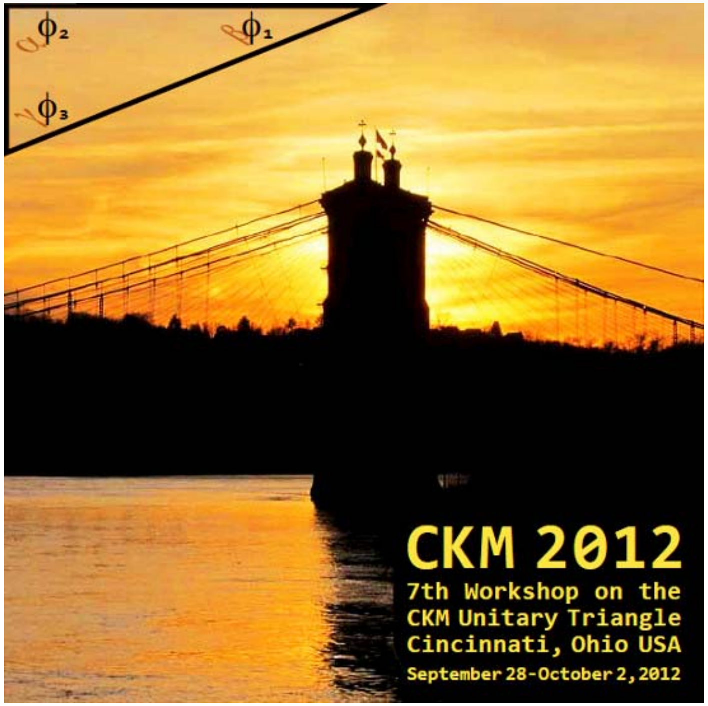
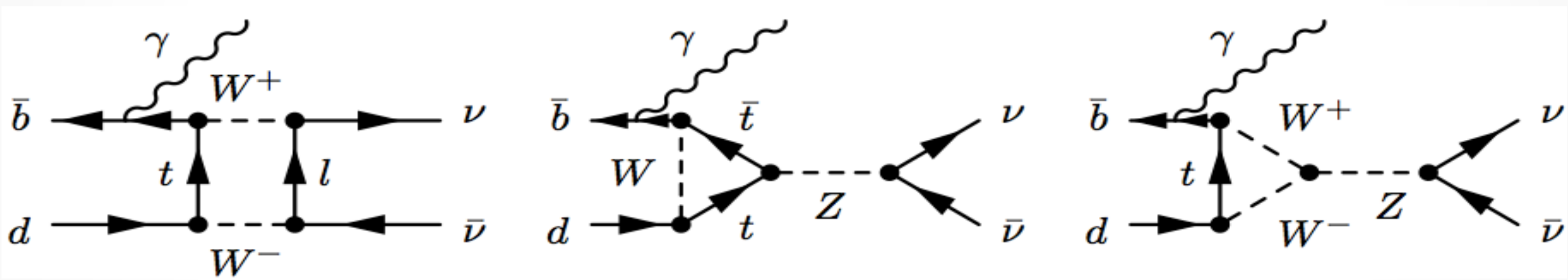


Search for $B \to \nu\bar{\nu}$ and related modes

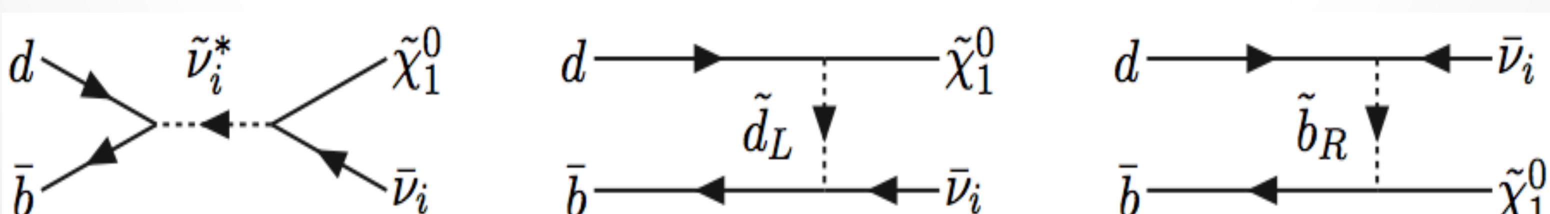
Alessandro Rossi, INFN Perugia
on behalf of BaBar collaboration

Physics Motivation

- Invisible decay products include neutrinos as well as exotic particles
- The SM $B^0 \to \nu\bar{\nu}$ decay is suppressed by a factor $(m_\nu / m_B)^2$ while the BF($B^0 \to \nu\bar{\nu}\gamma$) is of the order of 10^{-9}



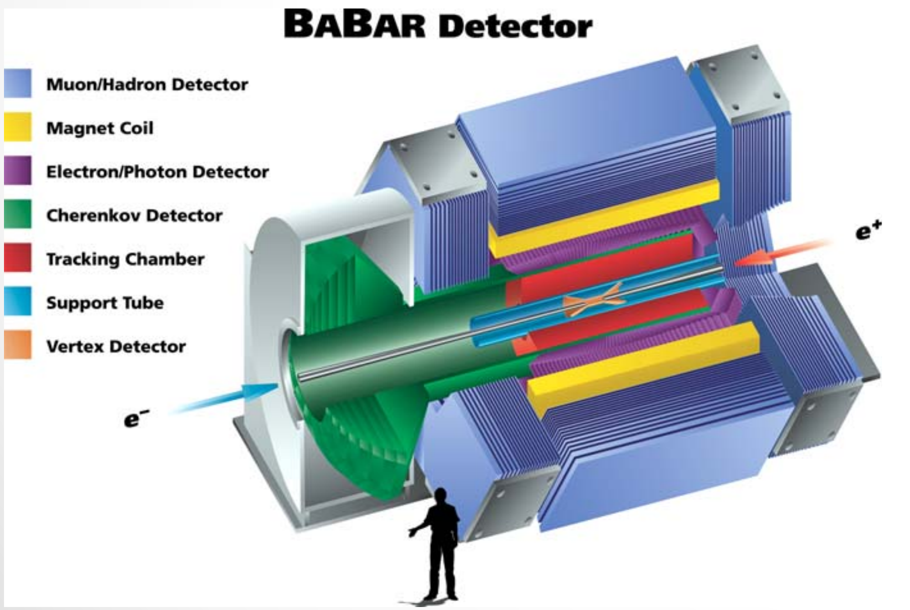
- In SUSY model **BR($B^0 \to$ Invisible)** is enhanced up to **10^{-7}-10^{-6}** due to neutrino+neutralino production in the final state

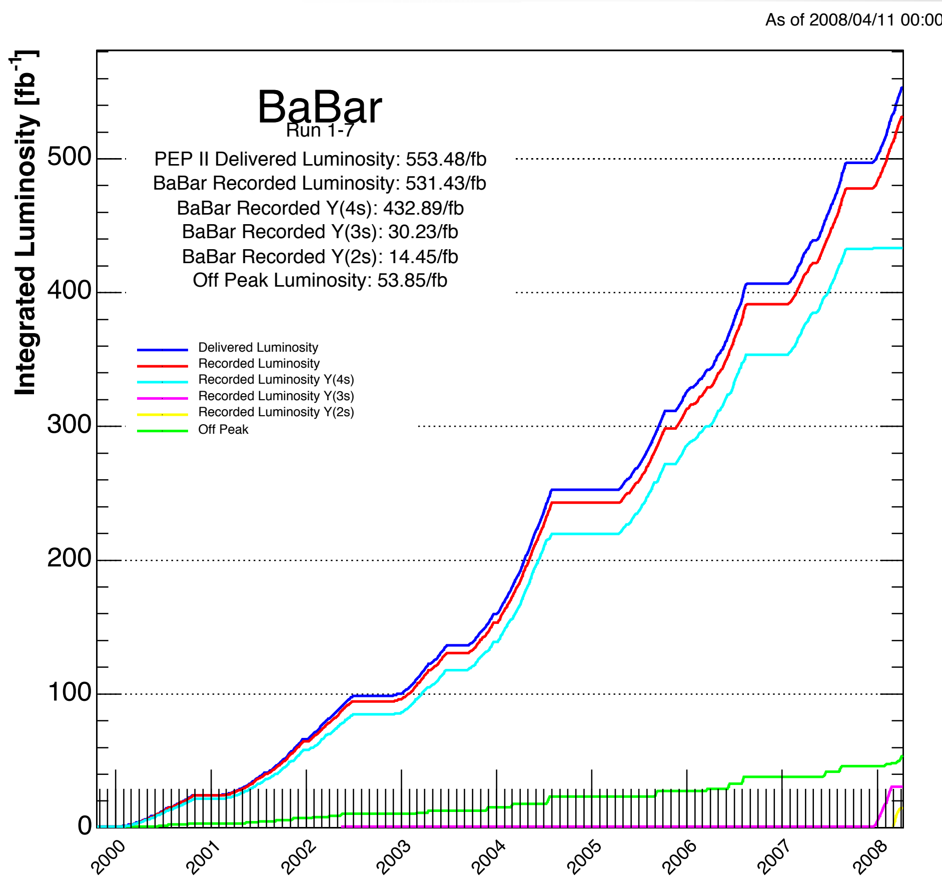


A. Dedes, H. Dreiner, and P. Richardson, hep-ph/0106199, Phys. Rev.D65, 015001 (2001)

BABAR @ PEP-II

- PEP-II @ SLAC
  - e^+e^- asymmetric energy collider
  - Center of mass energy **10.58 GeV**
    - $\Upsilon(4S)$ production
  - Runs also at $\Upsilon(2S)$ and $\Upsilon(3S)$ threshold





- "On-peak" data [@$\Upsilon(4S)$]
  - **424fb^{-1}**
  - BB Pairs: **~471M**
- "Off-peak" data
  - 40 MeV below $\Upsilon(4S)$ threshold
  - 45fb^{-1}

Analysis Overview

- Update of a previous BABAR result with an Integrated Luminosity of $88.5 fb^{-1}$

$$\mathcal{B}(B^0 \to \text{invisible}) < 22 \times 10^{-5}$$

$$\mathcal{B}(B^0 \to \text{invisible} + \gamma) < 4.7 \times 10^{-5}$$

B. Aubert et al. Phys.Rev.Lett.93:091802,2004

- New analysis strategy
- Semileptonic Recoil Technique:
  - reconstruct events in which a B^0 decays to $D^{(*)-} l^+ \nu$ ("tag side"), then look for consistency with an invisible(+γ) decay of the other neutral B ("signal side")

$B^0 \to D^- l \nu$

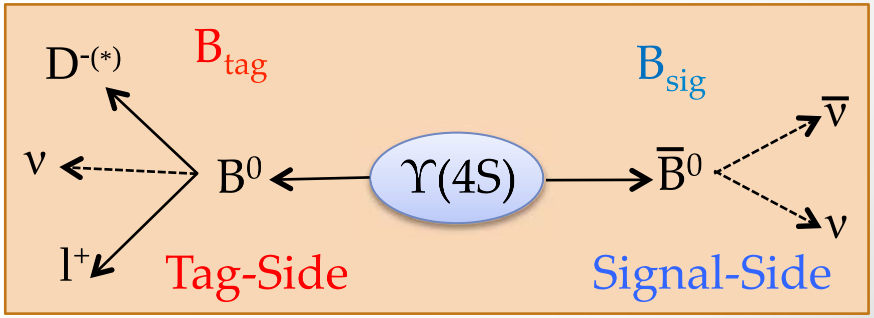
$D^- \to K^+ \pi^- \pi^-$

$D^- \to K_S \pi^-$

$B^0 \to D^{*-} l \nu$

$D^{*-} \to \overline{D}^0 \pi^-, D^- \pi^0$

$\overline{D}^0 \to K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^-\pi^+$



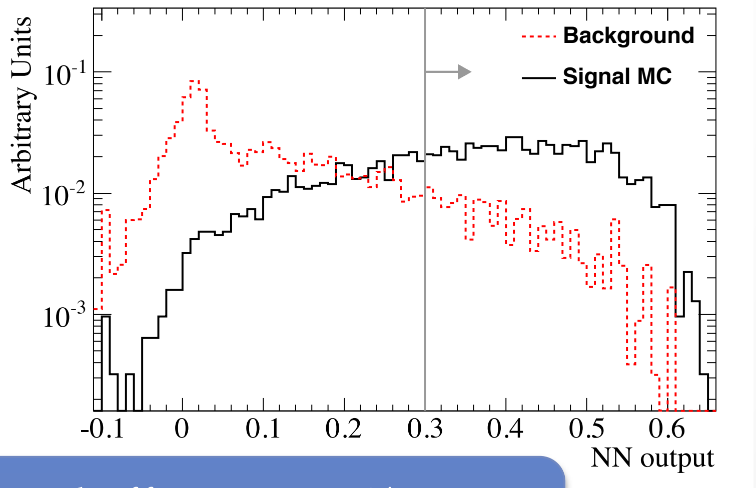
Preselection

- Preselection cuts based on :
  - o Nothing reconstructed on signal side or only one photon
  - o No extra charged tracks
  - o Missing momentum inside detector sensitive volume
    - $|\cos\theta^*_{miss}| < 0.9$: polar angle of the missing momentum
  - o Kinematical constraints on D meson decay products on tag side
  - o Events with one photon with energy > 1.2GeV are reconstructed as $B \to invisible + \gamma$

MultiVariate Analysis

- After the preselection a Neural Network is implemented
- Samples:
  - o Signal: Signal MC with D(*)lν generated on tag side (~5x10^6 events)
  - o Background: $B\bar{B}$ MC (x3 data lum.) + Off-peak data (all normalized to On-peak luminosity)
- Variables
  - o $B^0 \rightarrow$ Invisible
    - D_{tag} : 9 variables
    - D^*_{tag} : 6 variables
  - o $B^0 \rightarrow$ Invisible+γ
    - D_{tag} : 6 variables
    - D^*_{tag} : 4 variables

$$M^{tag}_{miss} = \sqrt{s - (P_D + P_\ell)^2} \qquad \cos\theta_{BY} = \frac{2E^*_B E^*_{Dl} - m^2_B - m^2_{Dl}}{2p^*_B p^*_{Dl}}$$



- Signal efficiency 50%
- Background rejection 85%

Signal extraction

- Unbinned Maximum Likelihood fit to E_{extra}

E_{extra} : "neutral energy that remains after all tag side tracks and neutral clusters have been accounted for"

- Fit strategy:
  - Offpeak can not be used, very low statistics
  - Background shape from M_D and ΔM Onpeak data sidebands
    - Side bands M_D : 15 MeV< | M_D-M_D^{PDG} | <60MeV
    - Side band ΔM : 148 MeV< ΔM<155 MeV
  - In this way the measured upper limit will not depend on the E_{extra} shape of the Offpeak data
  - Signal shape from MC simulation

M_D : D meson invariant mass

ΔM : difference between D* invariant mass and PDG D mass

E_{extra} Likelihood

$$\mathcal{L}(N_{sig}, N_{bkg}) = \frac{[(1-f_{sig})N_{sig} + (1-f_{bkg})N_{bkg}]^{N_1}\, e^{-[(1-f_{sig})N_{sig}+(1-f_{bkg})N_{bkg}]}}{N_1!}$$
$$\times \prod_{i=1}^{N_1}\left[P_{sig}(E_{extra,i}|\vec{p}_{sig})\frac{(1-f_{sig})N_{sig}}{N_1} + P_{bkg}(E_{extra,i}|\vec{p}_{bkg})\frac{(1-f_{bkg})N_{bkg}}{N_1}\right]$$
$$\times \frac{(f_{sig}N_{sig} + f_{bkg}N_{bkg})^{N_0}\, e^{-(f_{sig}N_{sig}+f_{bkg}N_{bkg})}}{N_0!}$$

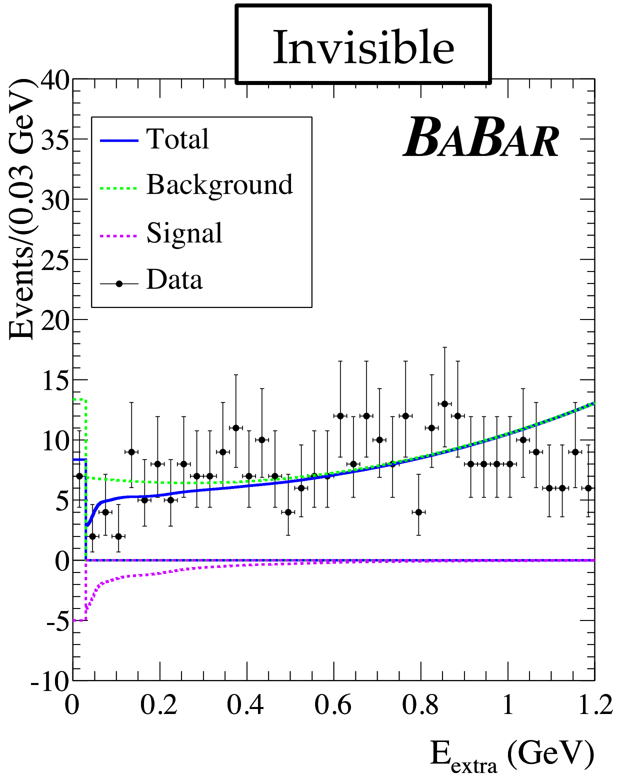
- Minimum neutral energy threshold 30 MeV
  - E_{extra} distribution not continuous
- Two different likelihood terms form E_{extra}>30MeV (N_1) and E_{extra}<30MeV (N_0)
- f_{sig} and f_{bkg} fraction of events with E_{extra}<30MeV (fixed)
- P_{sig} and P_{bkg} PDF distributions (fixed)

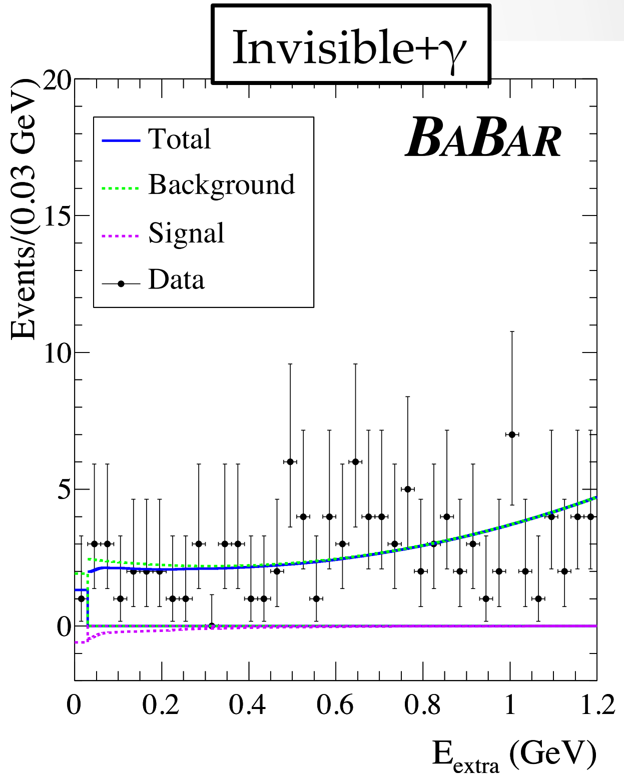
Signal Yield Extraction

- $B^0 \rightarrow$Invisible signal yield compatible with zero if systematic errors are considered

- $B^0 \rightarrow$Invisible+γ signal yield compatible with zero within 0.6σ

Mode	N_{sig}	N_{bkg}
$B^0 \rightarrow$ invisible	-22 ± 9	334 ± 21
$B^0 \rightarrow$ invisible+γ	-3.1 ± 5.2	113 ± 12





Systematic Uncertainties

- Signal Efficency:
  - Tag Efficency
    - From : $B\bar{B}$ MC + Offpeak data DoubleTag samples
  - Cut on D mass (ΔM)
    - Change Signal Region window
  - Preselection
    - Smearing of Signal variables
  - Neural Network
    - Smearing of Signal Input variables
  - Neutral Energy Resolution
    - Single Photon from π^0 decay

- B Counting
  - systematic error of 0.6%

- Signal Yield:
  - Background Parametrization
  - Signal Parametrization
  - E_{extra} Shape

Source	$B^0 \to$ invisible	$B^0 \to$ invisible+γ
Normalization Errors		
B-counting	0.6%	0.6%
Efficiency Errors		
Tagging Efficiency	3.5%	3.5%
m_D (Δm) Selection	1%	1.3%
Preselection	3%	2.4%
Neural Network	6.1%	8.2%
Single Photon	–	1.8%
TOTAL	7.7%	9.5%
Yield Errors (events)		
Background Param.	15.8	6.5
Signal Param.	2.0	1.2
Fit Technique	–	1.0
$E_{\rm extra}$ Shape	0.1	1.8
TOTAL	15.9	6.9

Upper Limit @ 90% C.L.

B→Invisible		
N_{BB}	ε_{sig}	N_{sig}
$(471\pm3)\times10^{6}$	$(1.776\pm0.021\pm0.137)\times10^{-3}$	$-22\pm9\pm16$
B→Invisible+γ		
N_{BB}	ε_{sig}	N_{sig}
$(471\pm3)\times10^{6}$	$(1.595\pm0.020\pm0.148)\times10^{-3}$	$-3.1\pm5.2\pm6.9$

$$\mathcal{BR} = \frac{N_{sig}}{\varepsilon_{sig} \cdot N_{B\bar{B}}}$$

- **Bayesian evaluation of the ULs:**
  - **BR(B→Invisible)<2.4x10^{-5} (at 90% C.L)**
  - **BR(B→Invisible+γ)<1.7x10^{-5} (at 90% C.L)**

Conclusions

This analysis:

arXiv: hep-ex/1206.2543

- B→Invisible
  - Signal Yield: $-22\pm9_{(stat)}\pm16_{(sys)}$
  - Signal Efficiency: $(1.78\pm0.02_{(stat)}\pm0.14_{(syst)})x10^{-3}$
- B→Invisible+γ
  - Signal Yield: $-3.1\pm5.2_{(stat)}\pm6.9_{(sys)}$
  - Signal Efficiency: $(1.60\pm0.02_{(stat)}\pm0.15_{(syst)})x10^{-3}$

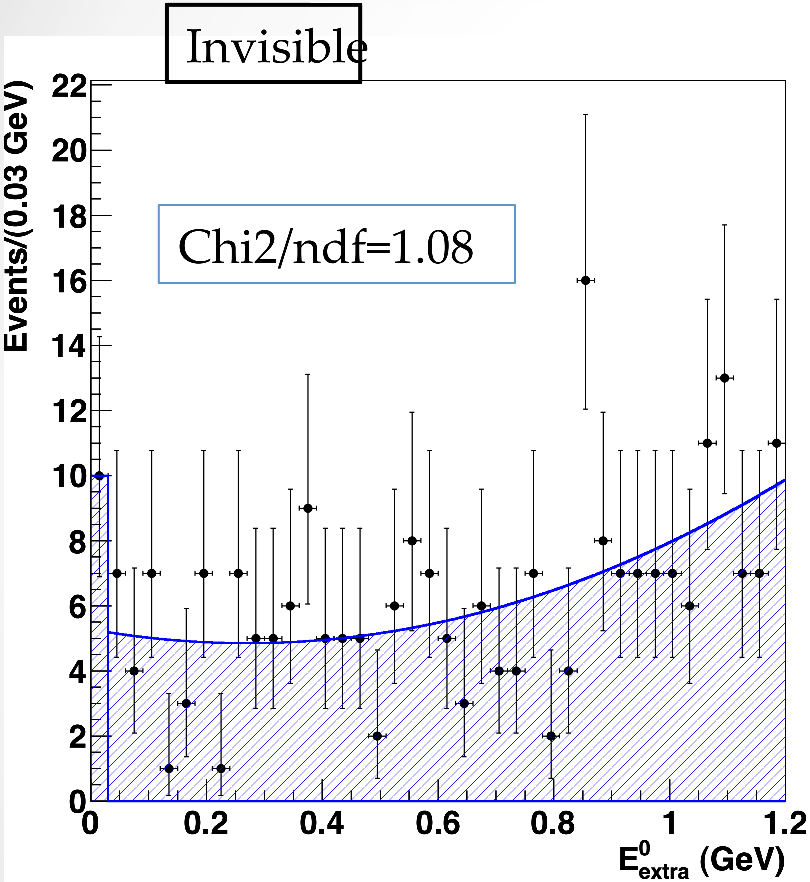
Upper Limits

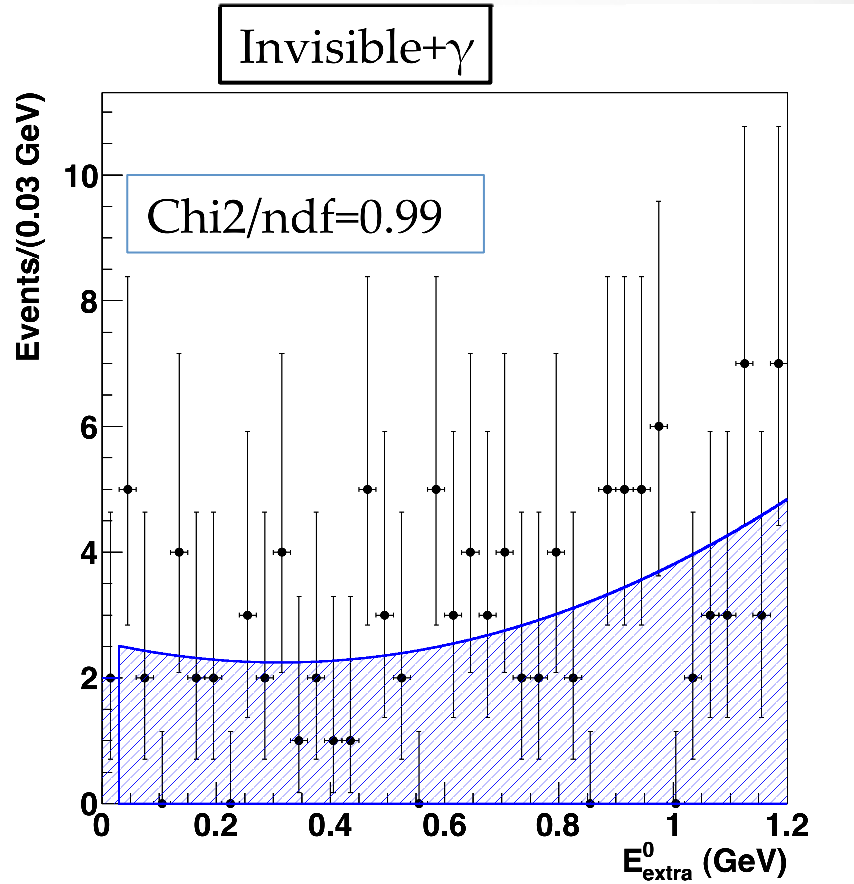
- **B to Inv. : $2.4x10^{-5}$**
- **B to Inv.+ γ : $1.7x10^{-5}$**
- **Improved by a factor 9 and 4 w.r.t previous BABAR results**
- Still far (1 order of magnitude) from NP sensitivity
  - New generation High Luminosity b-factories

Published Sep 27, Phys. Rev. D 86, 051105(R) (2012)

Back-UP

Background shape



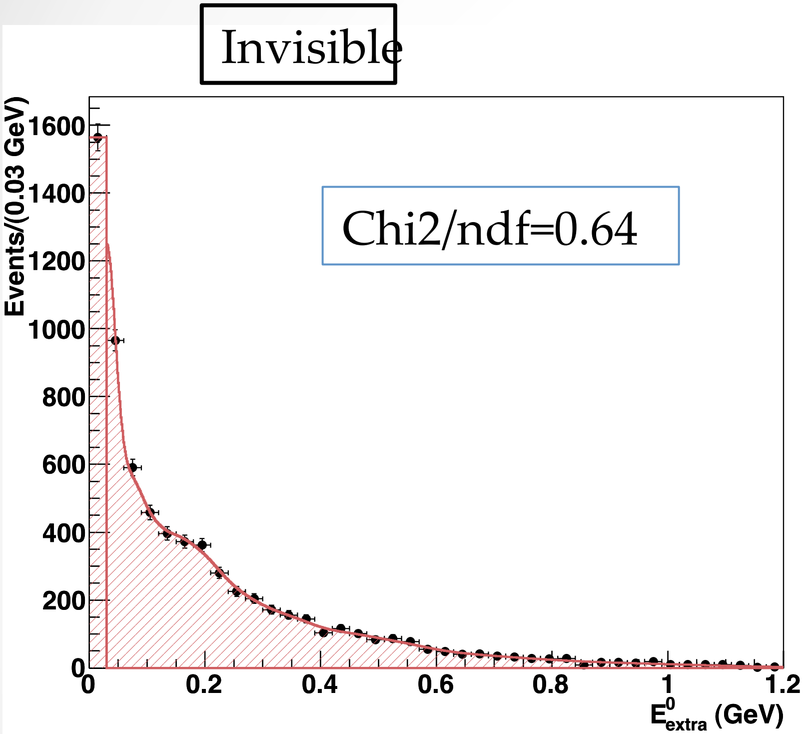


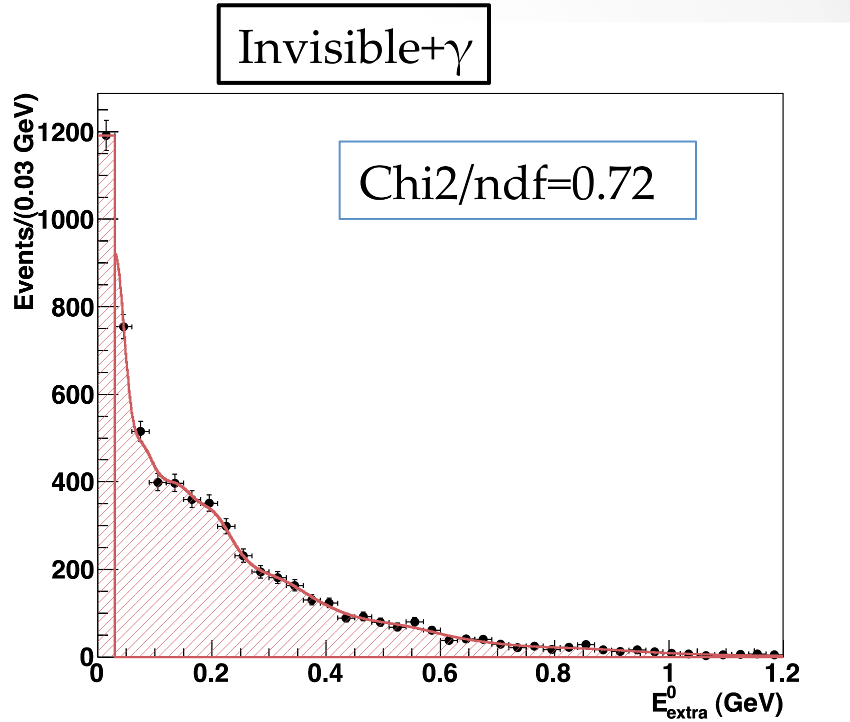
- Onpeak data M_D (ΔM) sidebands
- 2nd order polynomial plus a bin for Eextra=0

$$P_{bkg} \propto m_{bkg} \cdot E^0_{extra} + q_{bkg} \cdot (E^0_{extra})^2$$

	$B \to Inv.$	$B \to Inv. + \gamma$
z_{bkg}	0.040 ± 0.012	0.017 ± 0.012
$m_{bkg}(GeV^{-1})$	-0.60 ± 0.79	-0.80 ± 0.98
$q_{bkg}(GeV^{-2})$	1.10 ± 0.57	1.28 ± 0.74

Signal shape





- MC simulation
- RooKeysPDF (not analytic function) plus a bin for Eextra=0
  - Superposition of gaussian kernels one for each point with a 1/N weight

	$B \to Inv.$	$B \to Inv. + \gamma$
z_{sig}	0.226 ± 0.005	0.195 ± 0.005

Bayesian Approach

- Flat prior probability is assumed for positive values of branching fraction
- Gaussian likelihood is adopted for signal yield
  - Width is fixed to the sum in quadrature of the statistical and systematic yield errors
- Efficiency and normalization modeled with Gaussian PDF
- Posterior PDF extracted using Bayes' theorem
  - Random BR, number of BB pairs and efficiency
  - BR weighted with the probability that the Number of signal event calculated is coming from the Gaussian likelihood

$$\int_0^{UL} \mathcal{P}(\mathcal{B})d\mathcal{B} \Big/ \int_0^{\infty} \mathcal{P}(\mathcal{B})d\mathcal{B} = 0.9$$

Zero Signal Hypothesis

- Same method to evaluate the UL
- Same statistical and systematic errors
- Hypothesis $N_{sig}=0$ for both channel
- UL at 90% C.L.
  - o 3.8×10^{-5} wrt 2.4×10^{-5}
  - o 1.9×10^{-5} wrt 1.9×10^{-5}

Control Sample

- "Unphysical" decay $B^+ \to$ Invisible(γ) as control sample
- Same selection applies as for $B^0 \to$ Invisible(γ)
- Results compatible with zero within 1.1σ (stat. only)

- $B^+ \to$ Invisible
  - N_{sig}: -4.3±3.8
- $B^+ \to$ Invisible+γ
  - N_{sig}: -7.9±8.3