Prospects for Dark Sector Particle Searches with Υ(nS) Data

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Belle Collaboration

Dark Forces '09

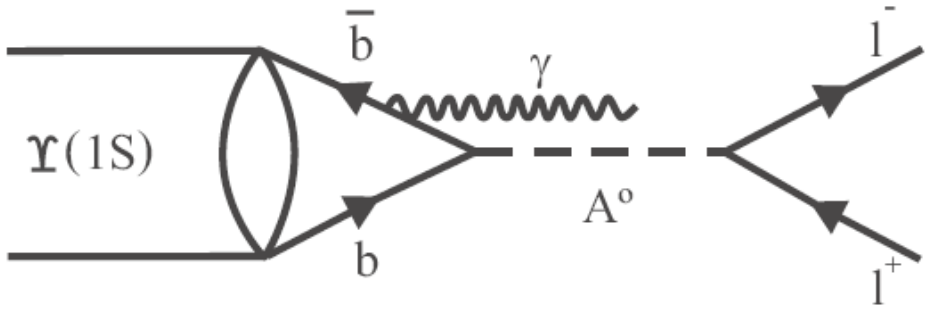
Introduction

Due to the extremely weak interaction with standard model particles, detection of "dark sector" particles will require detectors with high luminosity, good hermeticity, and low background. In this respect B factories have a vital role to play in dark sector searches of the form

$$X \rightarrow Y + b(b \rightarrow \ell^+ \ell^-)$$

This presentation will discuss the status of a search at Belle related to dark sector studies, the search for the CP odd light Higgs, A^0.

Introduction



Decays of the ϒ(1S) that follow this scheme should produce mono-energetic photons whose energy is determined by the mass of the CP-odd light Higgs, A^0. The A^0 will decay to two leptons; the mass dependant coupling makes the preferred pair a $\tau^+\tau^-$ if $M_{A^0} > 2M_\tau$.

With this limit in mind we search for a light Higgs with mass between ~7.5 GeV and ~9.4 GeV by looking for events with a mono-energetic photon and evidence of $\tau^+\tau^-$ decays.

Introduction

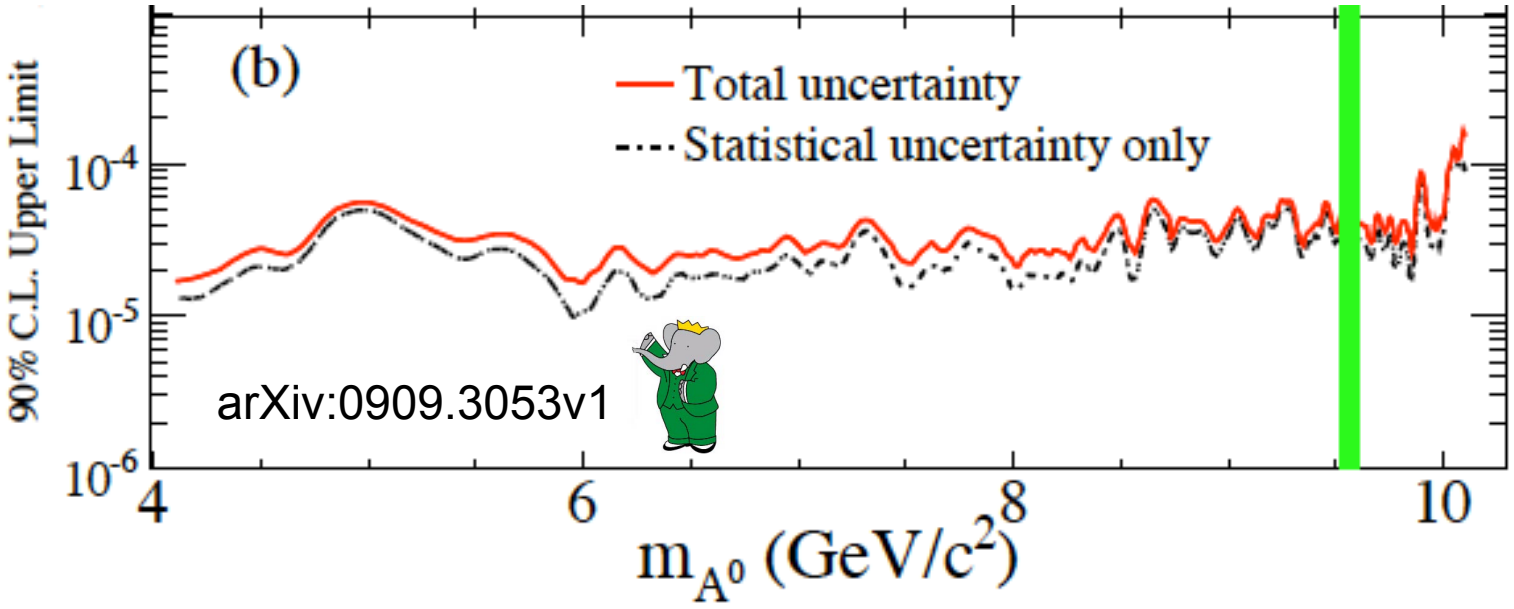
- This study can also be done with a $\Upsilon(2S)$ cascade decay.
  - A large portion, ~30% , of $\Upsilon(2S)$ decay via $\Upsilon(2S)$ goes to $\Upsilon(1S) + \pi\pi$
  - The $\pi\pi$ tag can be used to isolate a clean sample

Event Selection Criteria

		Comments
$\Upsilon(1S) \rightarrow \gamma + A^0$	10^{-4} - 10^{-5}	Mono-energetic photon*
$A^0 \rightarrow \tau^+ + \tau^-$	10^{-1}	Preference to $\tau^+ \tau^-$*
$A^0 \rightarrow e^+ e^-$ $A^0 \rightarrow \mu^+ \mu^-$	$<<10^{-1}$	A^0 mass >7.5GeV
$\tau^\pm \rightarrow \nu_e + \nu_\tau + e^\pm$	17.85%	Look for 2 charged tracks with 1 "e" and 1 "μ" event with balanced charge
$\tau^\pm \rightarrow \nu_\mu + \nu_\tau + \mu^\pm$	17.36%	

*see CLEO 0807.1427v1

Other Experiments



- Studies at BaBar have given a limit for

$$\Upsilon(3S) \rightarrow \gamma + A^0; A^0 \rightarrow \tau^+\tau^-$$

of 1.5x10^{-5} (pictured above)

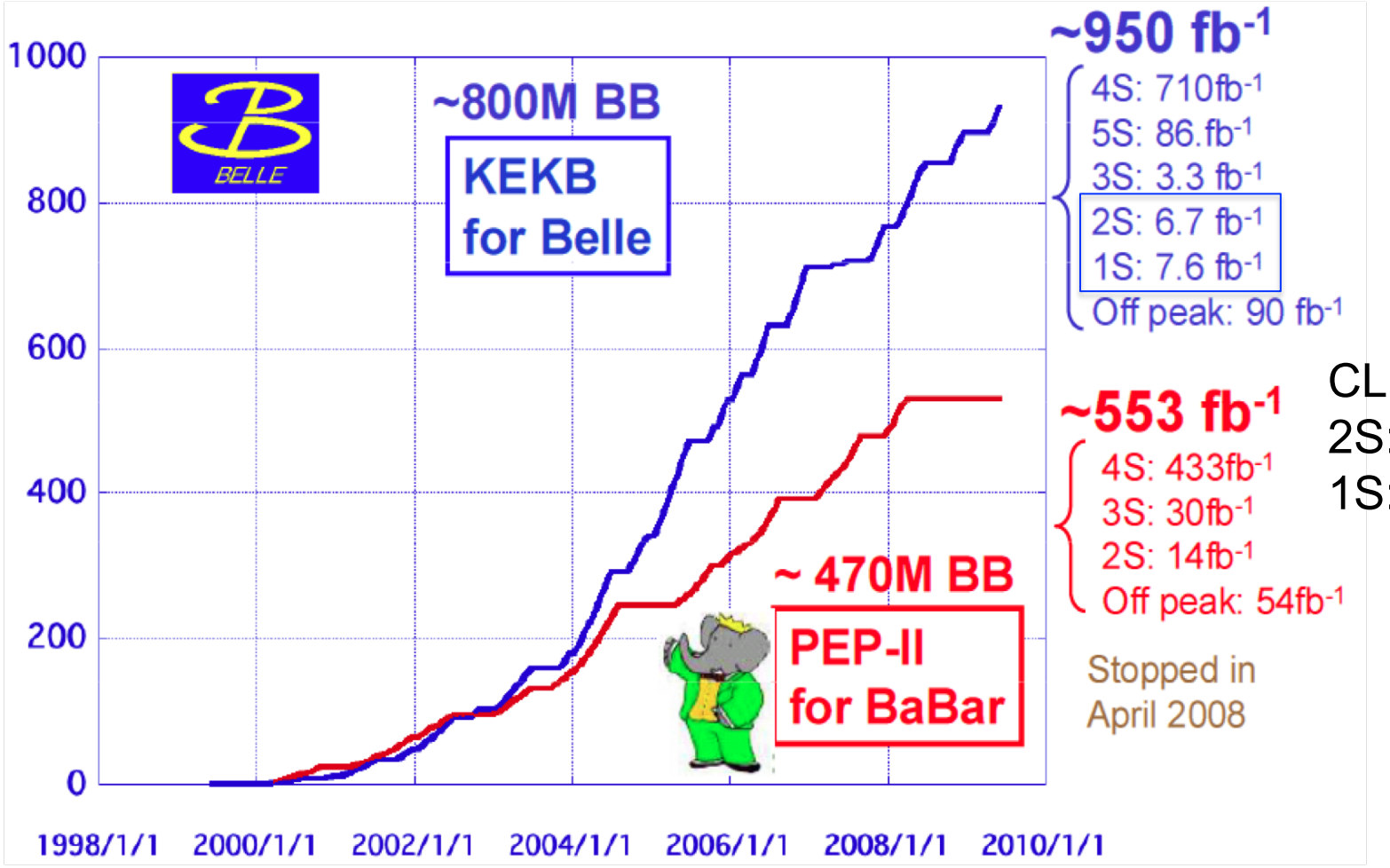
- A recent search at CLEO put the branching ratio of

$$\Upsilon(1S) \rightarrow \gamma + A^0; A^0 \rightarrow \tau^+\tau^-$$

on the order of 10^{-5} in this region.

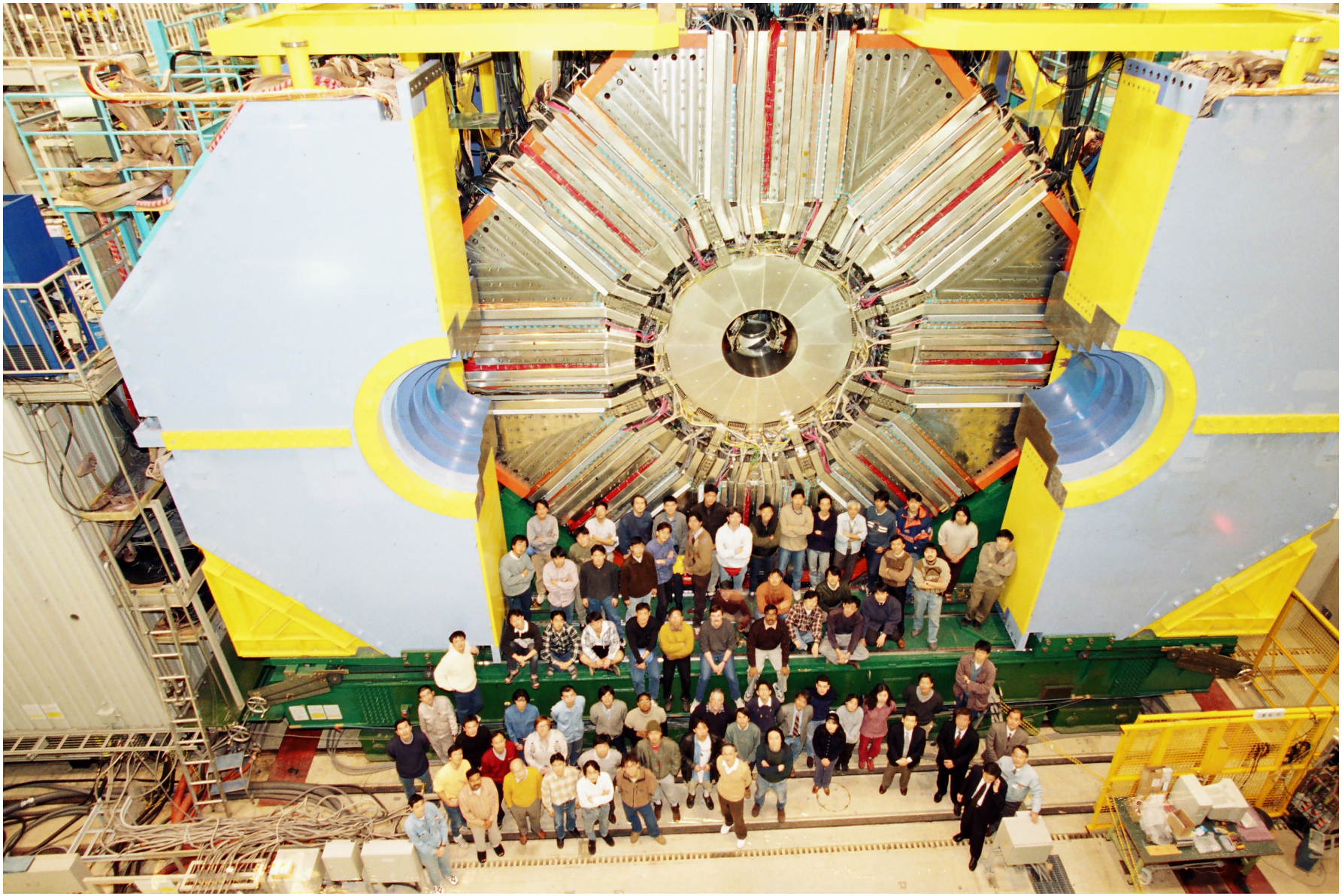
KEK campus in Tsukuba, Japan

KEKB



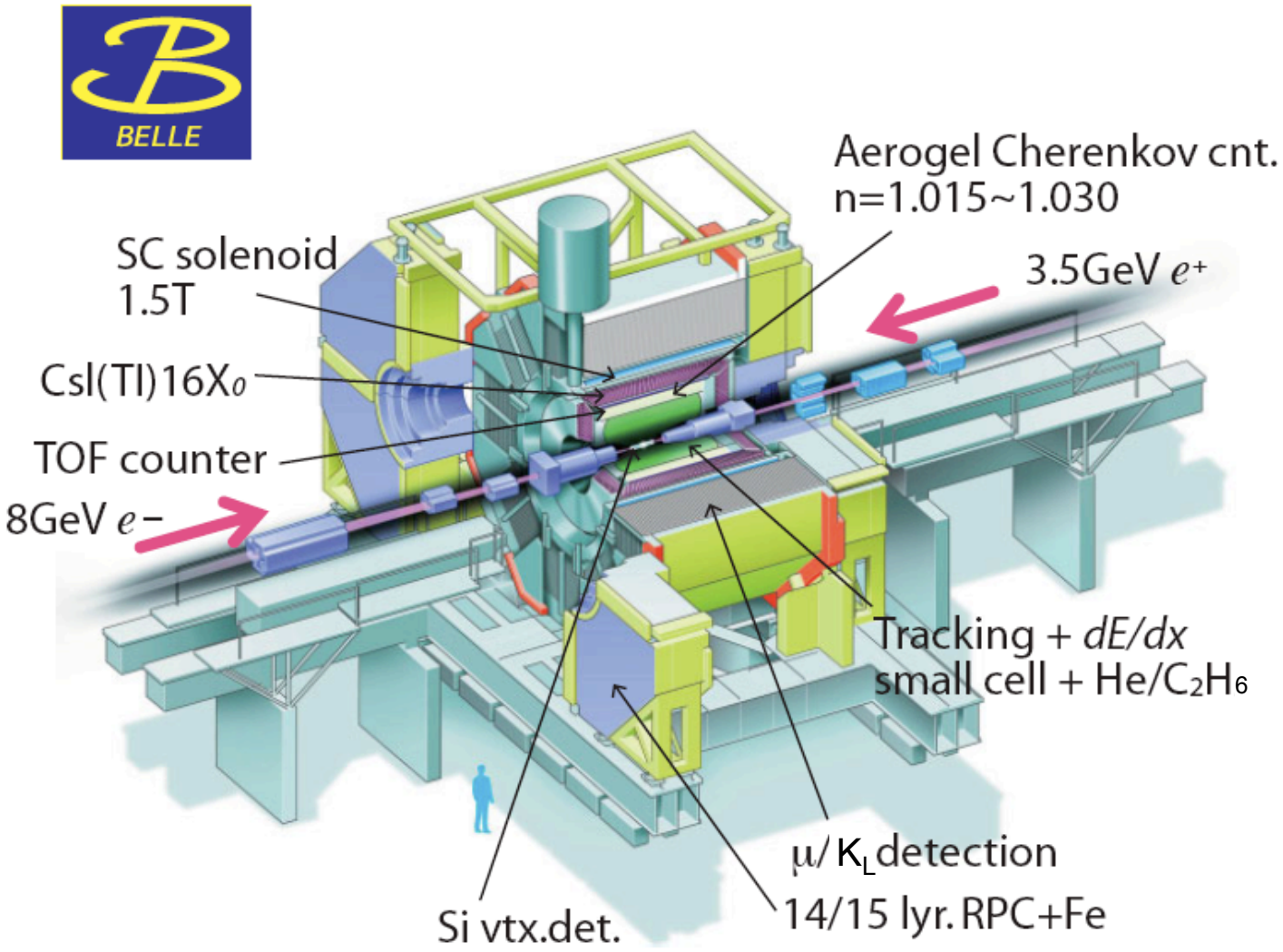
CLEO
2S: 1.2 fb^{-1}
1S: 1.1 fb^{-1}

…and a peak luminosity @ KEK of $21.1 \times 10^{34} cm^{-2} s^{-1}$!



The Belle Detector

Belle


BELLE
Aerogel Cherenkov cnt.
n=1.015~1.030
SC solenoid
1.5T
3.5GeV e^+
CsI(Tl)16X_0
TOF counter
8GeV e^-
Tracking + dE/dx
small cell + He/C_2H_6
μ/K_L detection
14/15 lyr. RPC+Fe
Si vtx.det.

Monte Carlo

Interactions of interest are simulated using EvtGen.

- Multiple light Higgs with masses between 7.5 GeV and 9.3 GeV were simulated
- All were assumed to have narrow widths (10^{-5} GeV) and prompt decays.

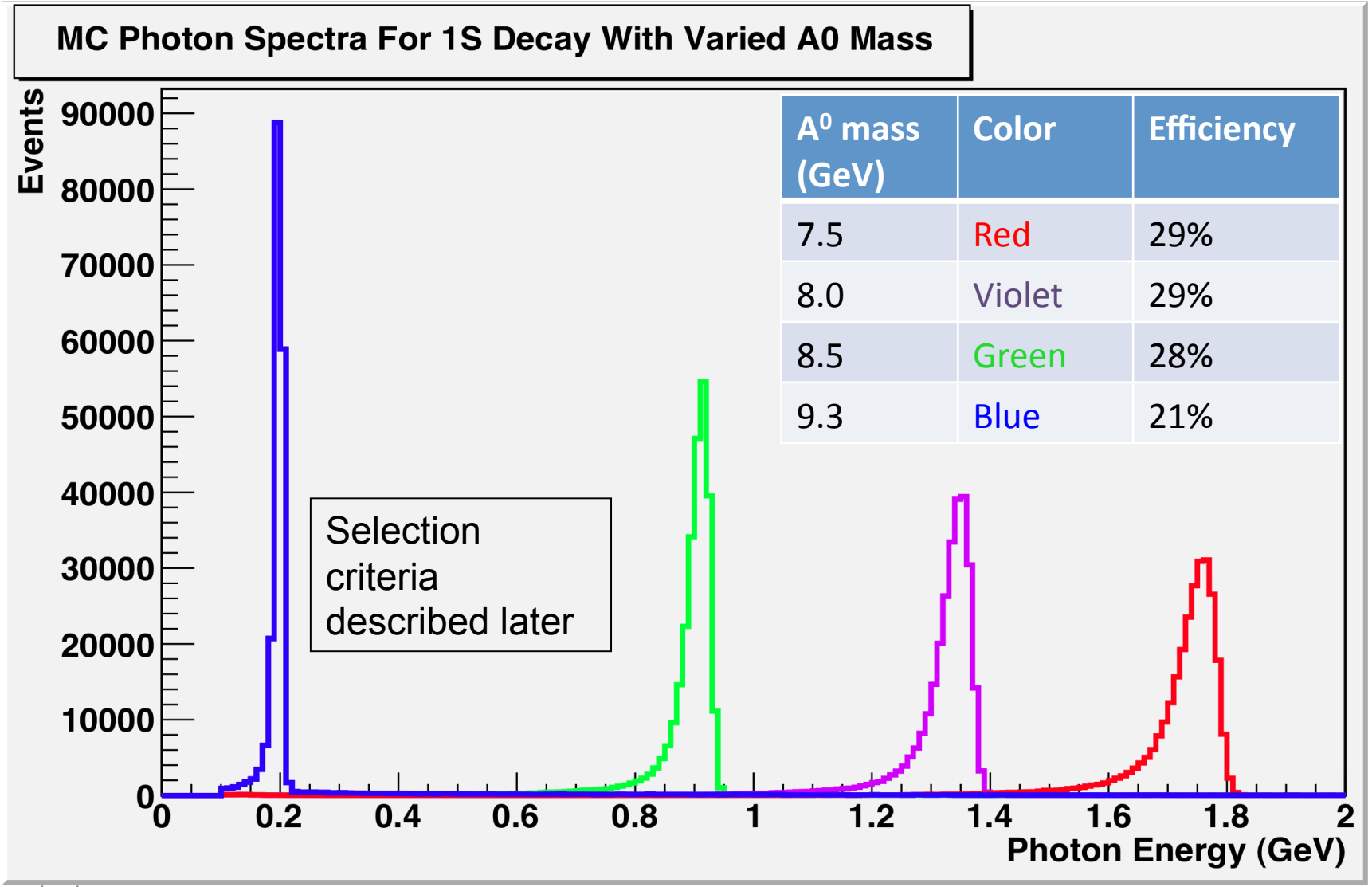
Detector response was simulated with a Geant3-based program

- Detector geometry, trigger efficiency
- Backgrounds added. Sourced from random triggers during real data taking, overlaid on MC.

Monte Carlo

- Signal Monte Carlo: multiple masses for A^0 in decay mode $\Upsilon(1S) \rightarrow \gamma + A^0$; $A^0 \rightarrow \tau^+ + \tau^-$ with $\tau^\pm \rightarrow \nu_e + \nu_\tau + e^\pm$ and $\tau^\mp \rightarrow \nu_\mu + \nu_\tau + \mu^\mp$
  - Sample size: 10^6 events from EvtGen
  - Packages used: PHOTOS, PHSP, TAULNUNU
  - Beam energy: 60 MeV below Υ(1S) resonance
- Plot
  - 10 MeV per bin
  - Simulated for 4 separate A^0 masses: 7.5 GeV, 8.0 GeV, 8.5 GeV, and 9.3 GeV

Monte Carlo



A^0 mass (GeV)	Color	Efficiency
7.5	Red	29%
8.0	Violet	29%
8.5	Green	28%
9.3	Blue	21%

Data: $\Upsilon(1S)$

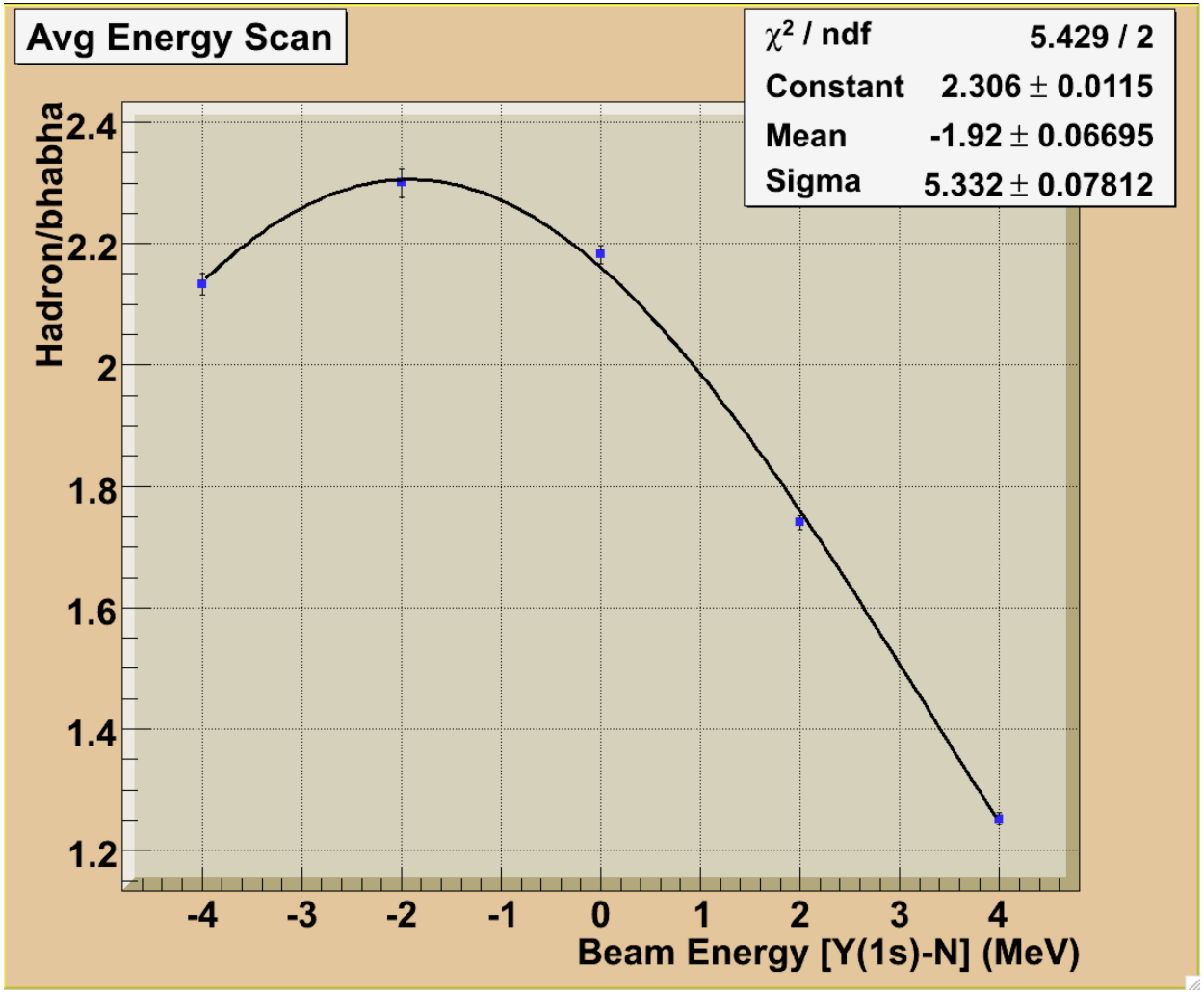
- In summer 2008 an $\Upsilon(1S)$ run was taken at Belle
  - 7.6 fb^{-1} data collected.
    - 5.8 fb^{-1} on-resonance
    - 1.8 fb^{-1} off-resonance (60 MeV below peak)
  - 88.4 million $\Upsilon(1s)$ recorded

$$N_{\Upsilon(1S)} = \frac{1}{\Gamma_{\Upsilon(1S)\to\mu^-\mu^+}} \frac{(N_{\mu\mu} C_{\mu\mu}^{excess})}{\epsilon_{\mu\mu}}$$

Nμμ – total # of $\mu^+\mu^-$, $\epsilon_{\mu\mu}$ – $\mu^+\mu^-$ detection efficiency

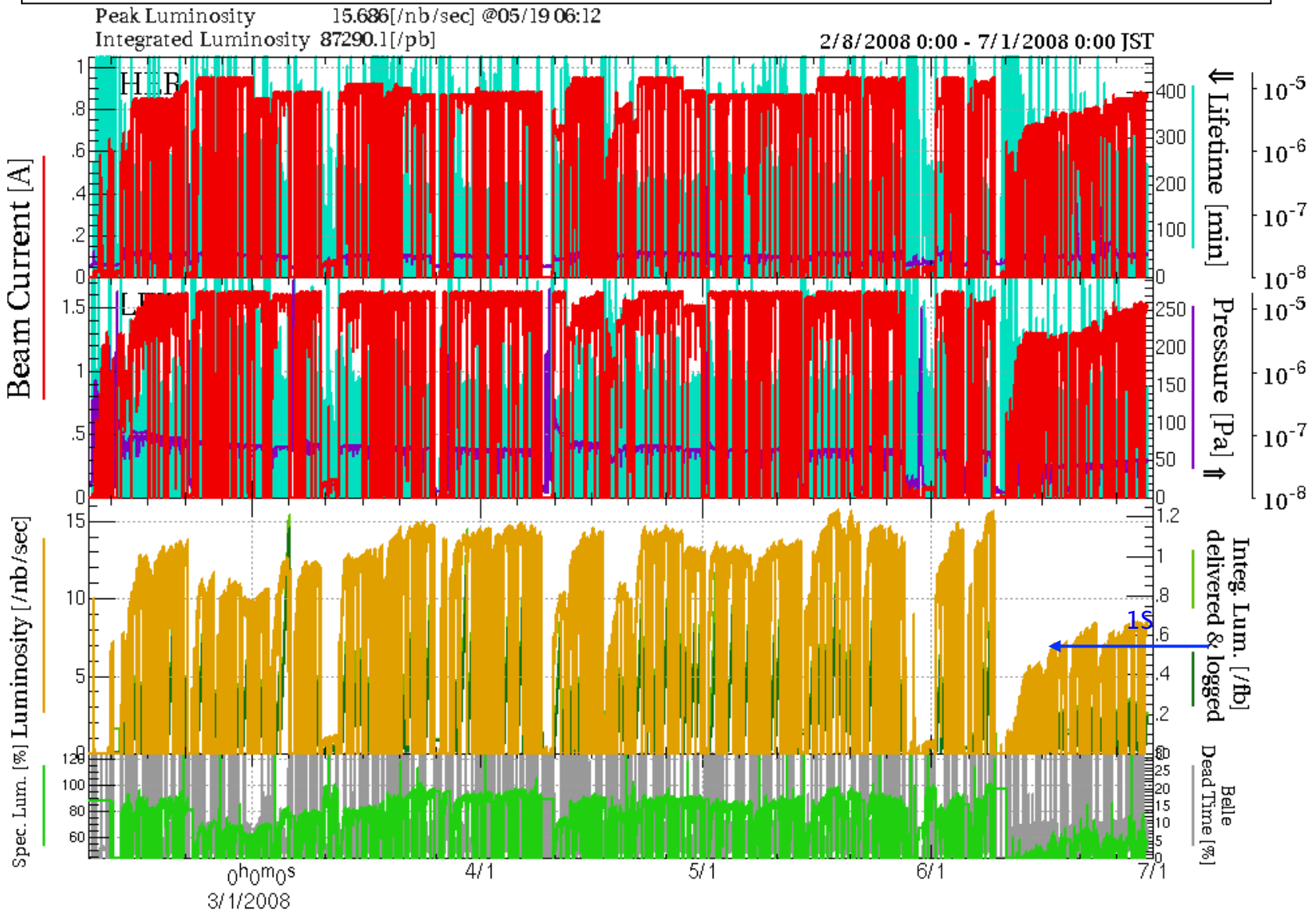
$C_{\mu\mu}^{excess}$ - scaled ratio of difference between on-resonance and off-resonance $\mu^+\mu^-$ to $\mu^+\mu^-$ on-resonance, $\sim \frac{5}{17}$

Energy Scan Around the $\Upsilon(1S)$ Peak

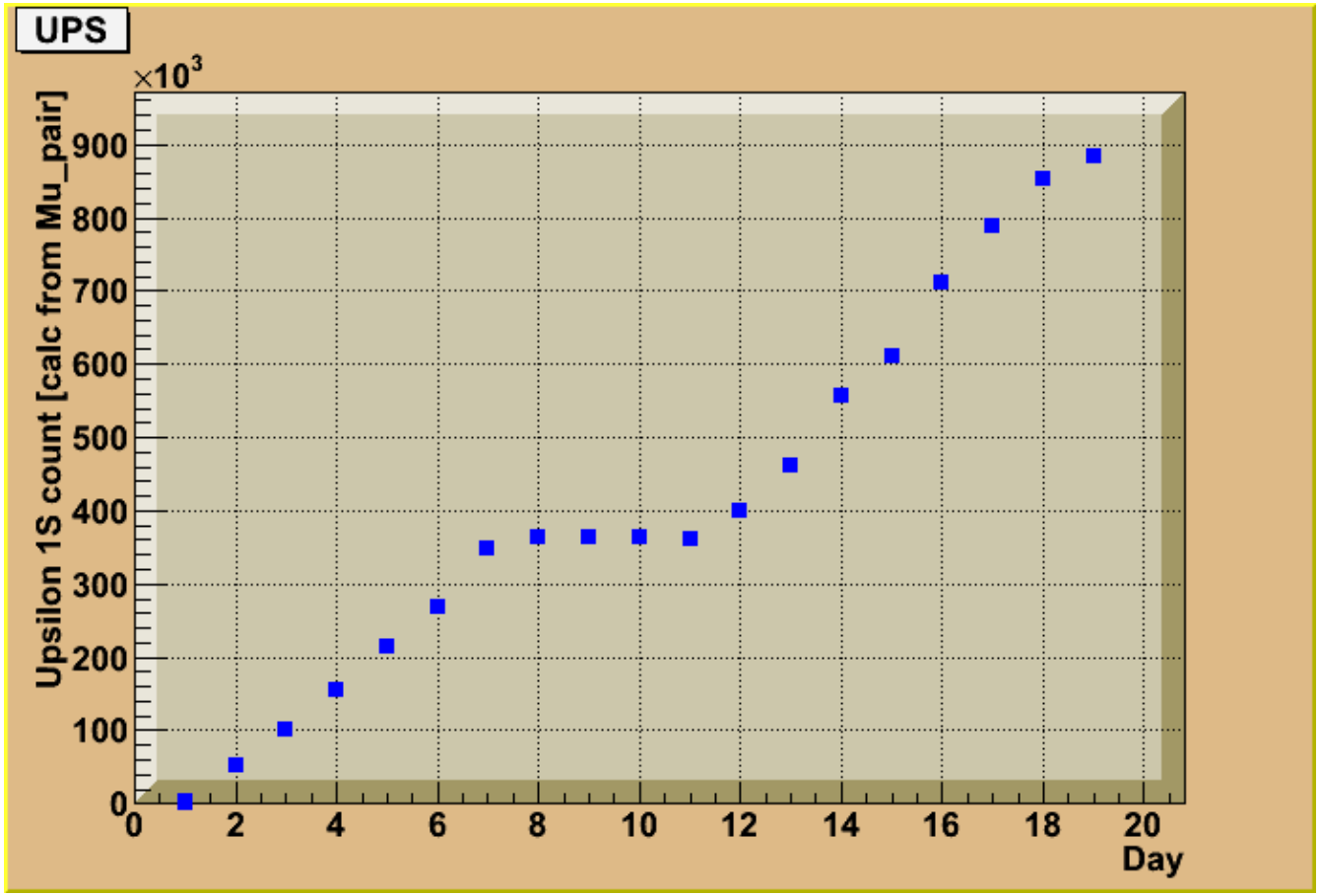


Fine peak scan at the start of the summer 2008 $\Upsilon(1S)$ run. Gaussian fit.

2008 Feb. – June Running

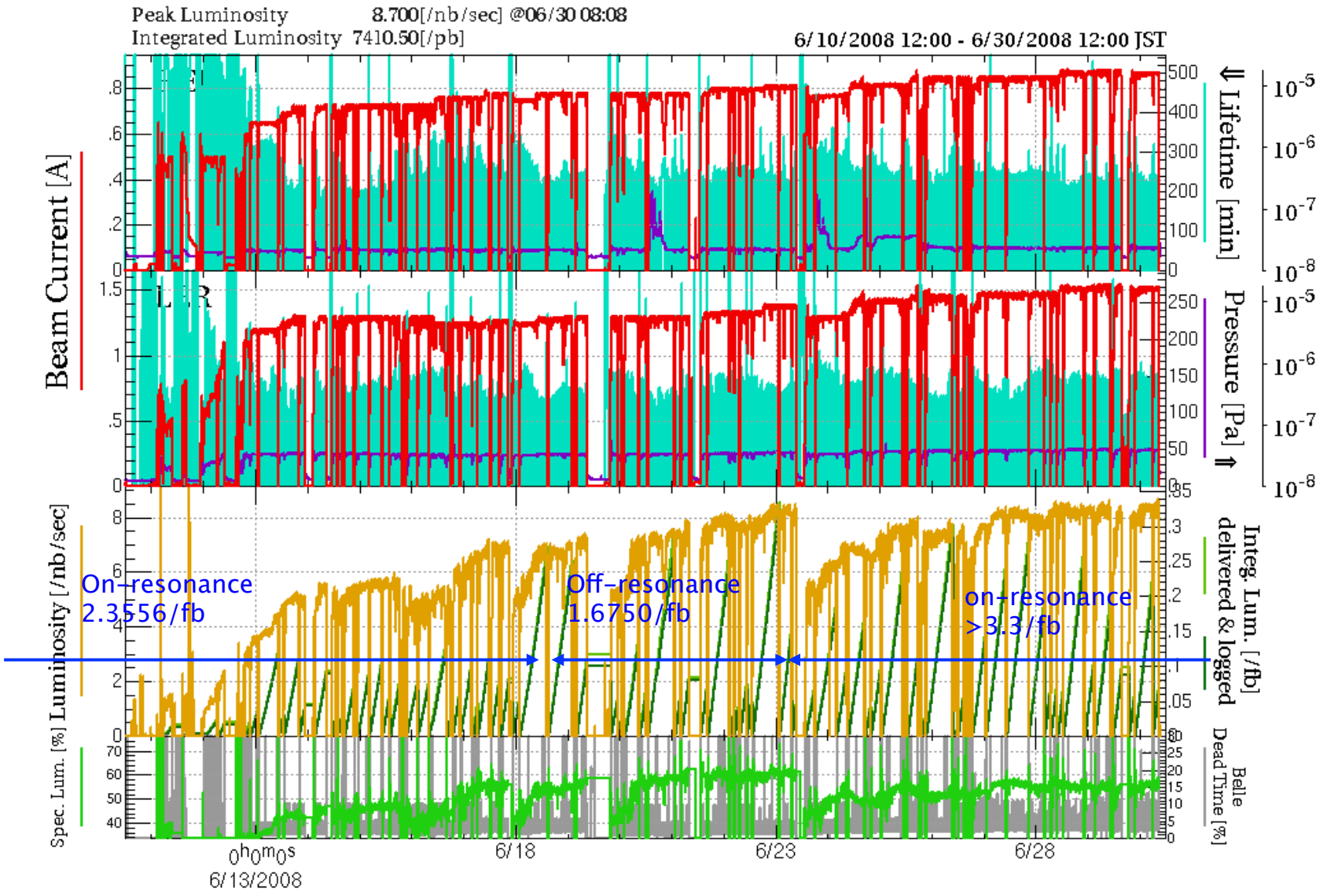


Data: $\Upsilon(1S)$



The 1S run lasted for 20 days after the initial energy scans: two periods of on-resonance data taking broken up by off-resonance data taking.

1S Running


Peak Luminosity 8.700[/nb/sec] @06/30 08:08
Integrated Luminosity 7410.50[/pb]
6/10/2008 12:00 - 6/30/2008 12:00 JST
Beam Current [A]
Lifetime [min]
Pressure [Pa]
Luminosity [/nb/sec]
Integ. Lum. [/fb]
delivered & logged
Spec. Lum. [%]
Belle Dead Time [%]
On-resonance
2.3556/fb
Off-resonance
1.6750/fb
on-resonance
>3.3/fb
0h0m0s
6/13/2008
6/18
6/23
6/28

Analysis Techniques

- Two photon spectrum analysis techniques are being used:
  - Select events that have $e^{\pm}\mu^{\mp}\gamma$. This should allow us to greatly reduce contributions from QED background
  - Explicitly reconstruct $\tau^+\tau^-$ pairs using previous Belle criteria and use events with a $\tau^+\tau^-$ as the sample.

Analysis Techniques

Loose data skim on the full data set to get a manageable sample to start with:

Low Multiplicity Skim Criteria	
Sum of track momentum	<6 GeV
Sum of ECL energy	<6 GeV
# of charged tracks, N	$2 \leq N \leq 4$
Sum of charge	0

Analysis Techniques

With the smaller sample taken from the full data set, one can start making cuts to look for $\Upsilon(1S) \rightarrow \gamma + (A^0 \rightarrow \tau^+\tau^-)$:

	Belle
Photon Selection	Most energetic photon is found in the barrel. >50 MeV cut on barrel photons.
Event Cut	2 charge tracks. 1 or more photons.
Lepton Cut	No e- e+ events allowed 1) At least one e or one μ (CLEO) 2) One e and one μ

Analysis Techniques

	CLEO	Belle
Pi0 Veto	Most energy barrel photon is combined with other photons (barrel and endcap); must not be within 3σ of π^0 mass. >50 MeV cut on endcap photons	
Missing Energy	2-7 GeV missing in calorimeter and charged tracks	
Angle Cut	$\mathrm{Cos}(\theta_{track}) < 0.99$	

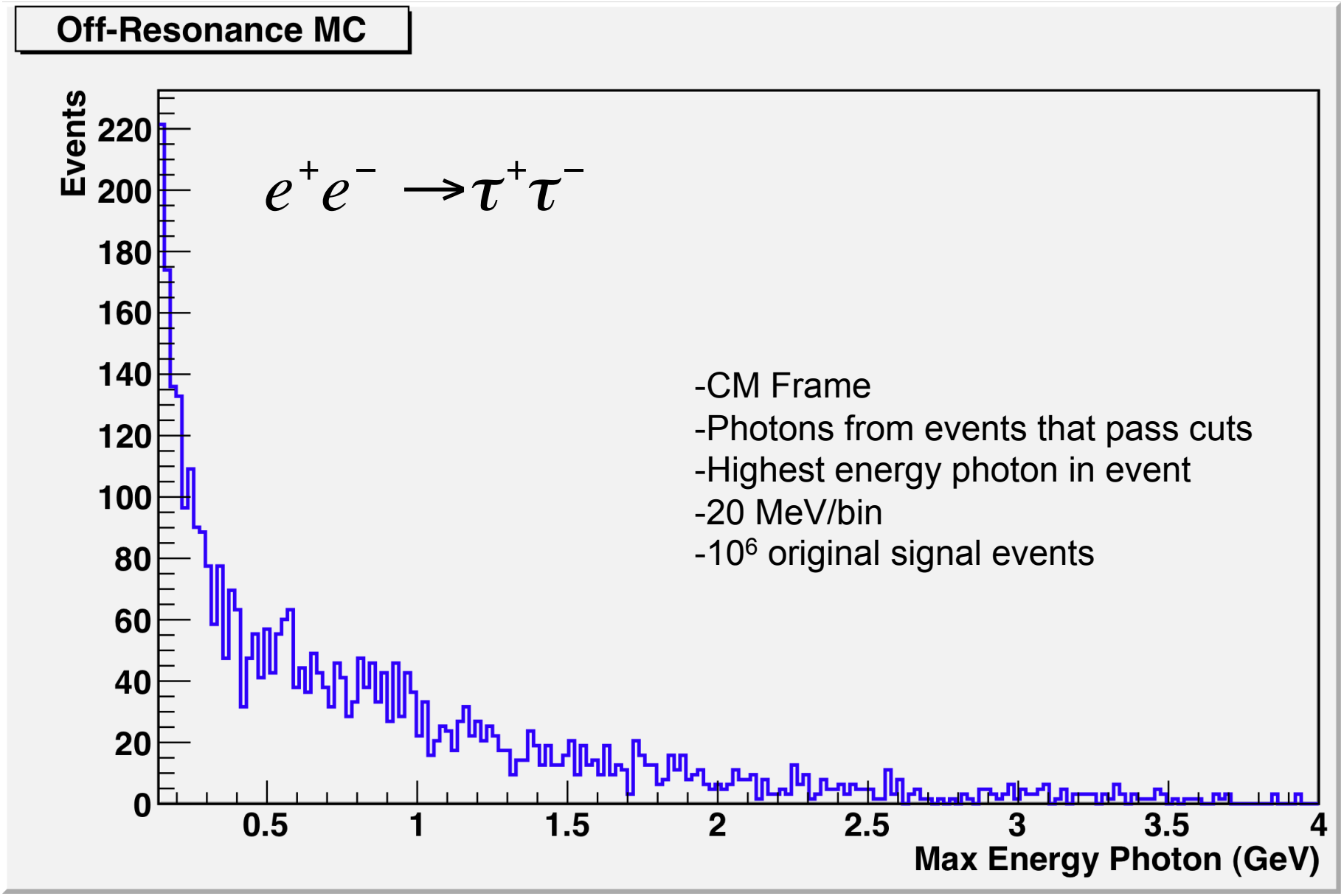
Θ_{track} = angle between photon momentum vector and charged particle momentum vector

Backgrounds

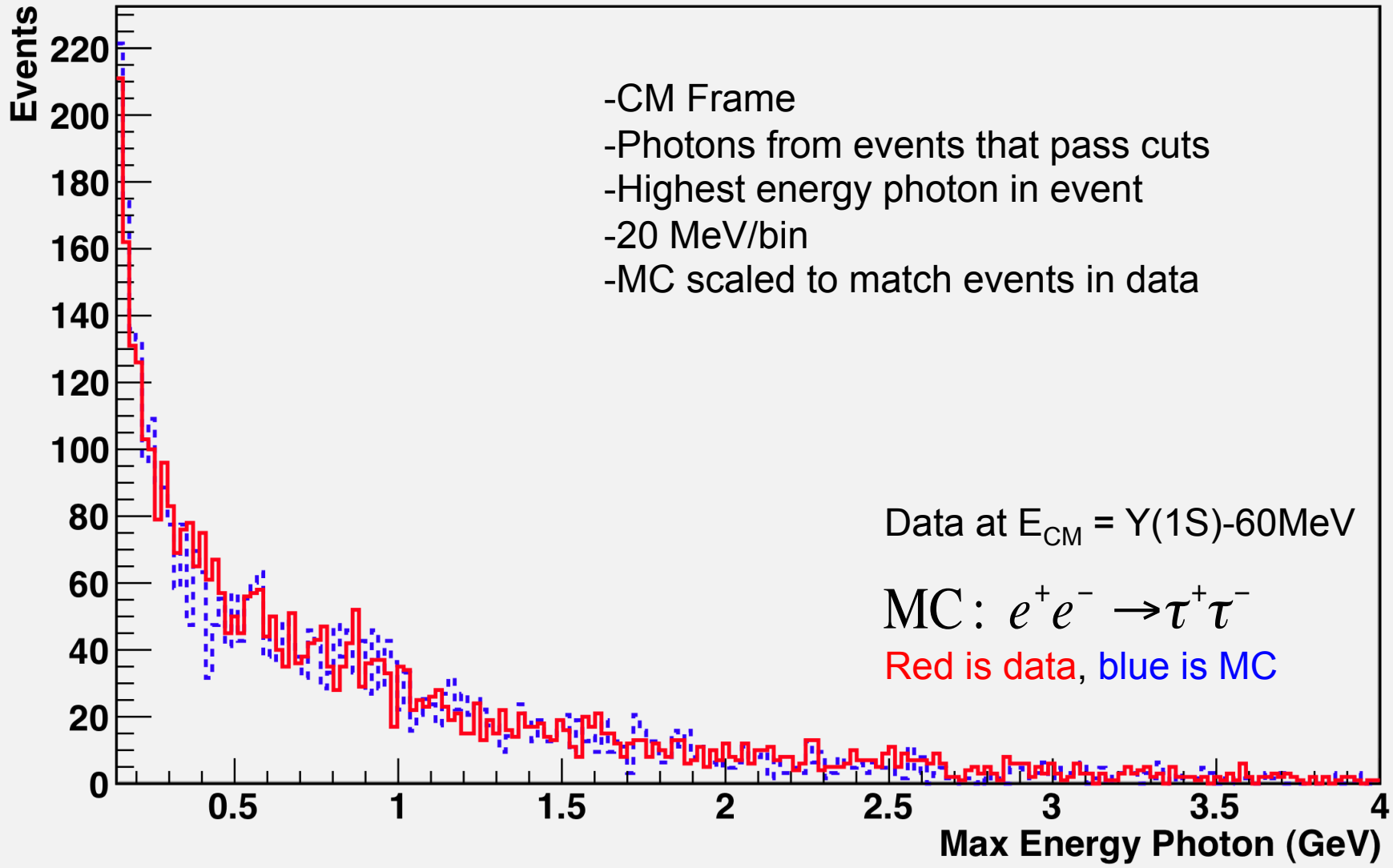
- Need to accurately model background
- Expect two processes to dominate
  - $e^+e^- \rightarrow \tau^+\tau^-$
  - $e^+e^- \rightarrow \tau^+\tau^-\gamma$
- Modeled each in MC, compared to off resonance data
  - 10^6 MC events from EvtGen for each mode
  - MC beam energy 60 MeV below resonance

Backgrounds

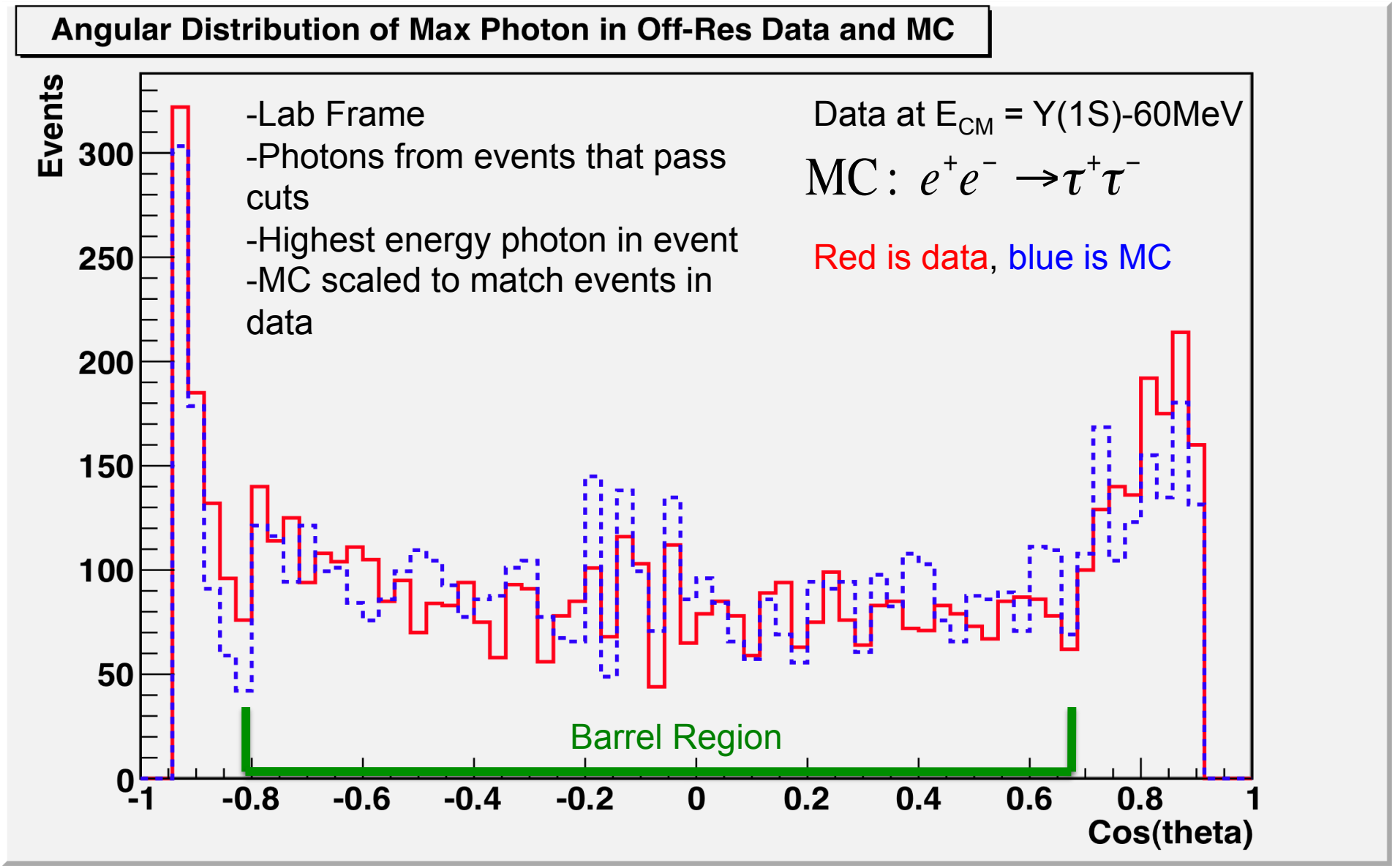
- Plot highest energy photon from events that passed all cuts for both modes and off resonance data.
- Boost photon into the CM frame
- 20 MeV/bin (ECL resolution is ~2% of photon energy)
- Random trigger backgrounds from $\Upsilon(1S)$ data taking is included


Off-Resonance MC
Events
220
200
180
160
140
120
100
80
60
40
20
0
$e^+e^- \rightarrow \tau^+\tau^-$
-CM Frame
-Photons from events that pass cuts
-Highest energy photon in event
-20 MeV/bin
-10^6 original signal events
0.5
1
1.5
2
2.5
3
3.5
4
Max Energy Photon (GeV)

Comparison of Off-Resonance MC and Real Data



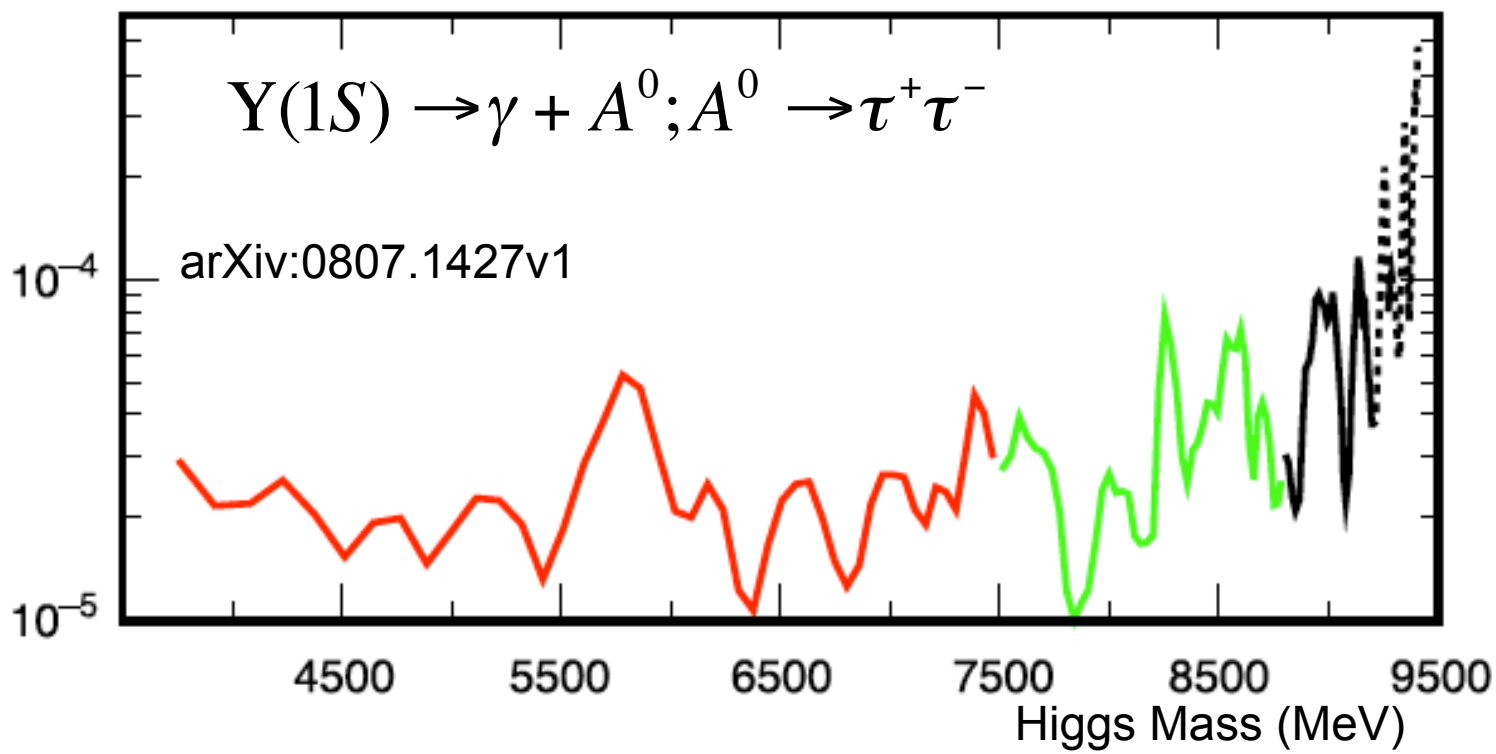
Angular Distribution of Max Photon in Off-Res Data and MC



Further Study

- Belle has a 7.5 fb^{-1} 2S sample on-resonance with 44 million estimated events.
- Running at/around the 2S resonance will continue this fall
  - Plan to take an additional ~14 fb^{-1} on the 2S resonance to bring the total 2S data sample size to ~21 fb^{-1} .
  - Expect to end running at the end of 2009.

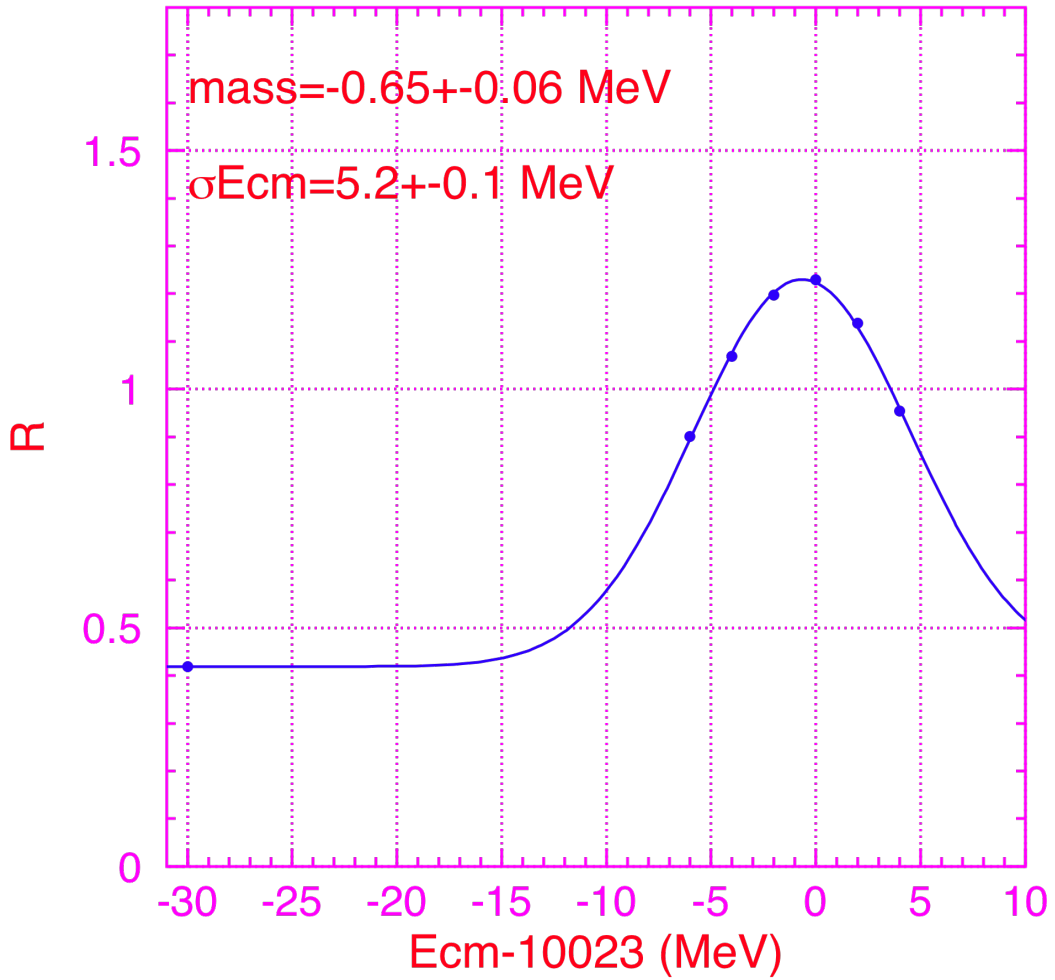
Further Study



- CLEO's search (above) in this mode used 21.5M Υ(1S)
- Belle's search in this mode has 88.4M Υ(1S)
  - should be able to set limits between 10^{-4}-10^{-6}

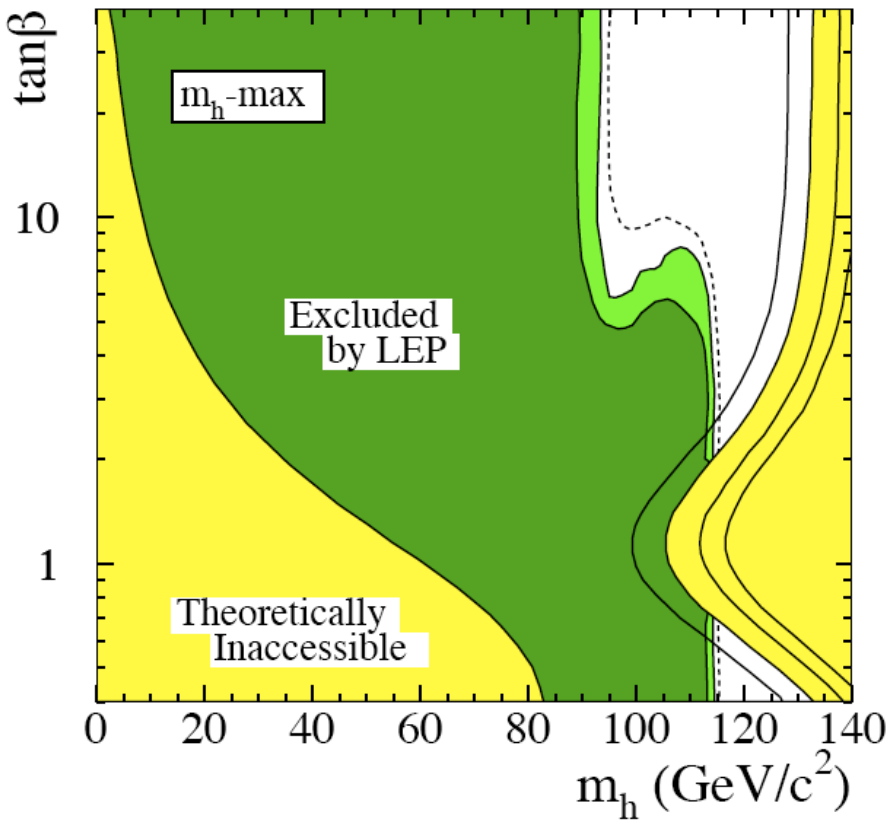
EXTRA

Y(2S) Energy Scan



The Standard Model

- LEP, etc restricted domain of Higgs
- Possible decay channel left:
  $H \rightarrow aa$ (a = light Higgs)
  ref: R. Dermisek, J.F. Gunion, R. McElrath. arXiv:hep-ph/0612031v1
- At Belle may see Υ goes to γ + a



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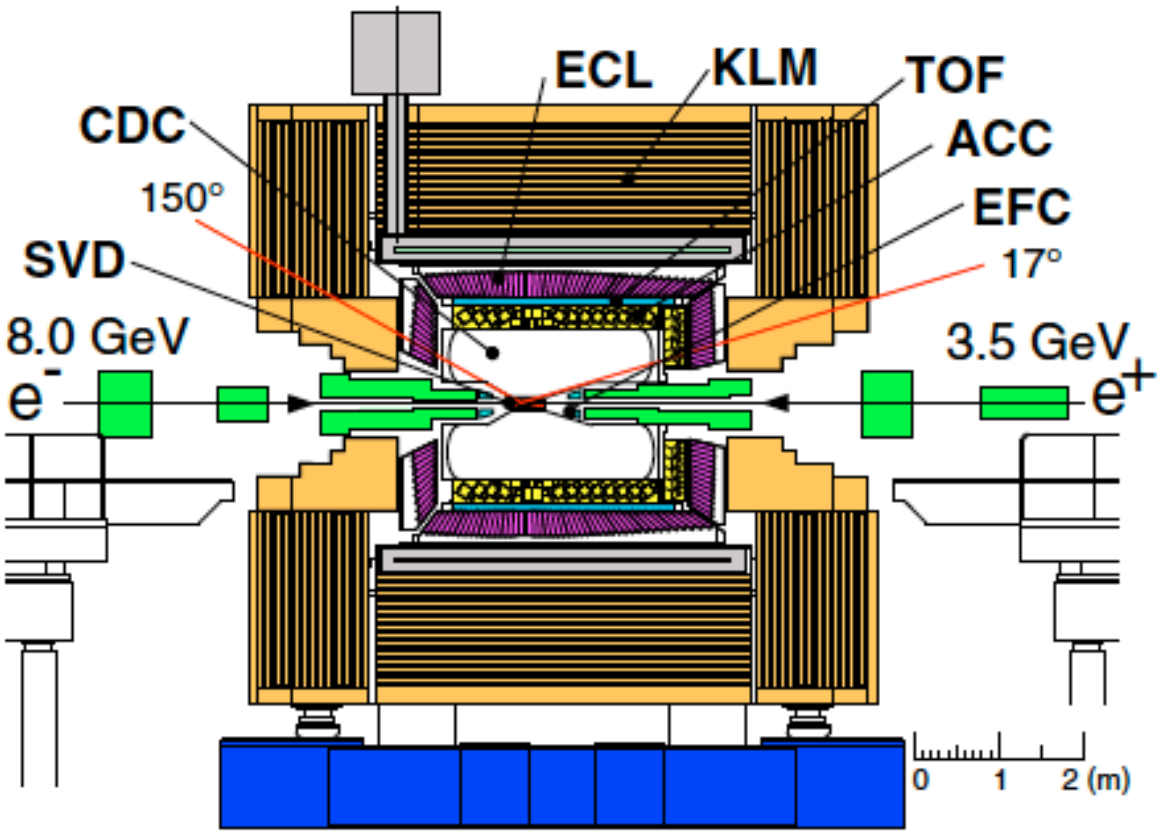

ECL
KLM
TOF
CDC
ACC
150°
EFC
SVD
17°
8.0 GeV
3.5 GeV
e-
e+
0
1
2 (m)

The Belle Detector

- SVD - Precise location of decay vertex
  - Electron/"hole" pairs generated
- CDC - Particle tracks, momentum
  - Ionize gas, ions go to wires in cells, fit track
- ACC - diff between K/π via Cerenkov
  - Designed for 1.2-3.5GeV(threshold)
- TOF - PID
  - Scintillation, event time and pulse shape

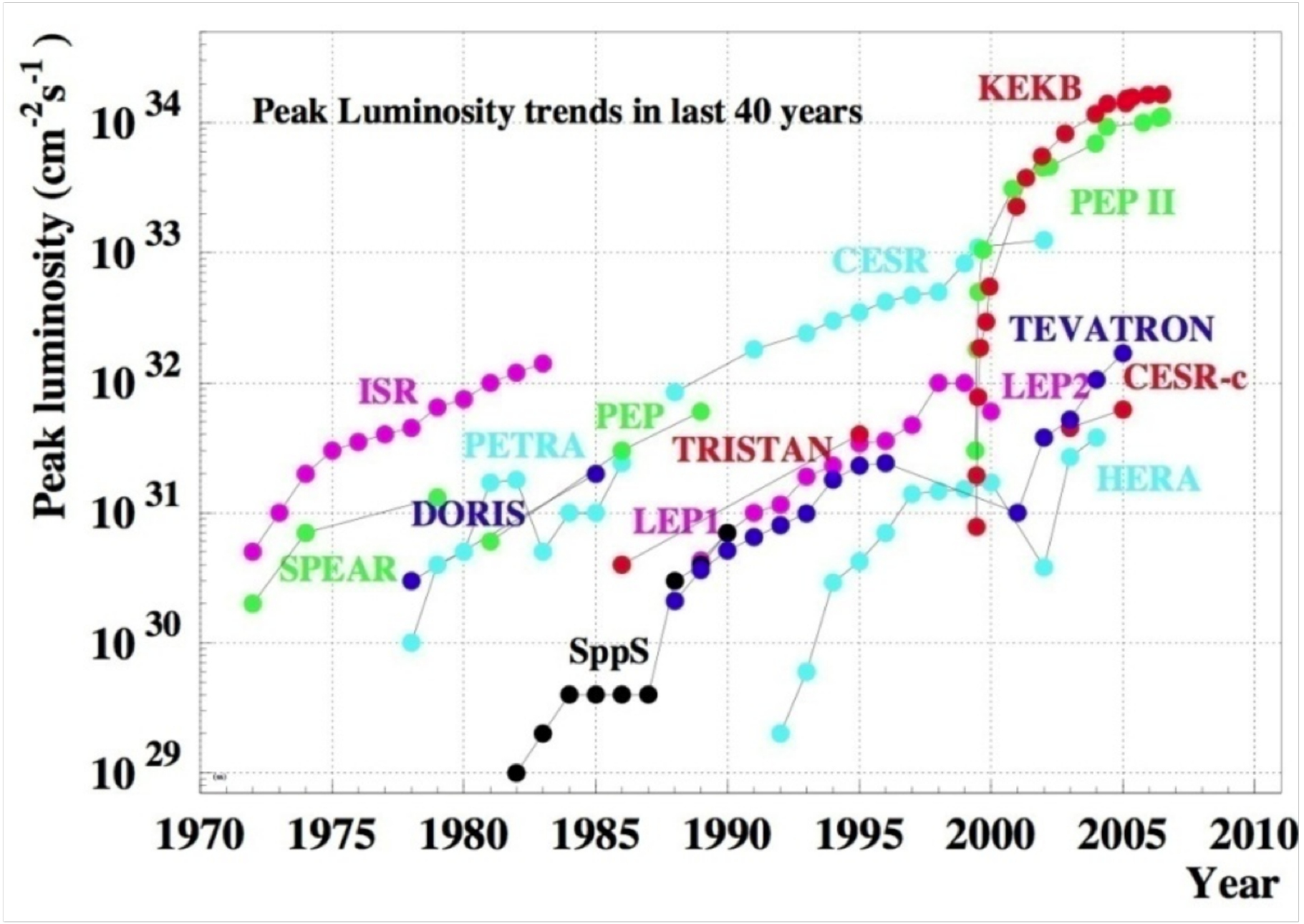
The Belle Detector

- ECL - Electron/photon measurements
  - CsI crystal. Pair production, Bremsstrahlung
- KLM -K_L/Muon differentiation
  - Resistive plate chamber, iron for K_L interaction
- EFC - extension of ECL
  - BGO

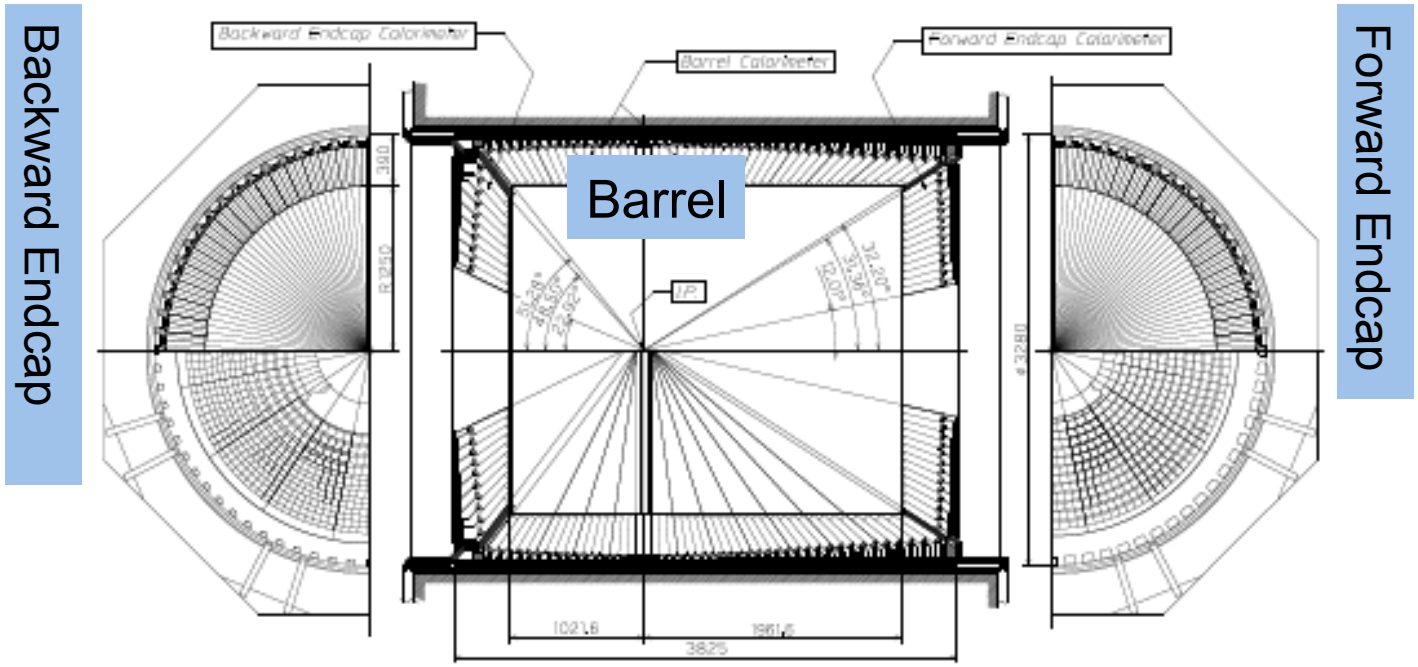
-- definitions

- good charged track:(this depends on evtcls default)
- Pt >= 0.1 GeV/c
- helix |dr|<2cm, |dz|<5cm
- good ECL cluster: E(ECL cluster) > 0.1 GeV
- good Gamma: E(ECL) > 0.1 GeV
- Erec = Sum of Pcm(good charged track) in c.m.s. + SumSelection criteria
- The following list shows the curernt selection criteria for the tau skim.
- -- definitions
- good charged track:(this depends on evtcls default)
- Pt >= 0.1 GeV/c
- helix |dr|<2cm, |dz|<5cm
- good ECL cluster: E(ECL cluster) > 0.1 GeV
- good Gamma: E(ECL) > 0.1 GeV
- Erec = Sum of Pcm(good charged track) in c.m.s. + Sum of Egamma in c.m.s.
- Ptmax : maximum Pt(good charged track)
- Etot = Erec + |Pmiss_CM|
- N_barrel: No. of track with 30< theta <130 degree (barrel region)
- E_ECL_trk = Sum of E(ECL) in c.m.s - Sum of Egamma in c.m.s.

- --- selection criteria
  - 1. 2<= No. of good track <=8
  - 2. |charge sum|<=2
  - 5. Ptmax > 0.5 GeV/c
  - 6m. Event vertex |r|<1cm,|z|<3cm
  - 7. for 2 track event
  - 7-2m. Sum of E(ECL) < 11 GeV
  - 7-3. 5 < theta(missing momentum) < 175 degree
  - 8. Erec > 3 GeV .or. Ptmax > 1.0 GeV/c
  - 9. for 2-4 charged track case
  - 9-1m. Etot < 9 GeV .or. maximum opening angle < 175 degree
  - .or. 2 < Sum of E(ECL) < 10 GeV
  - 9-2. N_barrel >= 2 .or. E_ECL_trk < 5.3 GeV

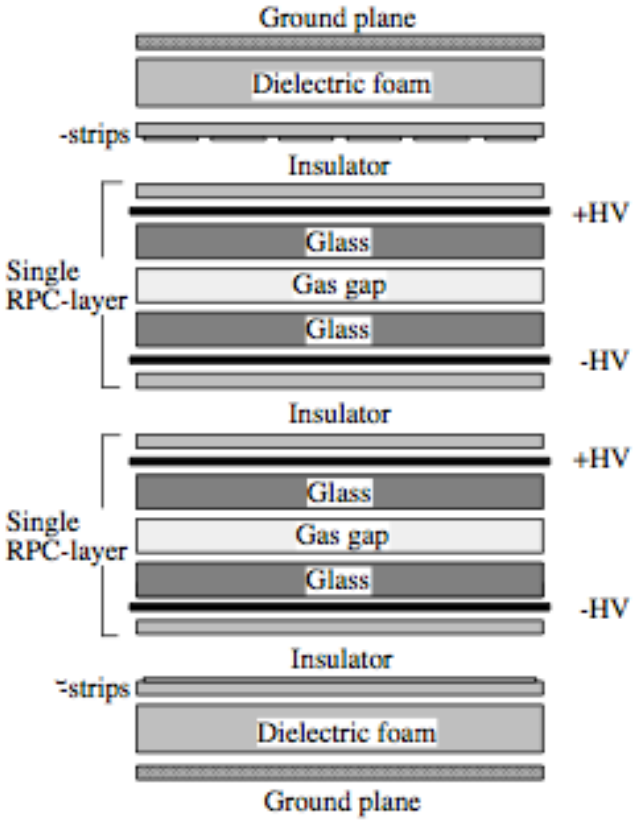

Peak Luminosity trends in last 40 years
Peak luminosity (cm-2s-1)
10 34
10 33
10 32
10 31
10 30
10 29
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
KEKB
PEP II
CESR
TEVATRON
LEP2
CESR-c
ISR
PEP
PETRA
TRISTAN
HERA
DORIS
LEP1
SPEAR
SppS

KEKB/Belle



- The Electromagnetic Calorimeter (ECL)
  - 8736 CsI crystals, each 30cm long and face
  - Energy resolution of ~1.6% at around 1 GeV
  - Light read out via silicon photodiodes mounted on the end of each crystal

KEKB/Belle



- K_L/Muon Detector (KLM)
  - Stack of alternating gas detector and iron planes
  - KLM provides ~4 interaction lengths for K_L
  - If E_{mu}>1GeV then KLM can detect it with 90% efficiency

Data Samples (as of March 2008):

Energy	Sample Size	
Y(5S)	420 /pb	
Y(4S)	15.5 /fb	
Y(3S)	1.2 /fb	6M decays
Y(2S)	1.2 /fb	9M decays
Y(1S)	1.1 /fb	22M decays
10.54 GeV	2 /fb	below Y(4S)
10.33 GeV	0.2 /fb	below Y(3S)
10.00 GeV	0.4 /fb	below Y(2S)
9.43 GeV	0.2 /fb	below Y(1S)
6.9-8.4 GeV	17 /pb	
3.97-4.26 GeV	60 /pb	includes 13 /pb at 4.26GeV
4.17 GeV	586 /pb	
psi(3770)	818 /pb	
psi(2S)		about 27M decays
3.673 GeV	21 /pb	

CLEO Extended