Leptonic B Decays from BaBar

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Outline

- Motivation
- BaBar Detector
- Present new results on the Leptonic B meson decays from the BaBar experiment.
  - $B^0 \to \ell^+\ell^-$ (accepted by PRD; arXiv:0712.1516)
  - $B^+ \to \ell^+\nu$, $B^0 \to \ell^+\tau^-$ (submitted to PRD-RC)
  - $B^+ \to K^+ \nu\,\bar{\nu}$ (Preliminary Result)

  ($\ell \Rightarrow e$ or μ)

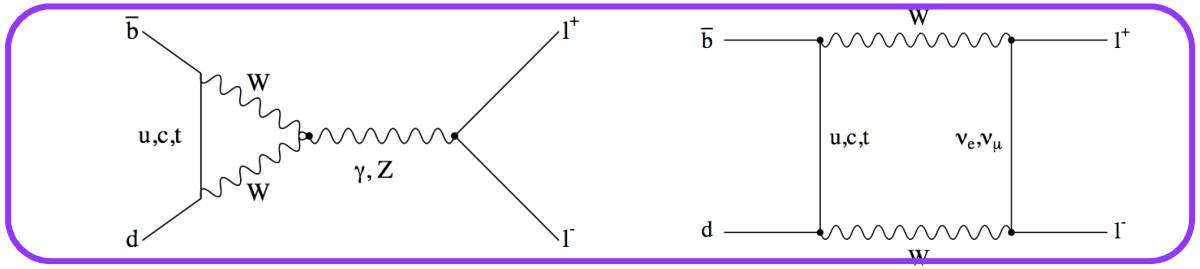
  (charge conjugation modes are included implicitly)
- Summary

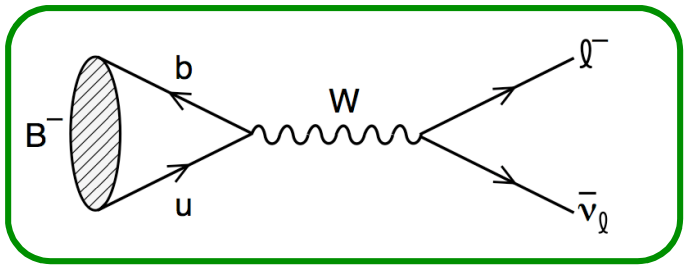
Motivation

- Can provide essential information on the parameters of the Standard Model (SM) like
  - CKM matrix element, $|V_{ub}|$. (SL B decays $\sigma(|V_{ub}|)$ ~8%)
  - Leptonic B decay constant f_B. (LQCD $\sigma(f_B)$ ~10%)

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

- Highly suppressed in the Standard Model.
  - Process mediated by electroweak penguin, box diagrams or quark annihilation into W-boson.

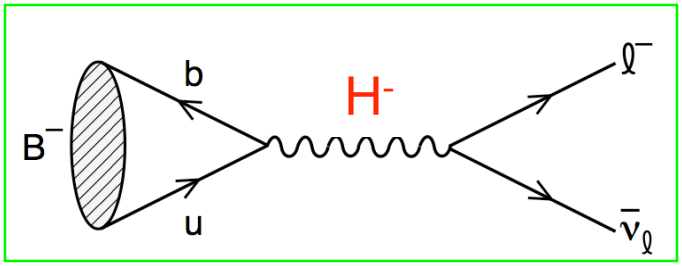




G_F: the Fermi coupling constants, $m_{B(\ell)}$: the mass of B meson (lepton), f_B: the decay constant
V_{ub}: a Cabibbo-Kobayashi-Maskawa matrix element, τ_B: the B meson lifetime

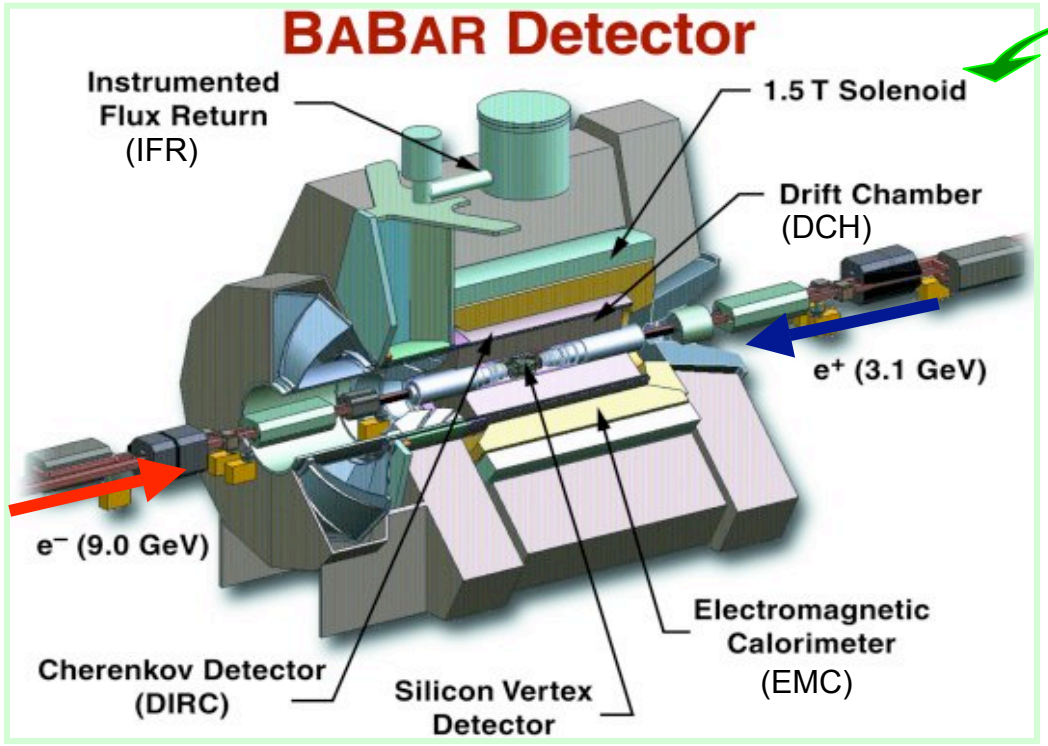
Motivation - cont.

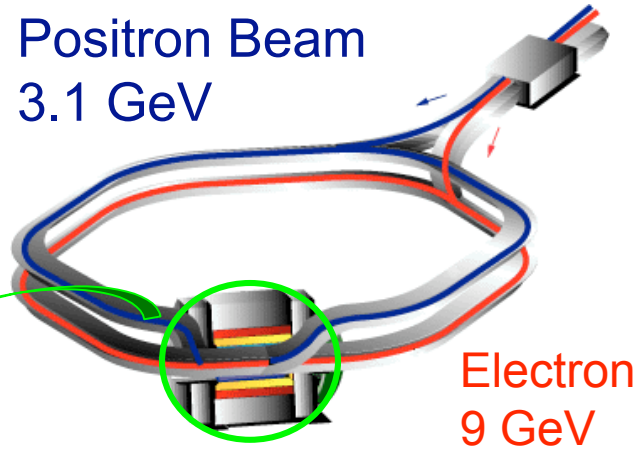
- Sensitive to New Physics (NP) beyond SM.
  - Some NP predicts bigger BF than SM prediction.
    - Minimum Supersymmetry SM (MSSM) predicts BF($B^0 \to \ell^+ \ell^-$) larger than SM (up to x100).
    - 2-Higgs doublet model of type-II can enhance or reduce BF($B^+ \to \ell^+ \nu$).
    - SUSY Seesaw model predicts BF($B^0 \to \ell^+ \tau^-$) ~ 10^{-10}.
  - Looking for deviations from SM.
- Clean to measure.



BaBar Detector

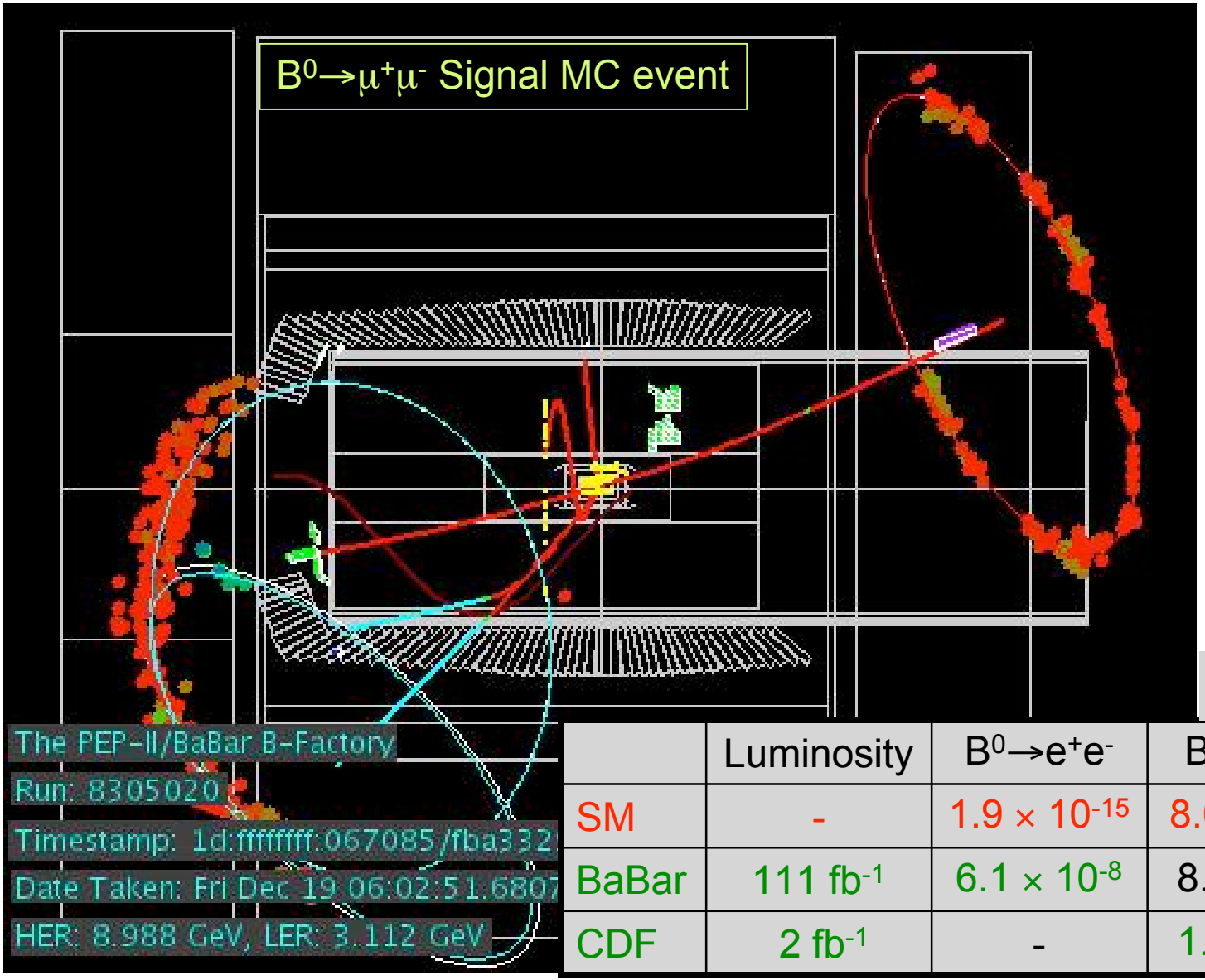
A multipurpose asymmetric particle detector





Electron ID: a likelihood method with EMC, DCH and DIRC information. efficiency ~93%, pion mis-id <0.1%
Muon ID: a neural network method with IFR information. efficiency ~73%, pion mis-id~2%
Kaon ID: From DIRC info. Good K-π separation up to ~5 GeV/c.

A Search for $B^0 \to \ell^+\ell^-$



	Luminosity	$B^0 \to e^+e^-$	$B^0 \to \mu^+\mu^-$	$B^0 \to e^+\mu^-$
SM	-	1.9×10^{-15}	8.0×10^{-11}	0
BaBar	111 fb^{-1}	6.1×10^{-8}	8.3×10^{-8}	18×10^{-8}
CDF	2 fb^{-1}	-	1.8×10^{-8}	-

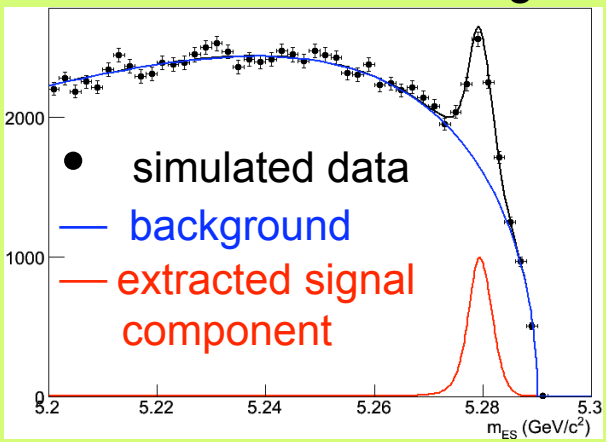
Best previous UL

Signal Selection

- Construct B^0 from two oppositely charged tracks.
- Use Kinematic Variable (m_{ES}, ΔE)

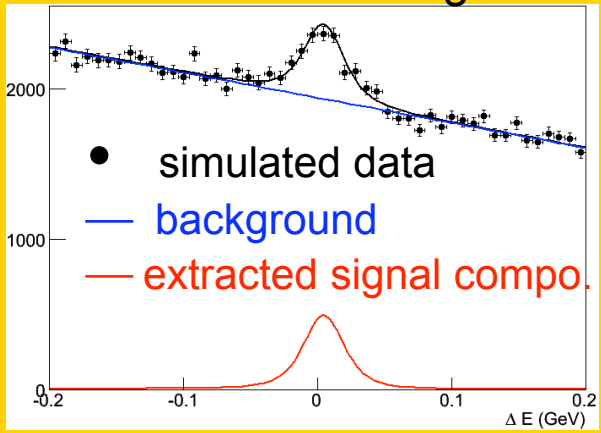
$$m_{\mathrm{ES}} = \sqrt{E^{*2}_{\mathrm{beam}} - p^{*2}_{B}}$$

Peaks at B mass for signal



$$\Delta E^{*} = E^{*}_{B} - E^{*}_{\mathrm{beam}}$$

Peaks at zero for signal



*: CM frame

- Perform maximum likelihood (ML) fit in m_{ES}-ΔE areas:
  - $|\Delta E| < 0.150$ GeV, $5.2 < m_{ES} < 5.2895$ GeV/c^2.

Background Rejection

B background

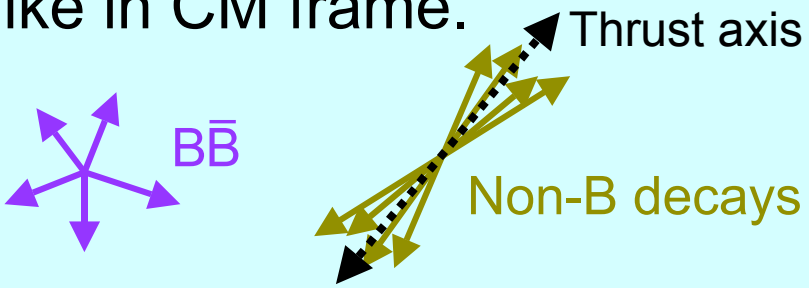
- Dominant background: $B^0 \to \pi^+\pi^-$, $B^0 \to K^+\pi^-$
- Stringent Particle ID
  - e eff. ~93% (misID < 0.1%)
  - μ eff. ~73% (misID < 3%)
  - Bremsstrahlung recovery for e.

QED events

- e and μ coming from e^+e^- interactions.
- Require at least 5 charged tracks in the event.

Non-B Background

- Non-B decays are more jet-like in CM frame.



- Use *event shape variables*
  - $|\cos\theta_S|<0.8$, θ_S: sphericity.
  - $R_2<0.95$, R_2: 2nd to 0th Fox-Wolfram moment.
- Use Fisher discriminant (*F*)
  - Based on 0th & 2nd Legendre moments.
  - Use it in ML fit.

Legendre moments: momentum weighted by Legendre expansion of the angle btw track and thrust axis.

ML fit

- 4 categories of samples:
  - Signal samples
    - **ee**: both pass e PID not others
    - **μμ**: both pass μ PID not others
    - **eμ**: each pass e/μ PID not others
    - **hh**: at least one of them does not pass e PID or μ PID
- Fit on hh sample (signal MC) for background (signal) shapes.

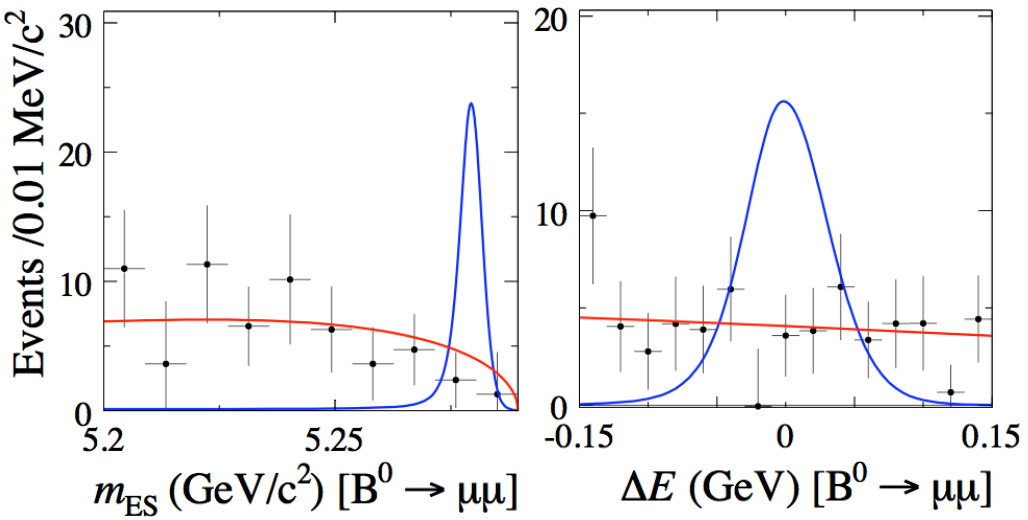
$$\mathcal{L} = \frac{e^{-(N_{sig}+N_{bg})/N}}{N\sqrt{(N_{sig}+N_{bg})}} \cdot \prod_{i=1}^{N} \Big(N_{sig} \cdot P_{sig}(m_{\rm ES})i \cdot P_{sig}(\Delta E)_i \cdot P_{sig}(\mathcal{F})_i + N_{bg} \cdot P_{bg}(m_{\rm ES})i \cdot P_{bg}(\Delta E)_i \cdot P_{bg}(\mathcal{F})_i \Big)$$

For signal, for background

- Perform fit on each signal sample
  - Float only signal and background yields
- Validation:
  - Toy MC study to check bias in background shape parameters.
  - Toy MC study with zero signal yield - only background yield floated.
  - No significant bias found.

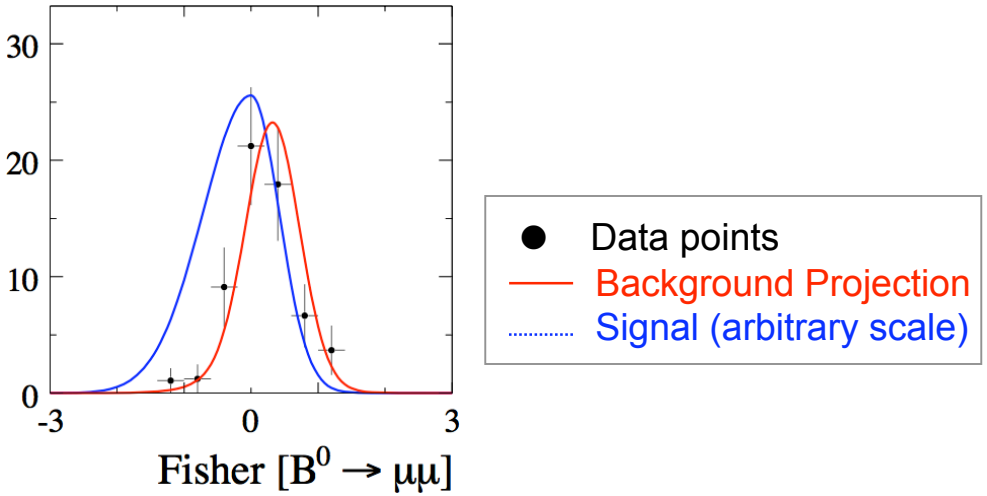
Result

- Systematic Uncertainties:
  - Total ~ 4%.
  - Dominant: Particle ID.
- Set 90% CL Upper Limit on the BF using a Bayesian approach (a flat prior for N>0), including systematics:

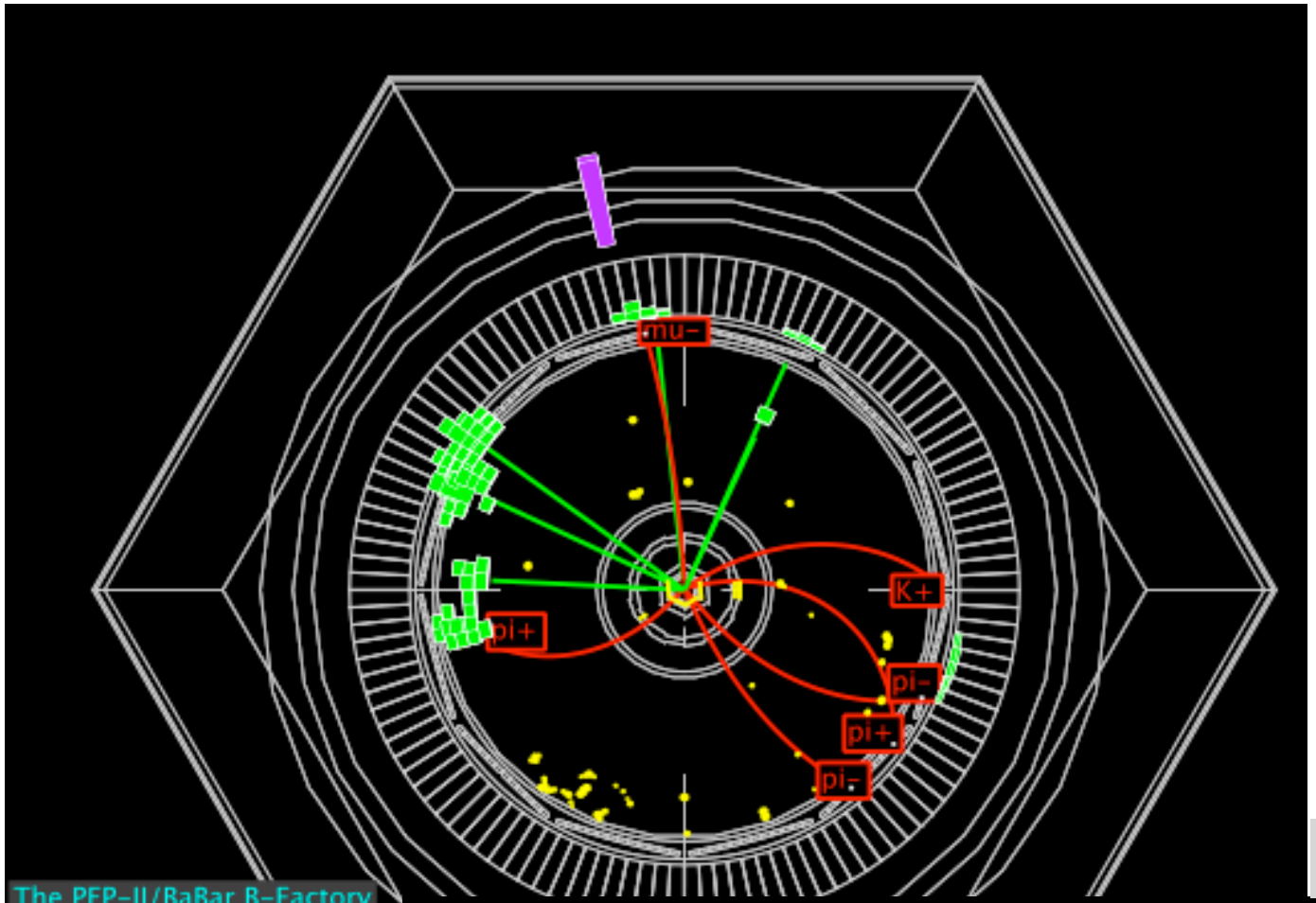


With 384 M $B\bar{B}$ events

	eff. (%)	# signal	UL(BF) $\pm 10^{-8}$
e^+e^-	16.6 ± 0.3	0.6 ± 2.1	11.3
$\mu^+\mu^-$	15.7 ± 0.2	-4.9 ± 1.4	5.2
$e^+\mu^-$	17.1 ± 0.2	1.1 ± 1.8	9.2



Search for $B^+ \to \ell^+\nu$ and $B^0 \to \ell^+\tau^-$

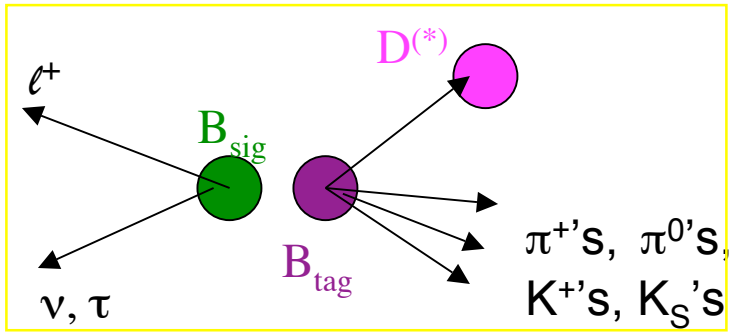


Best previous UL

	Lumi	$e\nu$	$\mu\nu$	$e\tau$	$\mu\tau$
SM	-	1.2×10^{-11}	5.2×10^{-7}	0	0
Belle	253 fb^{-1}	9.8×10^{-7}	1.7×10^{-6}	-	-
CLEO	9.6 M B's	-	-	1.3×10^{-4}	3.8×10^{-5}

Analysis Method

- Hadronic Tagging:
  - Due to undetectable particles at BaBar (neutrino)
  - Reconstruct one B meson in the event (B_{tag})
  - Look at the rest of event, try to reconstruct signal B (B_{sig})



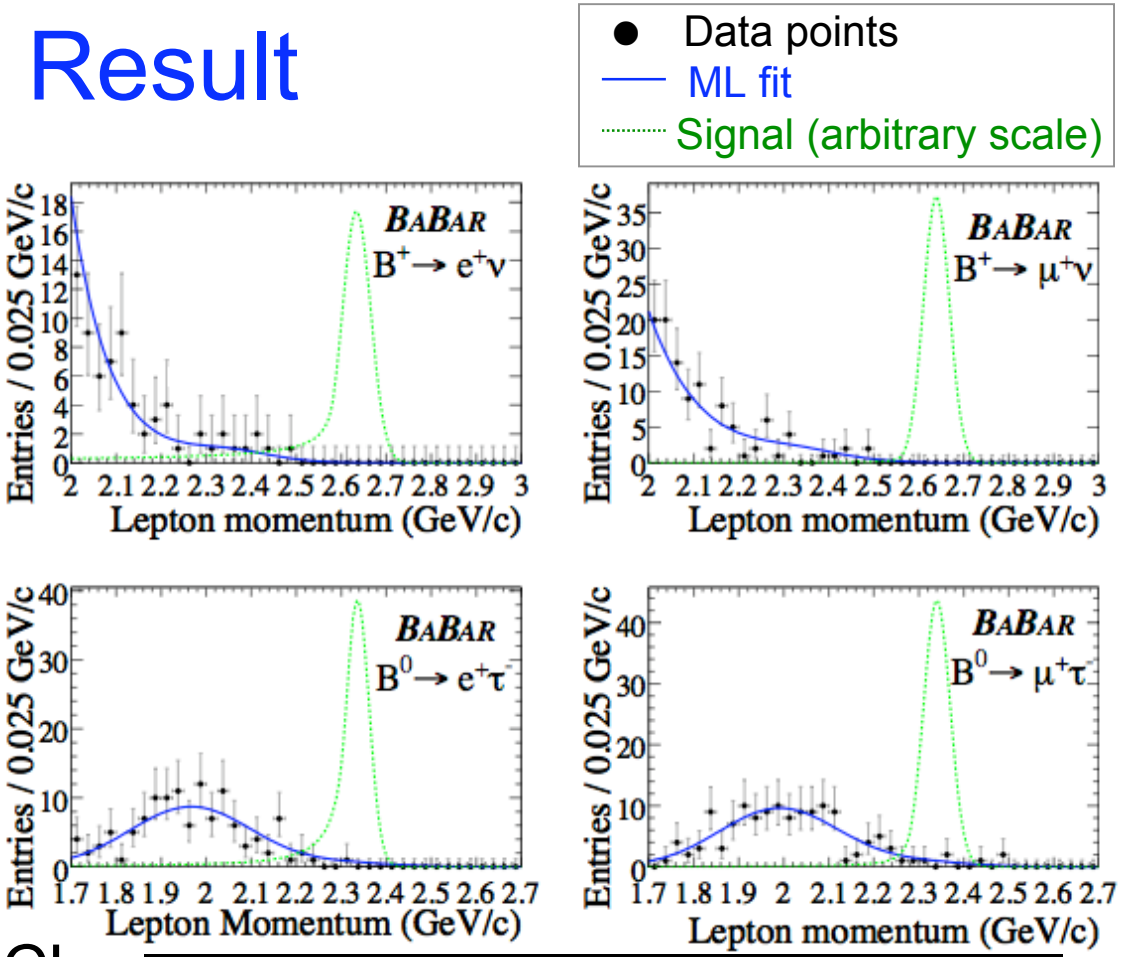
- Pros & cons:
  - Low background
  - Low statistics

- Tag side:
  - Use m_{ES}, ΔE, event shape variables.
  - Reco. efficiency: ~0.2%

- Signal side:
  - Lepton momentum is mono-energetic in B_{sig} rest frame.
  - Reconstruct ~90% of total tau decays
  - Utilize missing momentum (due to neutrino) and extra energy deposit in Calorimeter (should be close to 0 for signal).

Result

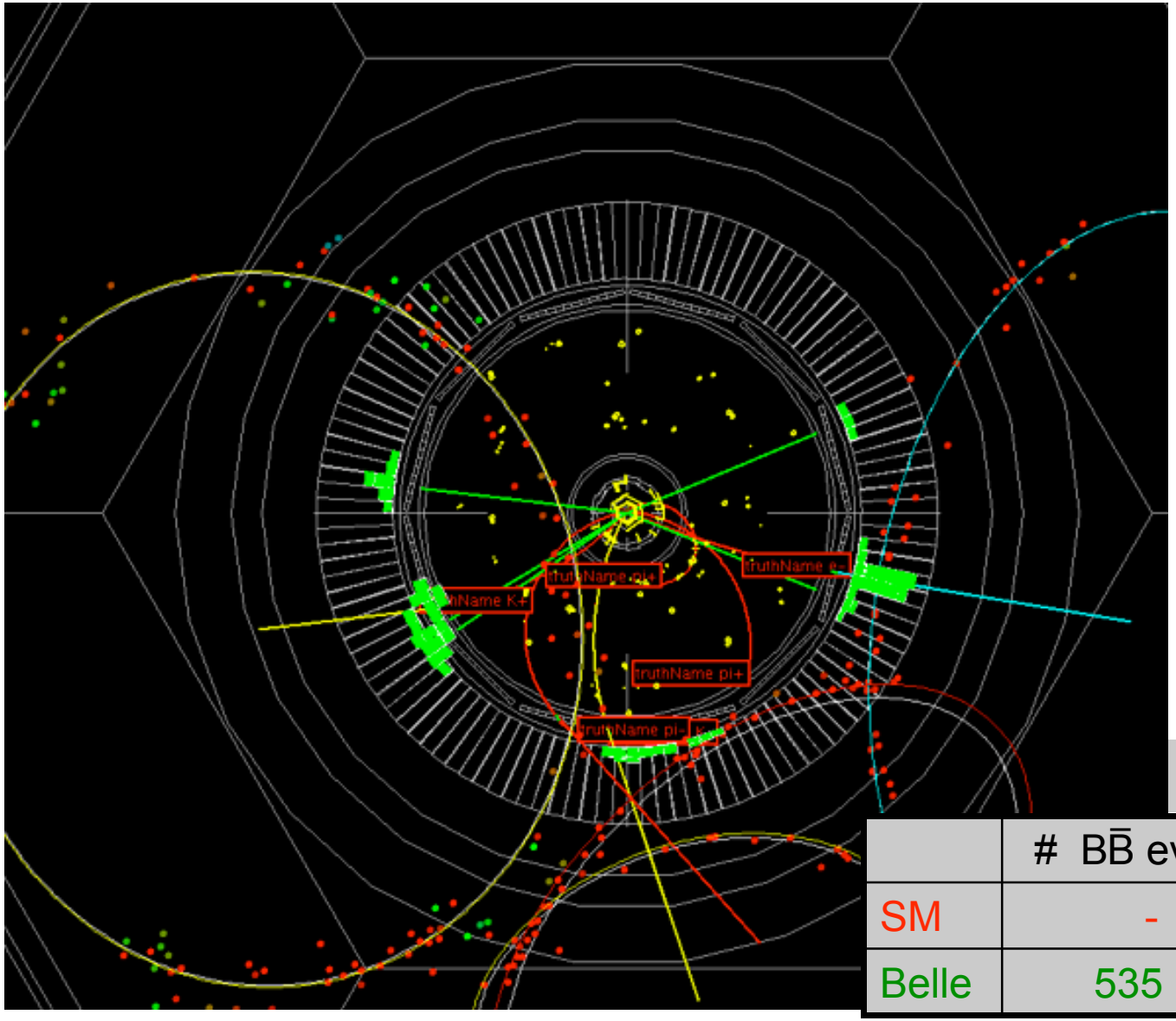
- Unbinned ML fit on lepton momentum in B_{sig} rest frame.
- Fit validation
  - No significant bias.
- Dominant systematics:
  - Fit function shape.
  - Tagging efficiency.
  - Total ~ 15%.
- Set an UL on BF at 90% CL including systematics using Bayesian method.
  - A flat prior for N>0



	# signal	UL ($\times 10^{-6}$)
$B^+ \to e^+ \nu$	-0.1 ± 2.6	5.2
$B^+ \to \mu^+ \nu$	-0.2 ± 2.7	5.6
$B^+ \to e^+ \tau$	0 ± 15	28
$B^+ \to \mu^+ \tau$	0 ± 11	22

With 342 fb^{-1} data (378 M $B\bar{B}$ events)

A Search for $B^+ \to K^+ \nu\bar{\nu}$

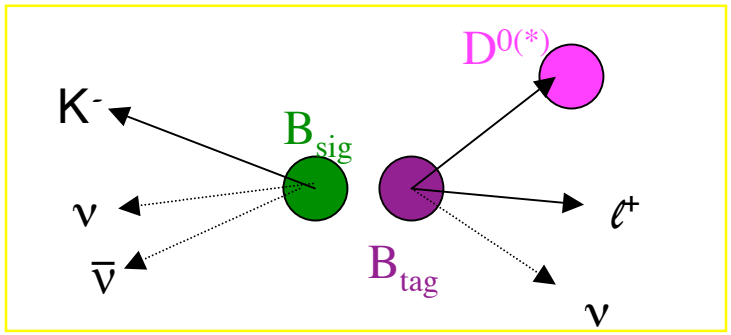


Best previous UL

	# $B\bar{B}$ events	$B^+ \to K^+ \nu\bar{\nu}$
SM	-	3.8×10^{-6}
Belle	535 M	1.4×10^{-5}

Analysis Method

- Semileptonic Tagging:
  - Due to undetectable particles at BaBar (neutrino)
  - Reconstruct one B meson in the event (B_{tag})
  - Look at the rest of event, try to reconstruct signal B (B_{sig})



- Compared to Hadronic tag, SL tag has:
  - More background.
  - More statistics.

- Tag side:
  - Use $|\cos\theta_{B,D^*l}|$ for combinatoric background discrimination (Assume ν is only missing particle)

$$\cos\theta_{B,D^{*0}\ell} \equiv \frac{2\,E_{\rm beam}\cdot E_{D^{*0}\ell} - m_B^2 - m_{D^{*0}\ell}^2}{2\,|\mathbf{p}_{D^{*0}\ell}|\cdot\sqrt{E_{\rm beam}^2 - m_B^2}}$$

- Signal side:
  - Utilize 23 variables. Examples:

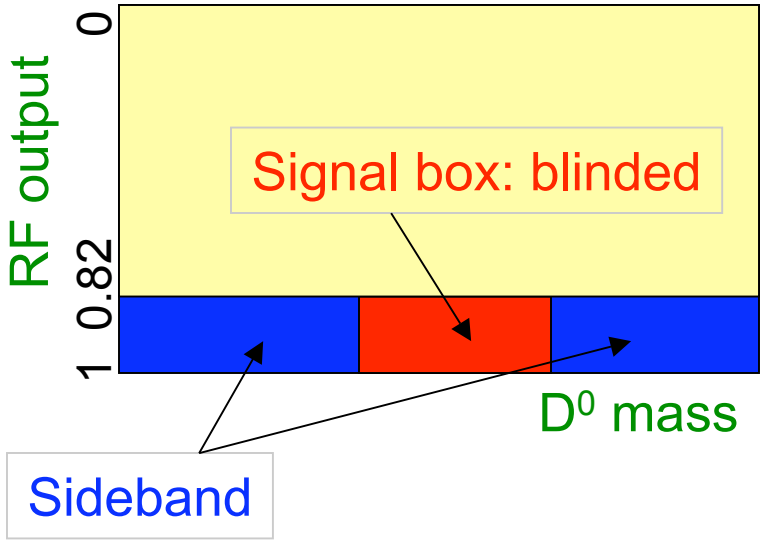
    # of tracks left, min momentum of the tracks, min missing energy due to neutrinos, extra energy deposit in Calorimeter, D^0 mass, etc.
  - Use 22 variables as input for Random Forest method. (except D^0 mass)

Analysis Method - cont.

- Random Forest method
  - A multivariate method.
  - 100 Decision Trees with random subset of input variables.
  - RF output: (naively speaking) how many fraction of Decision Trees think this event is signal.
    - Values are between 0 and 1.

https://sourceforge.net/projects/statpatrec

- Signal box in RF output and D^0 mass plane blinded.
  - RF output > 0.82
  - D^0 mass range (diff. for mode)

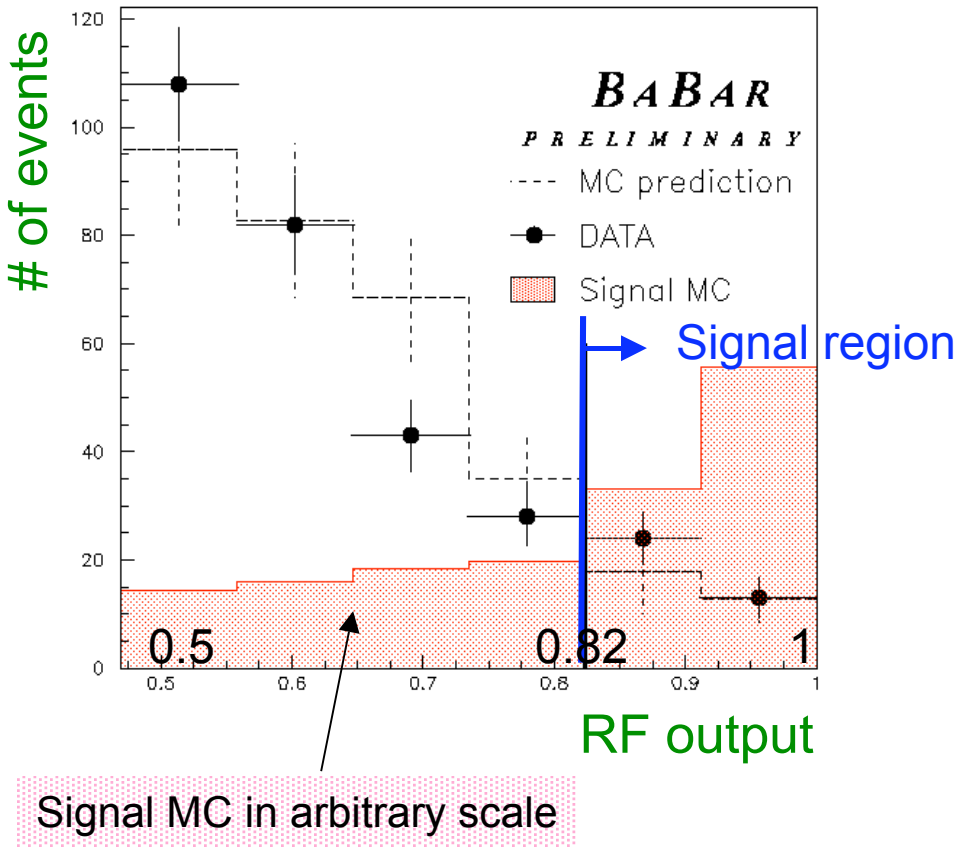


- Background estimation
  - Continuum background level estimated from sideband subtraction in D^0 mass distribution of data.
  - Peaking background level estimated from same method using MC events. Corrected for data.

Result

Systematics

- Total ~13.4%.
- Dominant:
  - Tagging efficiency.
  - Signal efficiency.
- Utilize double tag events.
  - Both B mesons decay to $D^{(*)}\ell\nu$.
  - Compare data/MC.
- Get 90% CL UL on BF, using frequentist's method, including systematics.



With 351 M $B\bar{B}$ events

Expected # events	Observed # events	UL @ 90% CL
30.71±10.71	38	4.2×10^{-5}

Summary

BaBar, CDF, Belle, CLEO

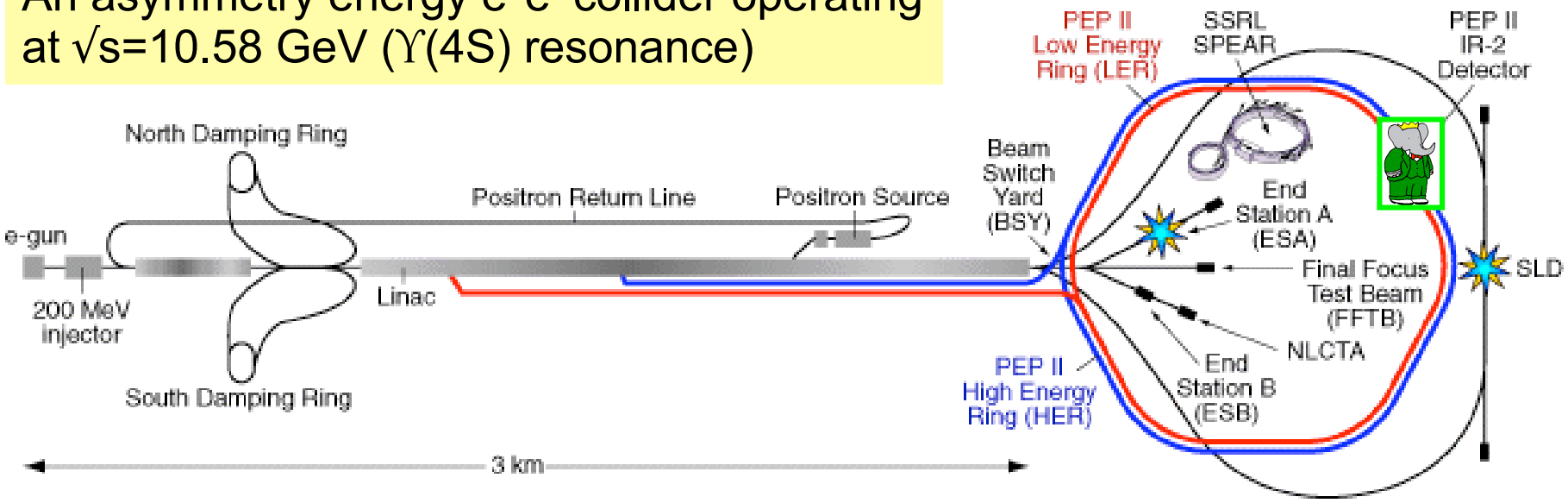
Mode	# $B\bar{B}$ events	UL @ 90% CL	Prev. Best UL
$B^0 \to e^+e^-$	384 M	11.3×10^{-8}	6.1×10^{-8}
$B^0 \to \mu^+\mu^-$		5.2×10^{-8}	1.8×10^{-8}
$B^0 \to e^+\mu^-$		9.2×10^{-8}	18×10^{-8}
$B^+ \to e^+\nu$	378 M	5.2×10^{-6}	9.8×10^{-7}
$B^+ \to \mu^+ \nu$		5.6×10^{-6}	1.7×10^{-6}
$B^0 \to e^+\tau^-$		2.8×10^{-5}	1.4×10^{-4}
$B^0 \to \mu^+ \tau^-$		2.2×10^{-5}	3.8×10^{-5}
$B^+ \to K^+ \nu \bar{\nu}$	351 M	4.2×10^{-5}	1.4×10^{-5}

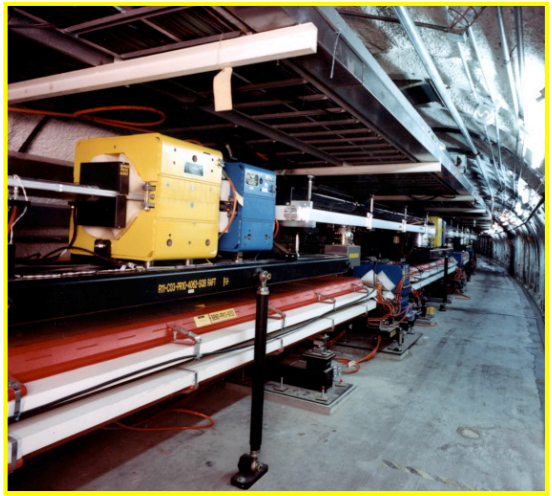
- BaBar is pursuing measurements on variety of rare leptonic B meson decays.
- No deviation from SM observed.

BACKUP SLIDES

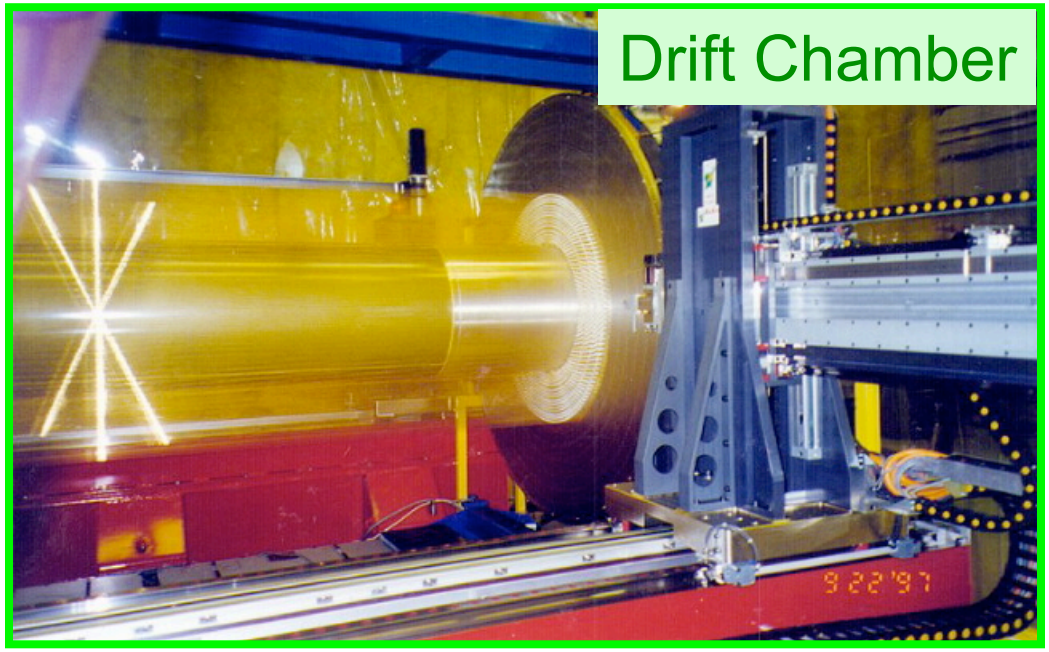
PEP-II Accelerator

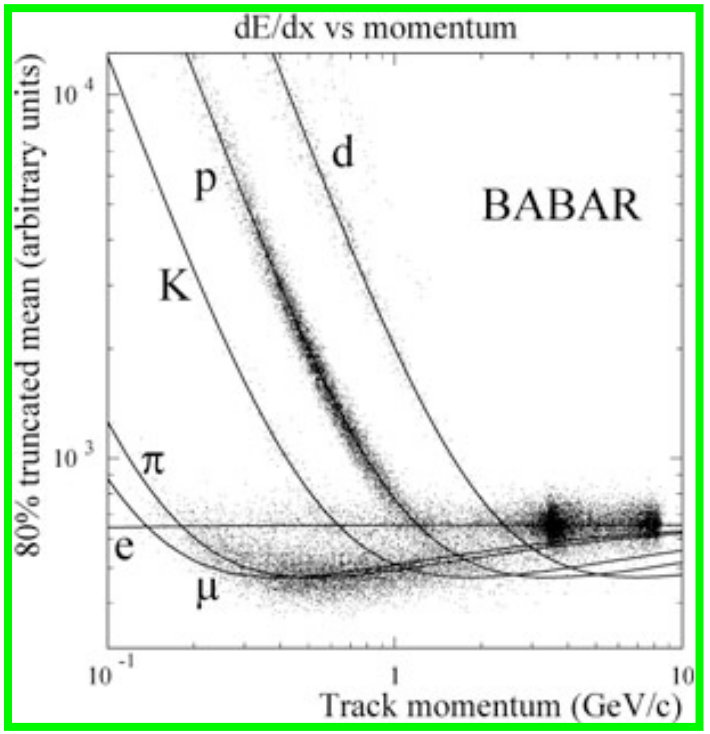
An asymmetry energy e^+e^- collider operating at $\sqrt{s}$=10.58 GeV (Υ(4S) resonance)



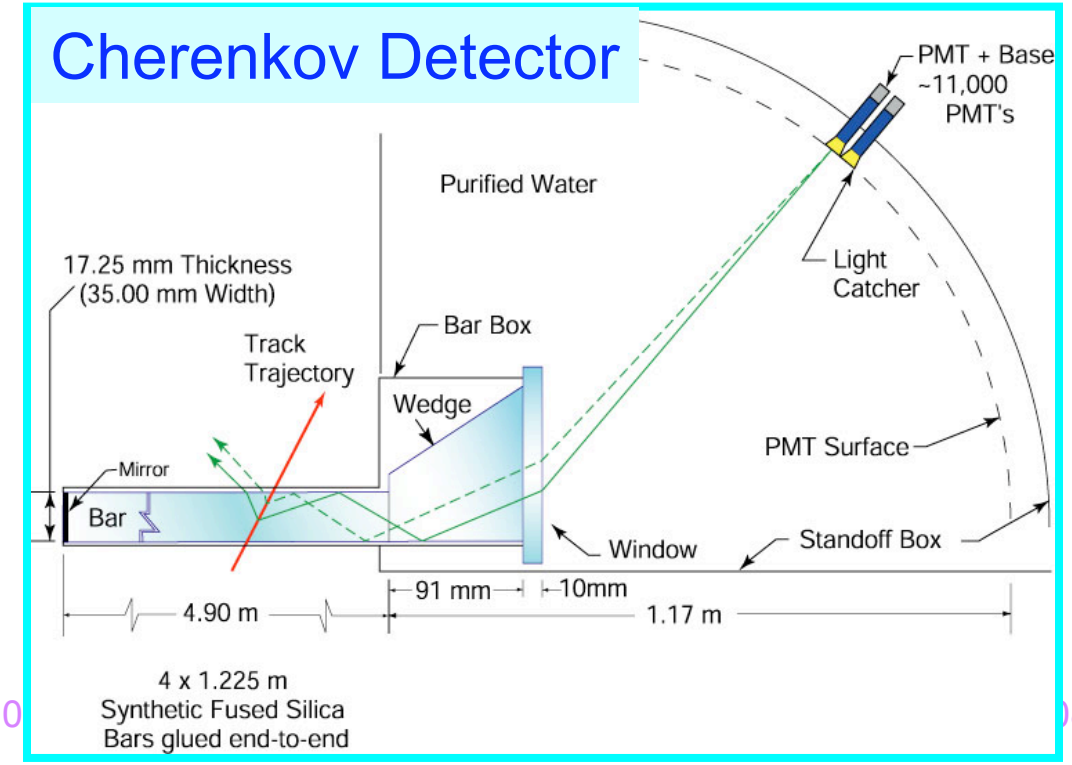


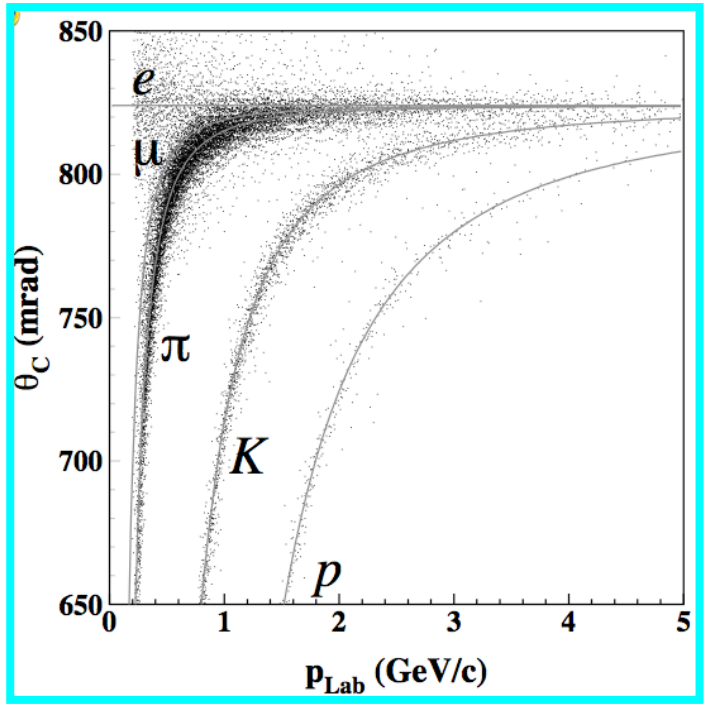
Drift Chamber



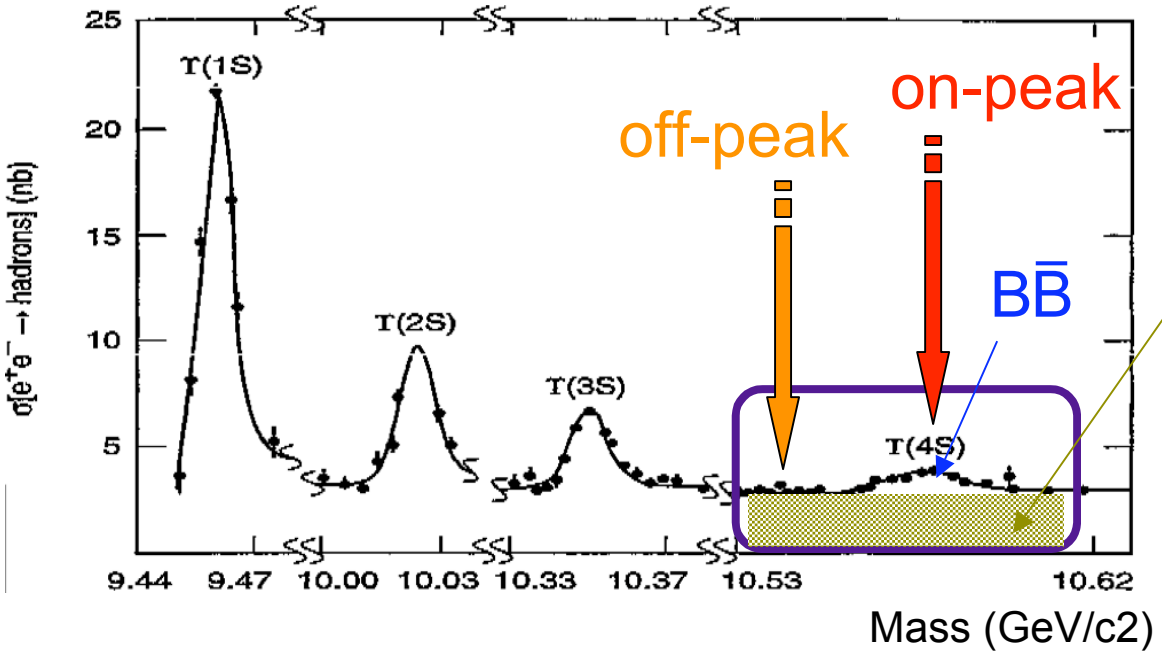


Cherenkov Detector





Data

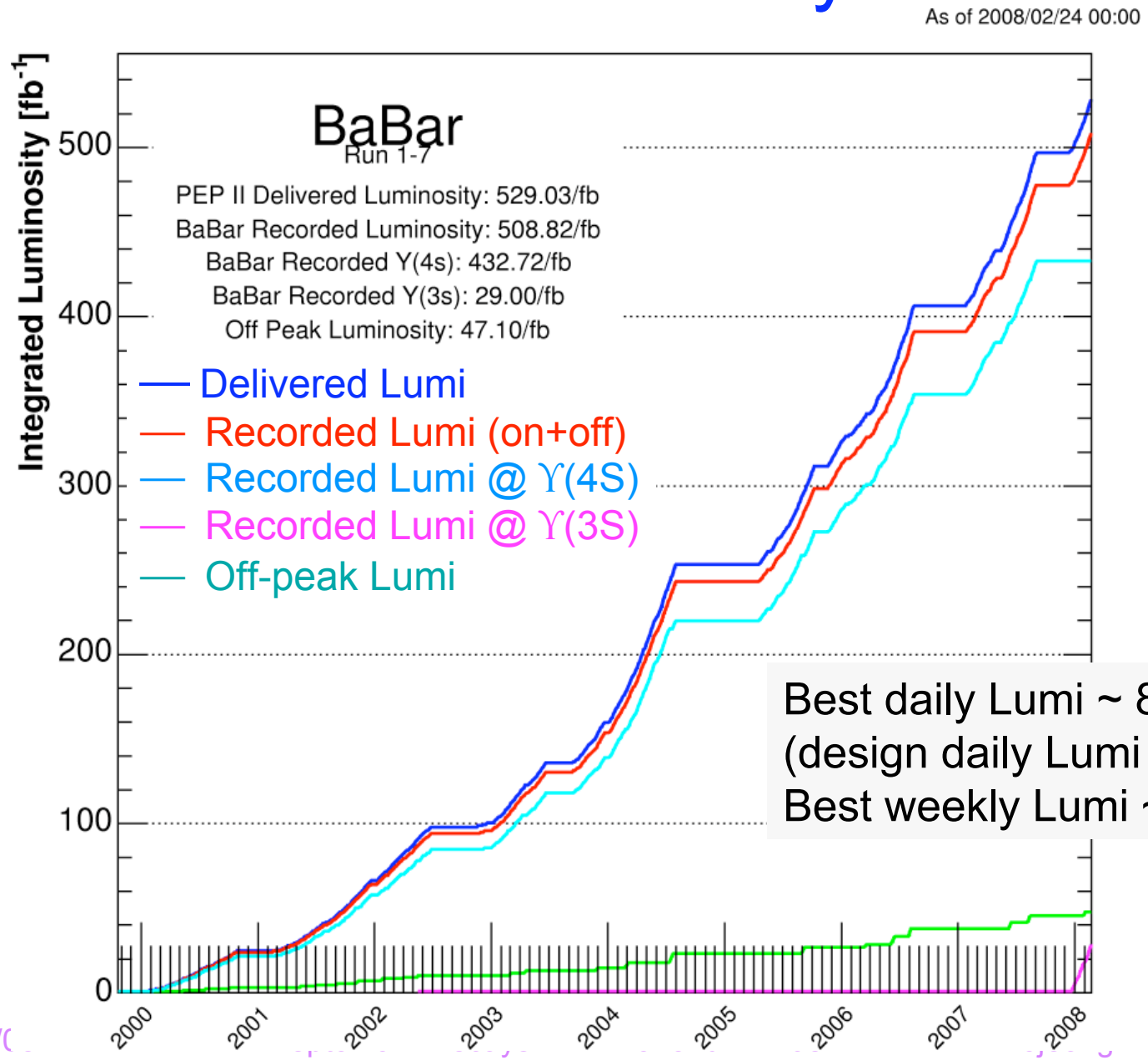


- Taken at $\Upsilon(4S)$ resonance (on-peak)
  - $\Upsilon(4S) \rightarrow B^0\bar{B}^0 : B^+B^- \sim 50:50$
  - Contains $b\bar{b}$ and continuum events.

$e^+e^- \rightarrow$	$b\bar{b}$	$c\bar{c}$	$u\bar{u}$	$d\bar{d}$	$s\bar{s}$	$\tau^+\tau^-$
Cross-section (nb)	1.05	1.30	1.39	0.35	0.35	0.94

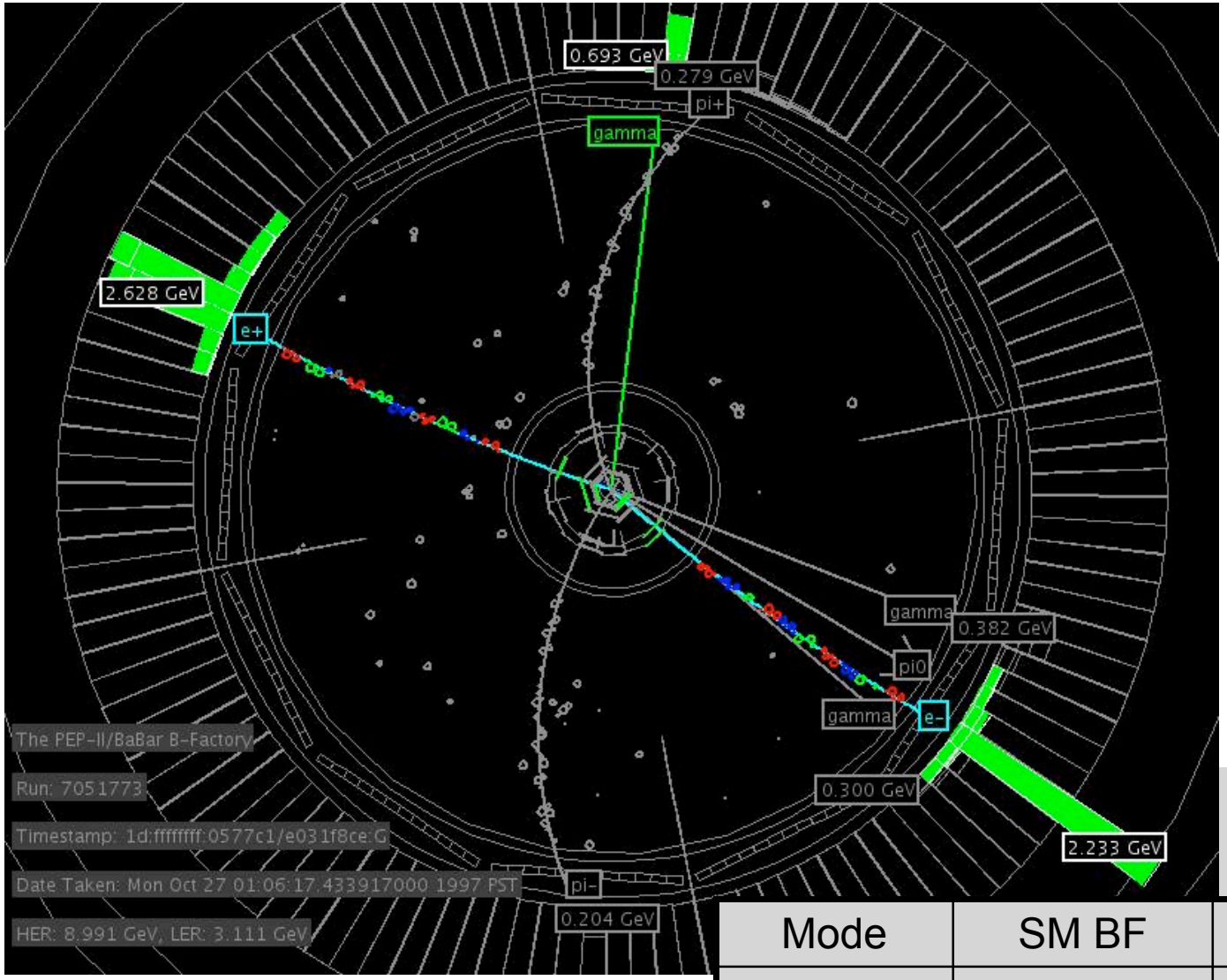
- Taken at 40 MeV below $\Upsilon(4S)$ resonance (off-peak)
  - Contains continuum events only.
- Monte Carlo (MC) samples on
  - Generic $B\bar{B}$ events.
  - Generic continuum events.
  - Specific signal events.

Luminosity



Best daily Lumi ~ 891 pb^{-1}
(design daily Lumi ~ 135 pb^{-1})
Best weekly Lumi ~ 5.25 fb^{-1}

A Search for $B^0 \to \ell^+ \ell^- \gamma$



There is no previous search on $B^0 \to \ell^+ \ell^- \gamma$.

Mode	SM BF	Mode	SM BF
$B^0 \to e^+ e^- \gamma$	$2\sim8 \times 10^{-10}$	$B^0 \to e^+ e^-$	2×10^{-15}
$B^0 \to \mu^+ \mu^- \gamma$	$1\sim6 \times 10^{-10}$	$B^0 \to \mu^+ \mu^-$	9×10^{-11}

A Search for $B^0 \to \ell^+\ell^-\gamma$

Analysis Method

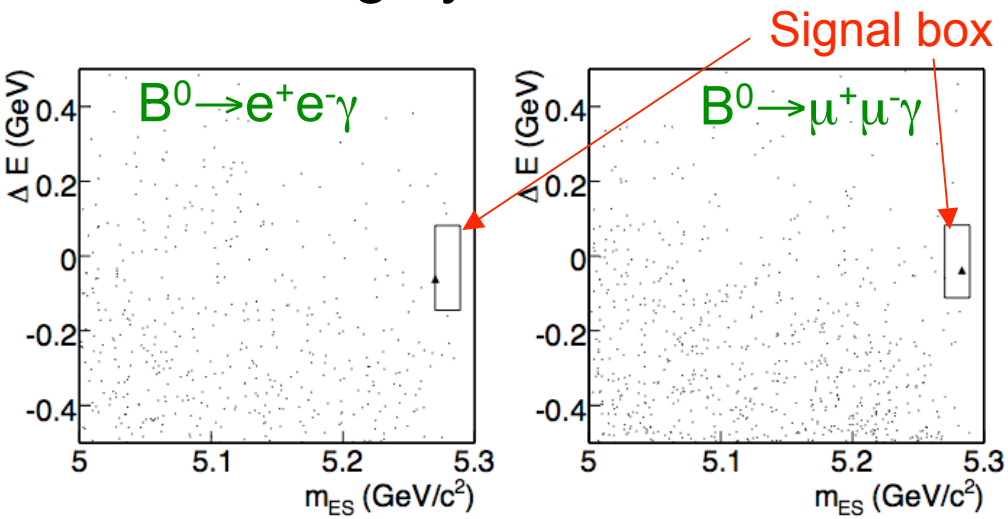
- Reconstruct two oppositely charged tracks and γ
- Signal Box is blinded until analysis is finalized.

Background

- Similar backgrounds as $B^0 \to \ell^+\ell^-$ analysis.
- Minimum photon energy: 300 MeV
- Background estimation is from sideband areas in m_{ES}-ΔE plane.

Result

- Set 90% CL UL (freq. method) including systematics.



With 320 M $B\bar{B}$ events

	# obs	# estimated	UL
$ee\gamma$	1	1.75±1.38±0.36	1.2×10^{-7}
$\mu\mu\gamma$	1	2.66±1.40±1.58	1.6×10^{-7}

Phys. Rev. D (RC) 77, 011104 (2008)