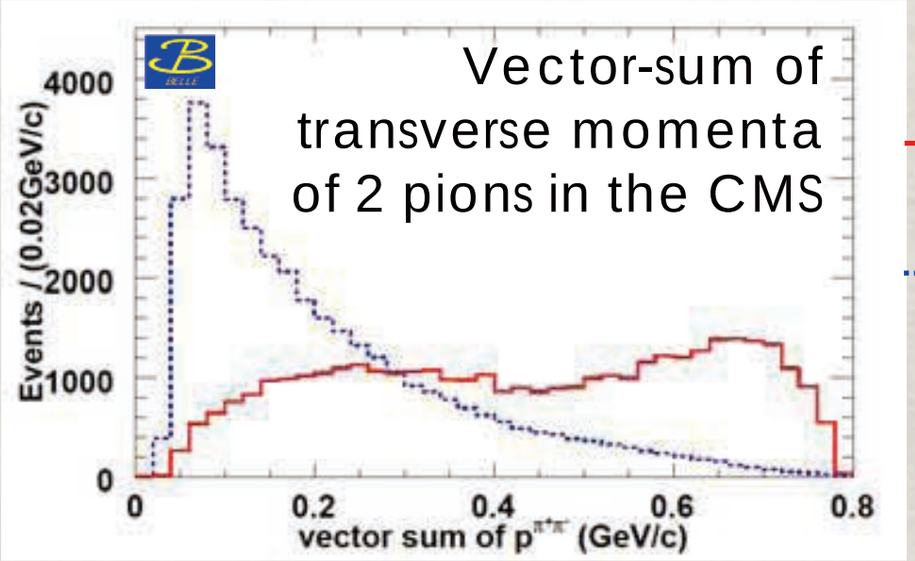
$\mathrm{eff}^{MC} = 9.16 \pm 0.01\%$ w/o trigger efficiency

yoshihito.iwasaki@kek.jp

Backgrounds

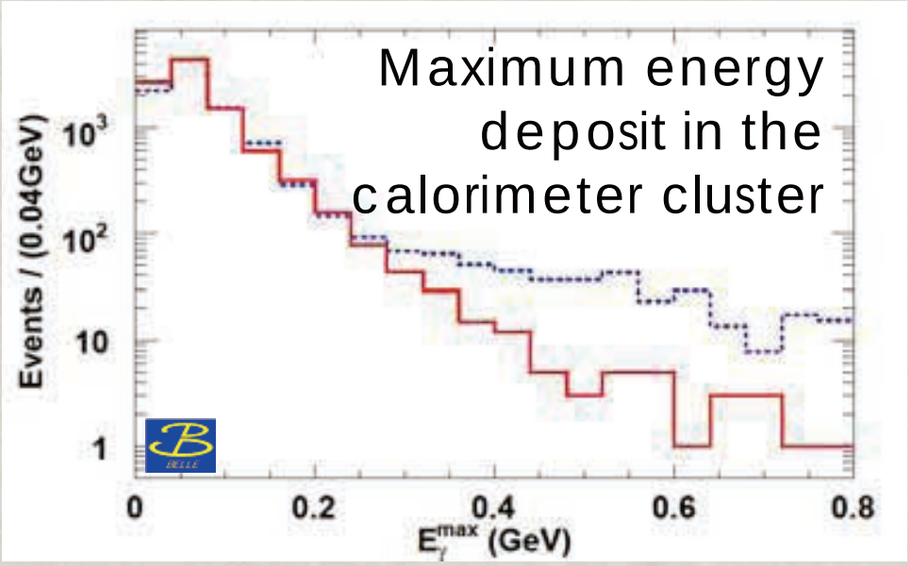
~ Suppression of 2 photon process ~



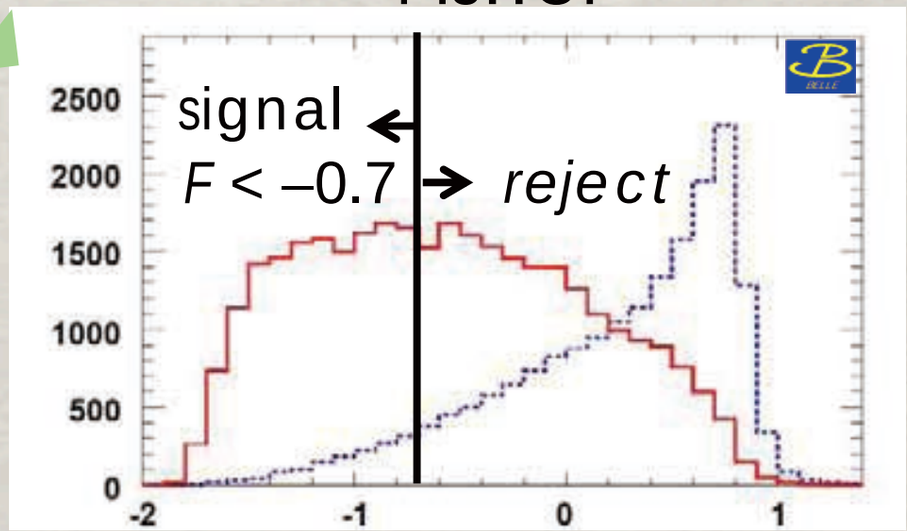


signal

BG

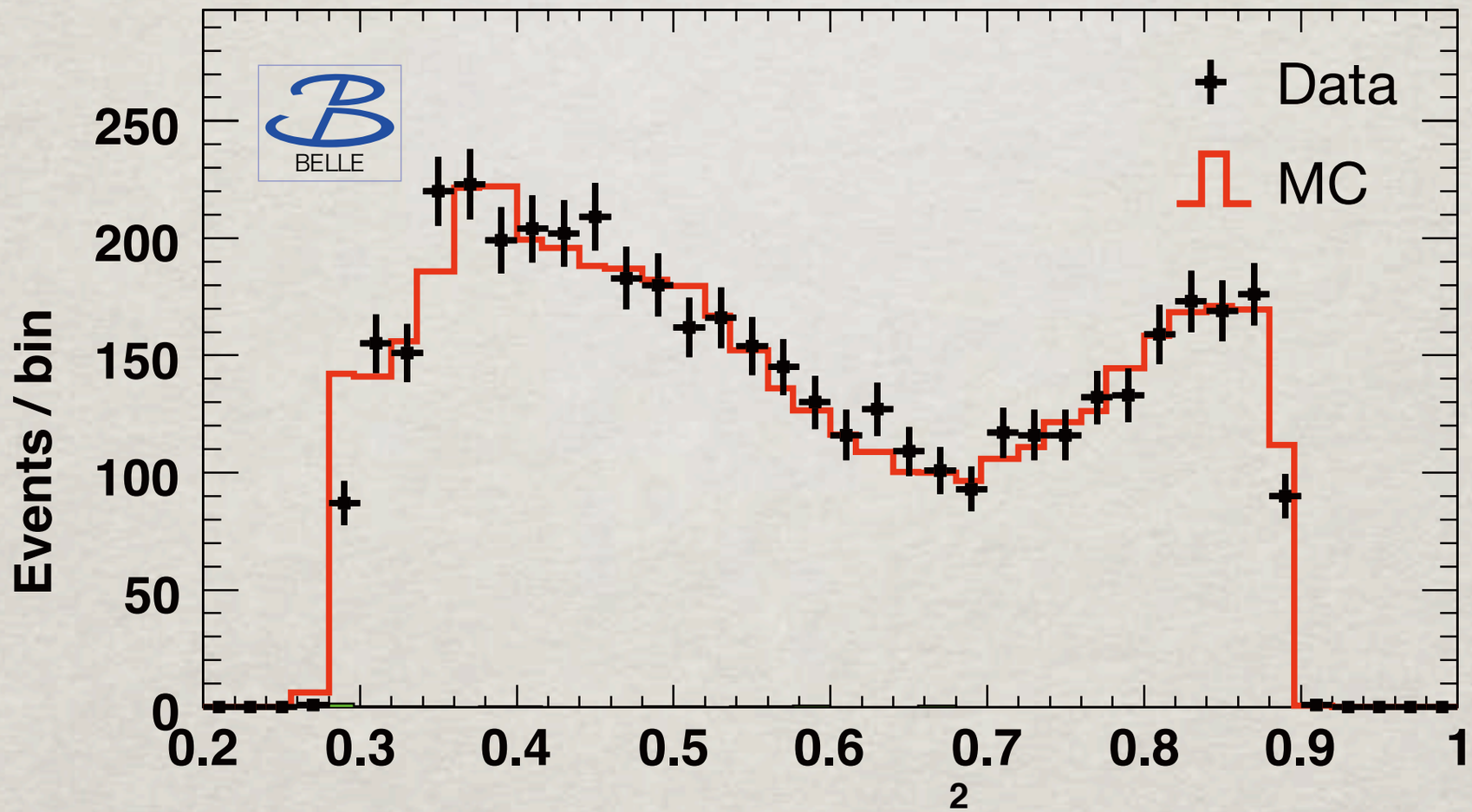


Fisher



yoshihito.iwasaki@kek.jp

MC Reproducibility



- Mass spectrum of the two pions is reproduced in MC very well

yoshihito.iwasaki@kek.jp