Searches for Rare and Forbidden B and Charm Decays with BABAR

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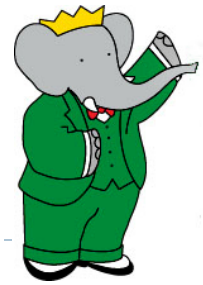
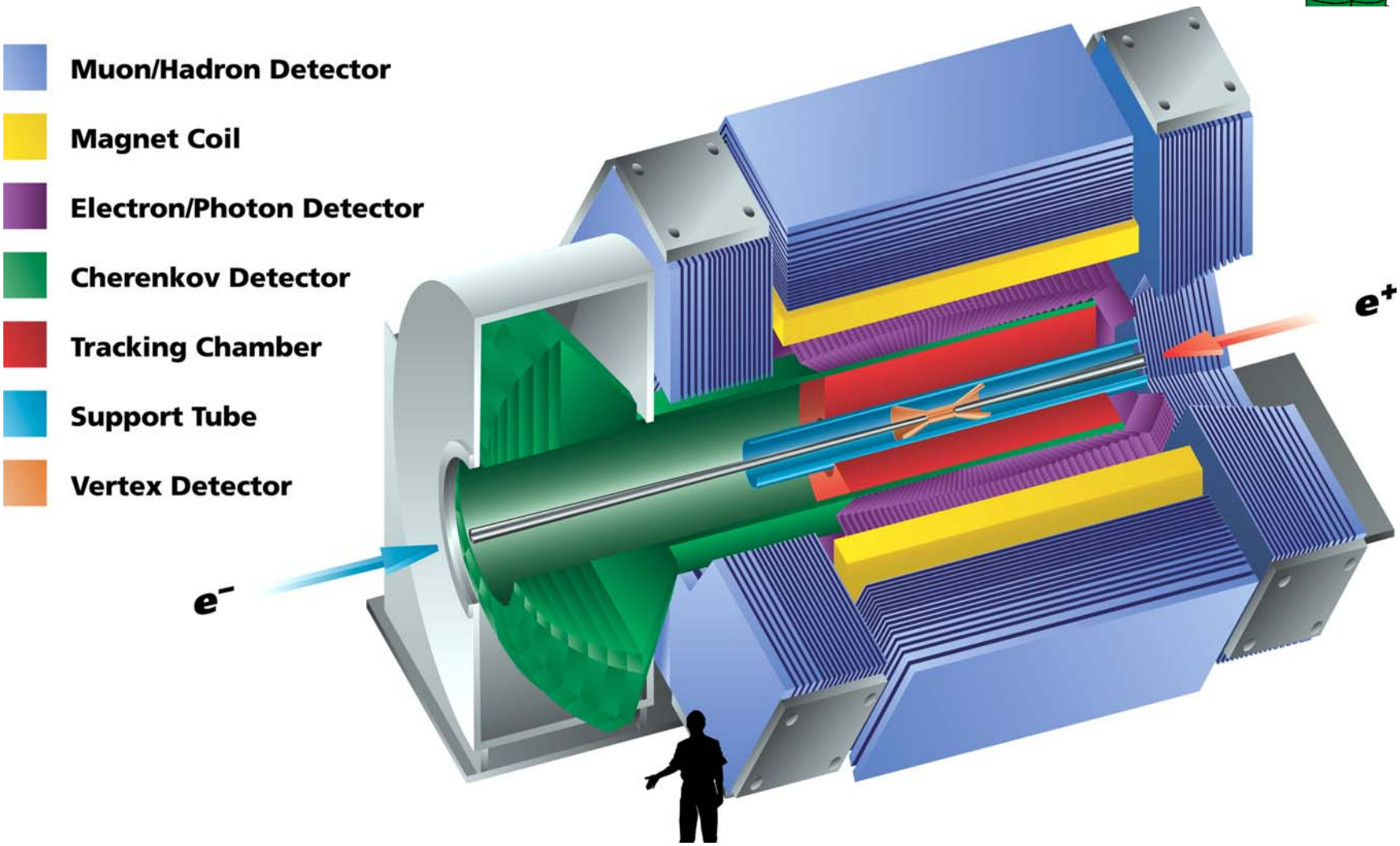
on behalf of BABAR collaboration

Outline



- The BABAR detector & dataset
- B-physics
  - Very rare FCNC decay : $B \to \gamma\gamma$
  - Very rare BNV decays : $B \to \Lambda_{(c)} l$
- Charm-physics
  - Very rare FCNC: $D \to \gamma\gamma$
  - $X_c \to hll$ with $X_c = D$, D_s and Λ_c

The BABAR detector

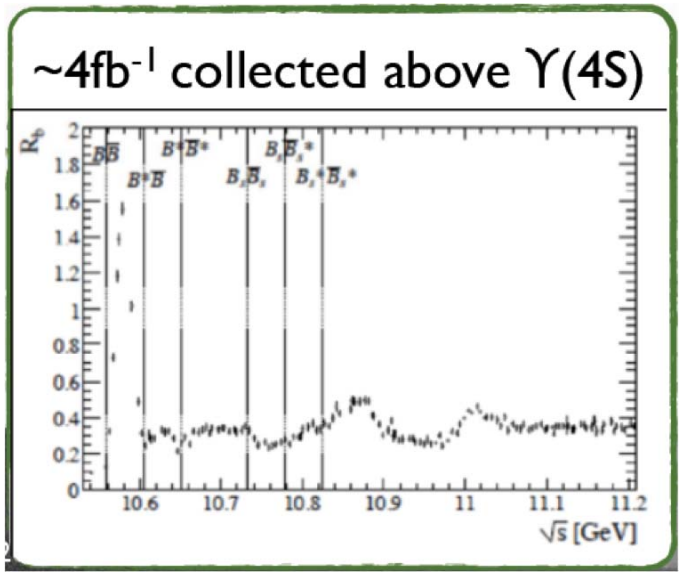


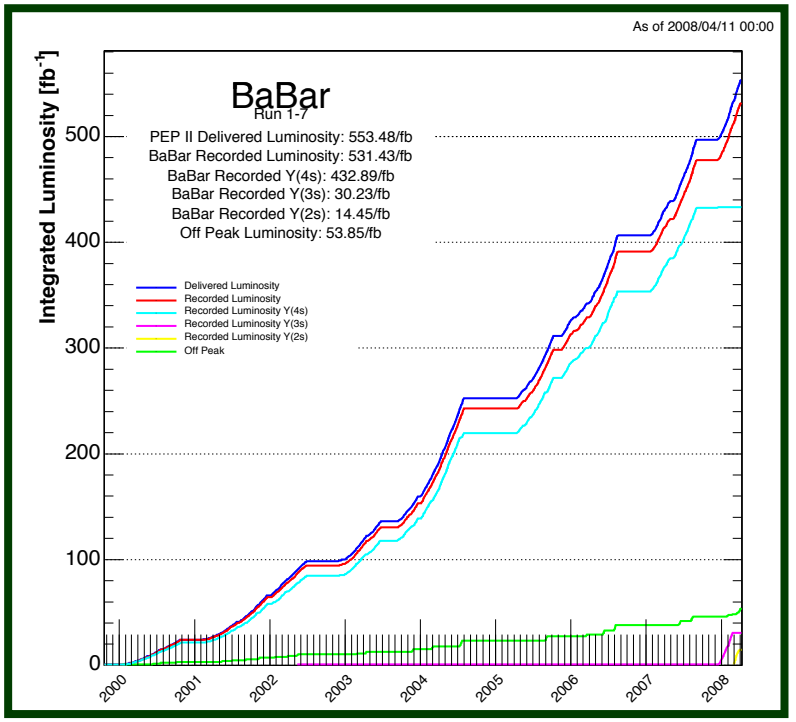
Dataset

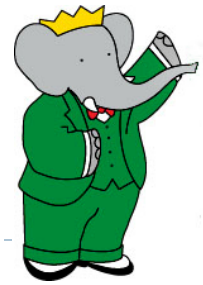
- 530 fb^{-1} in the 9 years of operation
  - ~470x10^6 BB pairs

Not only BB pairs:
690M cc pairs
500M $\tau\tau$ pairs

sample	fb^{-1}
$\Upsilon(4S)$	430
$\Upsilon(3S)$	30.2
$\Upsilon(2S)$	14.5
Off-Υ(nS)	54

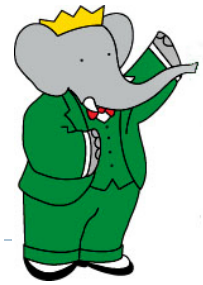






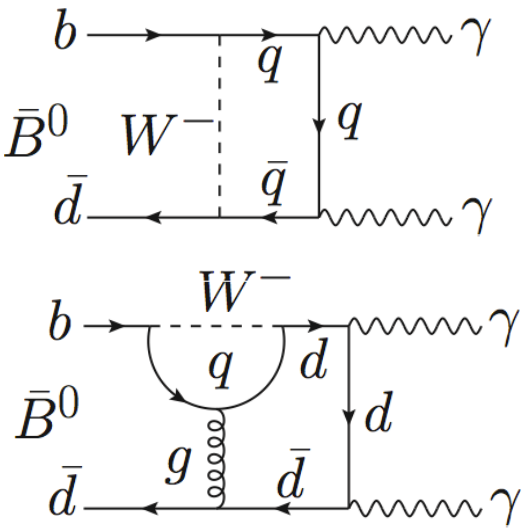
B physics

$B \to \gamma\gamma$: Motivation



- $B \to \gamma\gamma$ is an effective FCNC $b \to d\gamma\gamma$
- Small SM BF :
  - @ L.O. $BF_{SM} \sim 3.1^{+6.4}_{-1.6} \times 10^{-8}$

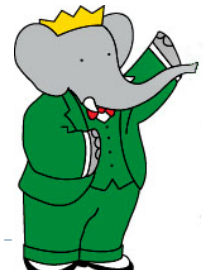
JHEP 0208:054 (2002)



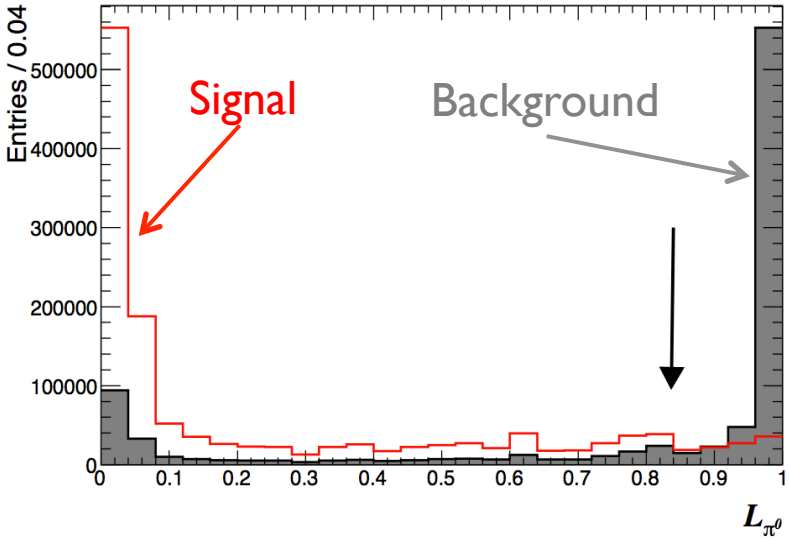
- Different NP scenarios can enhance the BF:
  - Extended Higgs sector *PRD 58,095014 (1998)*
  - Susy with broken R-parity *PRD 70,35008 (2004)*

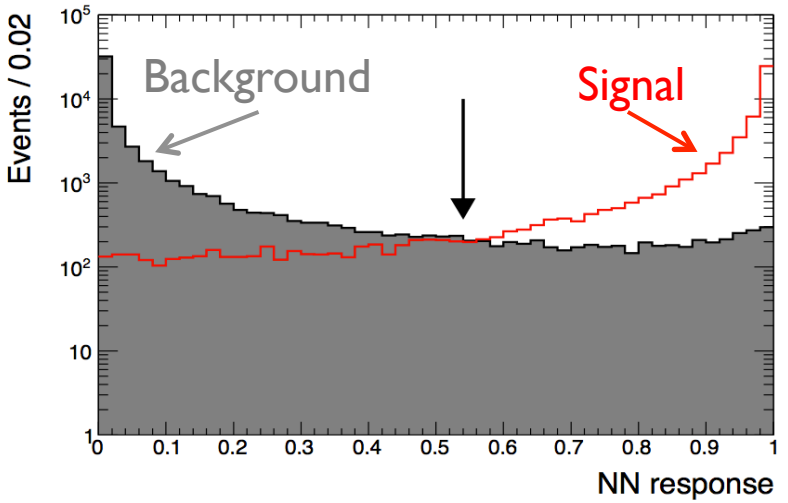
Best Limit to date : $BF(B \to \gamma\gamma) < 6.2 \times 10^{-7}$ @ 90% C.L
Belle, *PRD 73,051107 (2006)*

B→γγ : Backgrounds



- **Main background sources:**
  - π^0 and η decays
    - Rejected through a likelihood ratio technique based on $m(\gamma\gamma')$ and $E_{\gamma'}$
  - Out-of-time Bhabha events
    - Rejected with total energy and timing cuts
  - Continuum background events
    - Neural Network based on 19 input variables

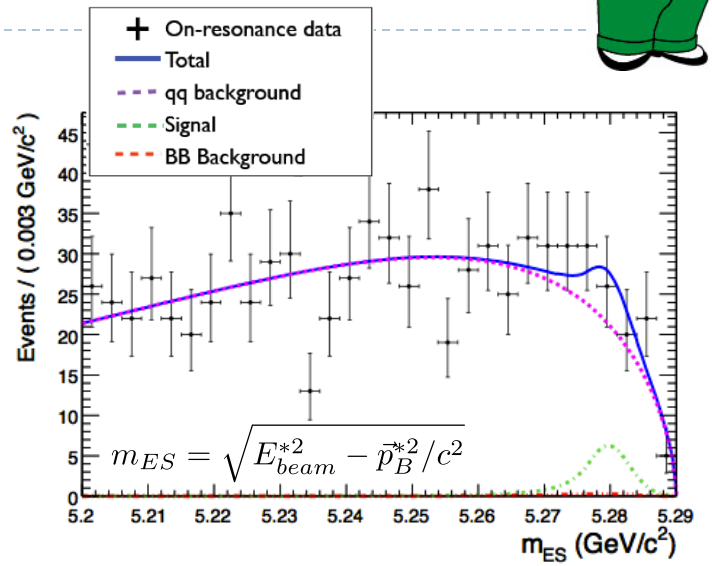


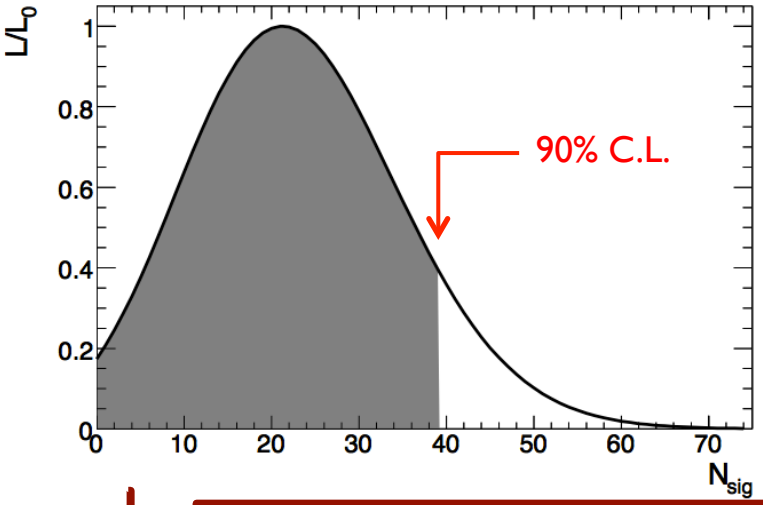


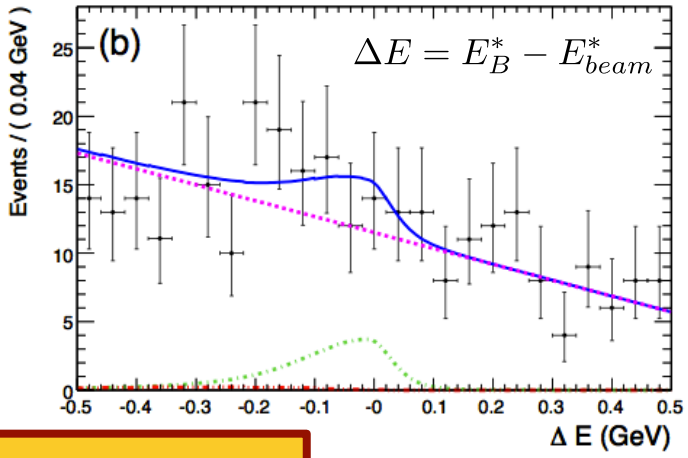
B→γγ : Result

- 2D likelihood fit to m_{ES} and ΔE
- Signal Yield: 21^{+13}_{-12}

BF(B→γγ)= (1.7±1.1$_{stat}$±0.2$_{sys}$)×10^{-7}
1.9σ significance



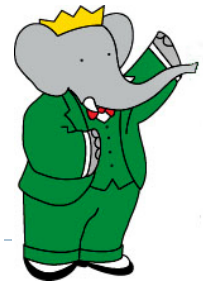




Upper Limit: BF(B→γγ)<3.3x10^{-7} @ 90% C.L.

PRD 83,032006 (2011)

$B \to \Lambda_{(c)} l$: Motivation

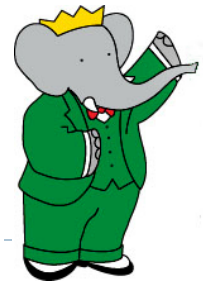


- An explanation for matter-antimatter asymmetry require:
  - CP violation (CPV)
  - Baryon number violation (BNV)
- SM CPV and BNV cannot explain asymmetry
- Search for BNV extra sources:

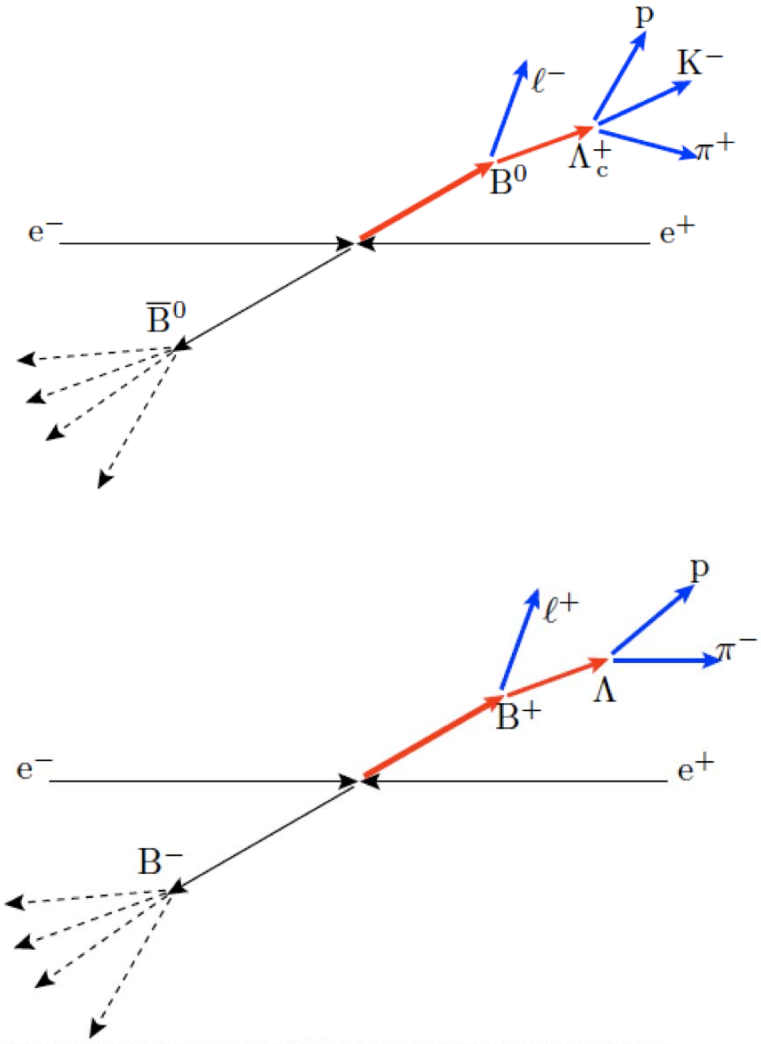
  $l = e, \mu$

  - $B^0 \to \Lambda_c^+ l^-$ where $\Lambda_c^+ \to p K^- \pi^+$
    - $BF_{SM}(B^0 \to \Lambda_c^+ l^-) < 4 \times 10^{-29}$ *PRD 72,095011 (2002)*
  - $B^- \to \Lambda^0 l^-$ where the $\Lambda^0 \to p \pi^-$
  - $B^- \to \Lambda^{0}\text{-bar}\, l^-$ where the $\Lambda^{0}\text{-bar} \to \text{p-bar}\, \pi^-$
- First measurement of the BF for these decays

$B \rightarrow \Lambda_{(c)} l$: Technique



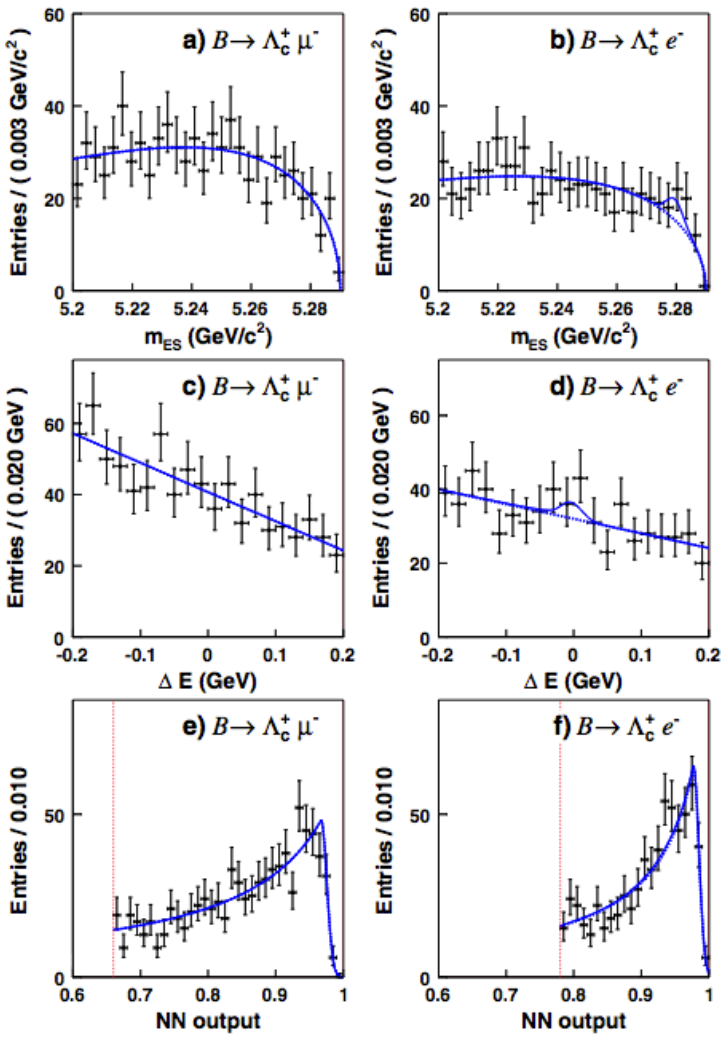
- Finale state hadrons and leptons selected through PID algorithms
  - Use of dE/dx, DIRC, EMC and IFR information
- Candidate selection optimization by balancing both lowest UL and signal sensitivity
  - Punzi FoM : $\frac{\varepsilon_{sig}}{a/2 + \sqrt{N_{bkg}}}$, a=5
- Background $e^+e^- \rightarrow e^+e^-\gamma$ ($\gamma \rightarrow e^+e^-$) rejected requiring more than 4 ch. trks in the event.
- Multivariate classifier (NN) based on 6 variables



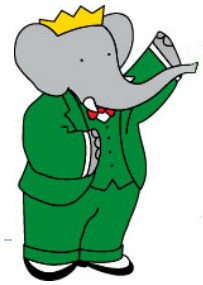
$B \to \Lambda_{(c)} l$: Result

- Dataset: 429 fb^{-1} @ $\Upsilon(4S)$ (470M BB pairs)
- Unbinned extended maximum likelihood fit to extract Signal yield
- 2D PDF in $m_{ES}/\Delta E$ plane (3D with TMVA output for Λ_c decay modes)
- No significant signal observed

Decay mode	N_{cand}	$\mathcal{B}$ ($\times 10^{-8}$)	ϵ (%)	$\mathcal{B}_{90\%}$ ($\times 10^{-8}$)
$B^0 \to \Lambda_c^+ \mu^-$	814	-4^{+71}_{-56}	26.3 ± 0.9	180
$B^0 \to \Lambda_c^+ e^-$	651	190^{+130}_{-90}	25.7 ± 0.7	520
$B^- \to \Lambda \mu^-$	320	$-2.3^{+3.5}_{-2.5}$	28.7 ± 0.9	6.2
$B^- \to \Lambda e^-$	194	$1.2^{+3.7}_{-2.6}$	27.2 ± 0.6	8.1
$B^- \to \bar{\Lambda} \mu^-$	192	$1.5^{+2.6}_{-1.7}$	31.3 ± 1.0	6.1
$B^- \to \bar{\Lambda} e^-$	74	$-0.9^{+0.7}_{-0.0}$	30.0 ± 0.6	3.2

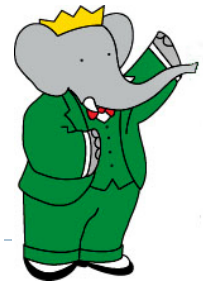


PRD 83,091101(R) (2011)

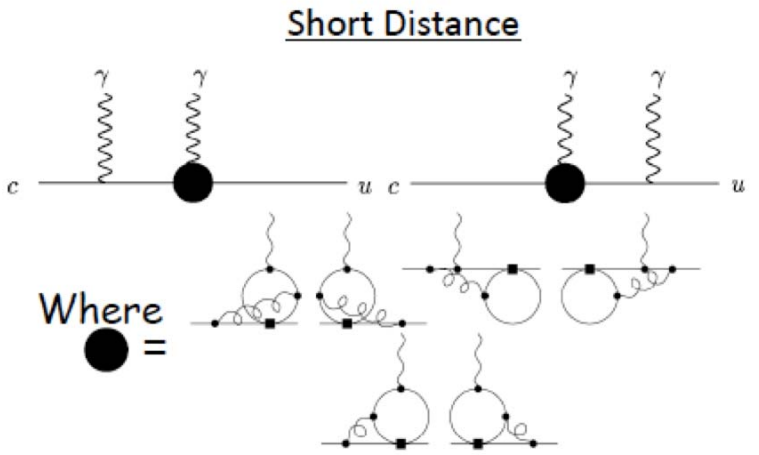


Charm physics

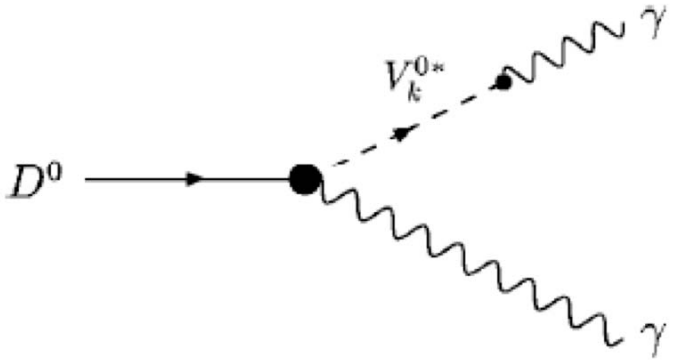
D→γγ : Motivation



- FCNC, large suppression at loop level from the GIM mechanism
- SM dominated by long-distance contribution *PRD 66,014009 (2002)*
- Looking for NP entering the loop



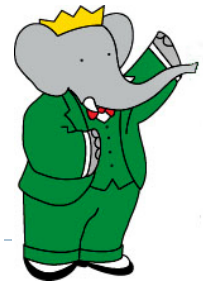
Long Distance



Theoretical predictions	
Mode	Value
$D^0 \to \gamma\gamma$ (SM,VMD)	$\approx (3.5\ ^{+4.0}_{-2.6}) \times 10^{-8}$
$D^0 \to \gamma\gamma$ (SM,HQχPT)	$(1.0 \pm 0.5) \times 10^{-8}$
$D^0 \to \gamma\gamma$ (MSSM)	6×10^{-6}

Experimental results	
Mode	Value
$D^0 \to \gamma\gamma$	$< 2.7 \times 10^{-5}$ *CLEO, PRL 90,101801 (2003)*
$D^0 \to \pi^0\pi^0$	$(8.0 \pm 0.8) \times 10^{-4}$
$D^0 \to K^0_S\pi^0$	$(1.22 \pm 0.05) \times 10^{-2}$

$D \to \gamma\gamma$: Technique

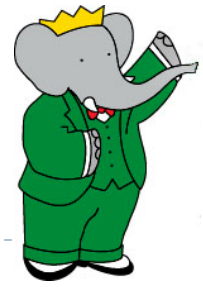


- Signal dominated by combinatorial background
  - Require a D meson originates in $D^{*+} \to D^0\pi^+$ (D^{*+} tag)
- BF measurement relative to BF $(D^0 \to K^0_S\pi^0)=(1.22\pm0.05)\%$
- Dominant background from $D \to \pi^0\pi^0$
  - Rejected through a π^0 veto (95% bkg rejected, 66% signal kept)

D*+ tag: D from $D^* \to \pi D$
Normalized to $D \to K\pi D$

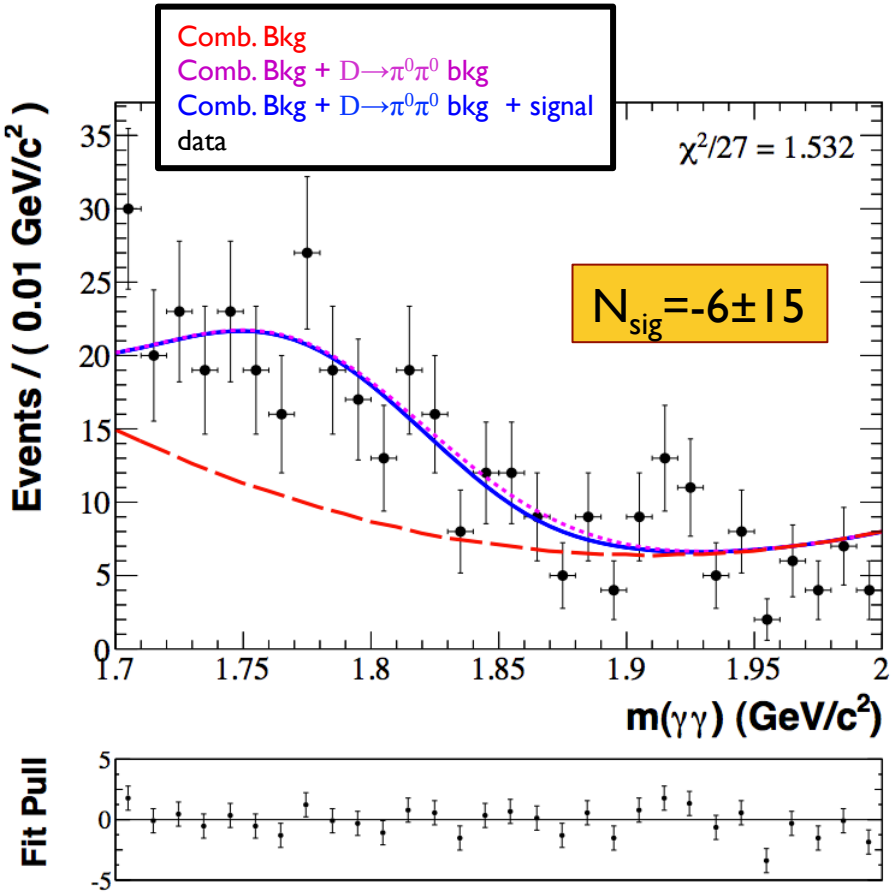
	$D^0 \to \gamma\gamma$	$D^0 \to \pi^0\pi^0$
selection efficiency		
signal	15.2 %	6.1%
normalization	12.0%	7.6%

D→γγ : Result



- Unbinned likelihood fit to D^0 invariant mass

Preliminary, 470.5fb^{-1}



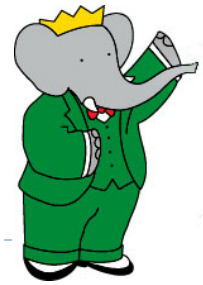
Main systematic due to π^0-veto

Source of Systematic Uncertainty	$\sigma(D^0 \to \gamma\gamma)$ (%)
Tracking (K^0_S) and Vertexing	0.96
Photon Reconstruction	0.60
π^0 Veto	1.80
D^{*+} Hadronization	0.02
Signal Shape	*
Background Shape	*
Selection Criteria	*
$D^0 \to K^0_S\pi^0$ Signal Shape	0.53
$D^0 \to K^0_S\pi^0$ Background Shape	0.01
$D^0 \to K^0_S\pi^0$ Selection Criteria	0.76
Total Systematic Uncertainty	*

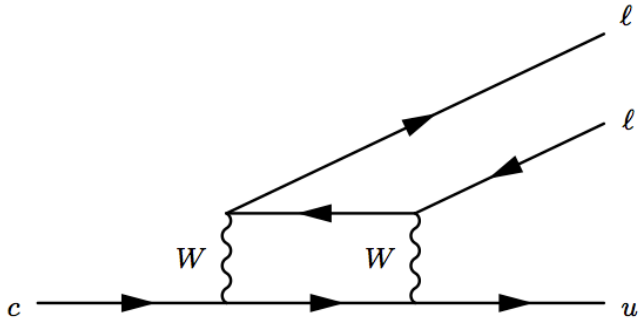
BF(D→γγ)<2.4x10^{-6} @ 90% C.L.

x10 improvement wrt PDG

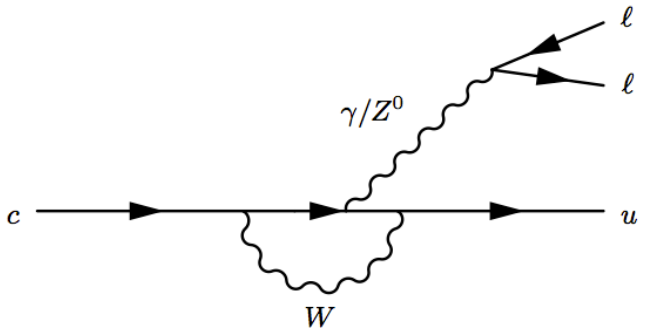
$X_c \rightarrow hll$: Motivation



- Search for decays of the form: $X_c \rightarrow hll$
  - X_c: D^+, D^+_S or Λ^+_C
  - l : e or μ
  - h : K or π for D and p for Λ^+_C

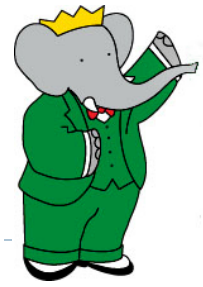


- Charm decays heavily GIM suppressed in SM: BF(c→ull)~10^{-8}

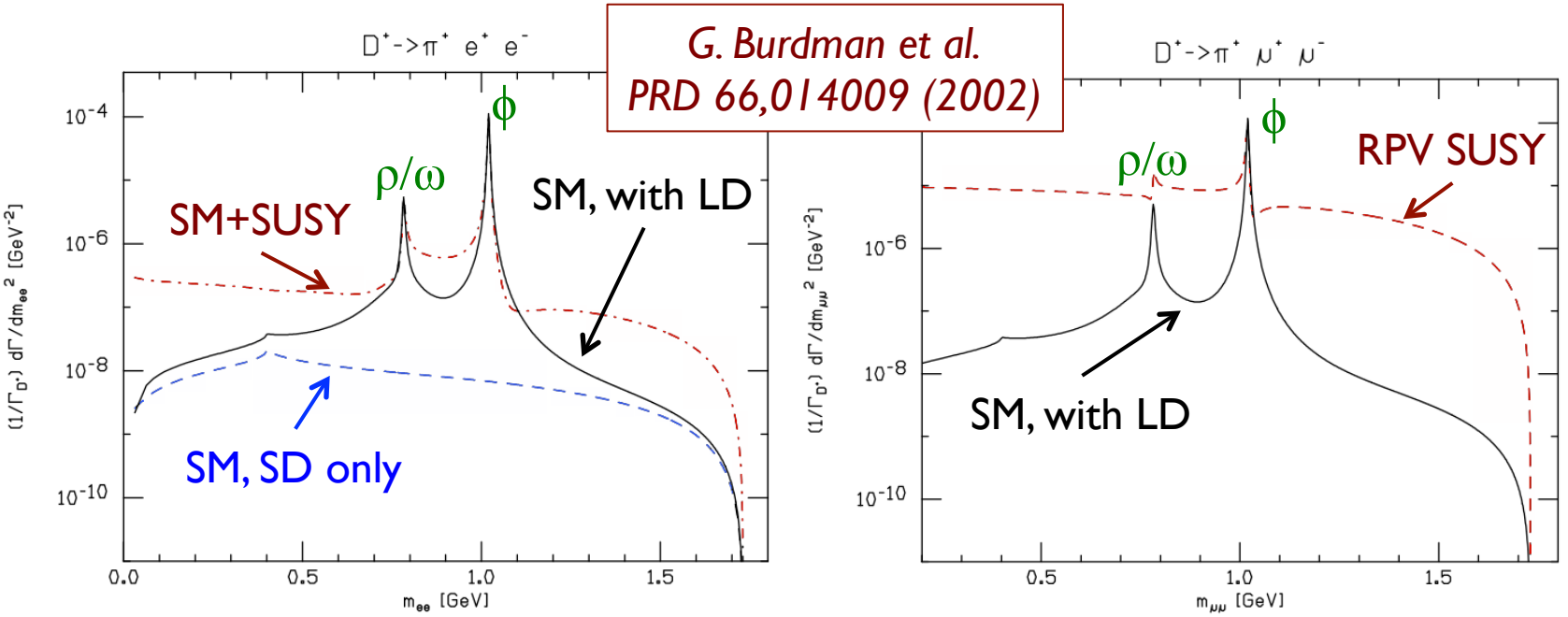


- Some NP models increase BF up to 10^{-5}
  - *PRD 66,014009 (2002), PRD 73,054036 (2006), PRD 83,114006 (2011)*
- Also looking for exotic decays violating lepton flavor and/or lepton number

$X_c \to hll$: Technique

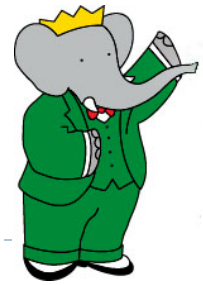


- FCNCs in SM have contributions from leptonic decays of intermediate resonances: $D_{(s)} \to hV$, $V \to ll$

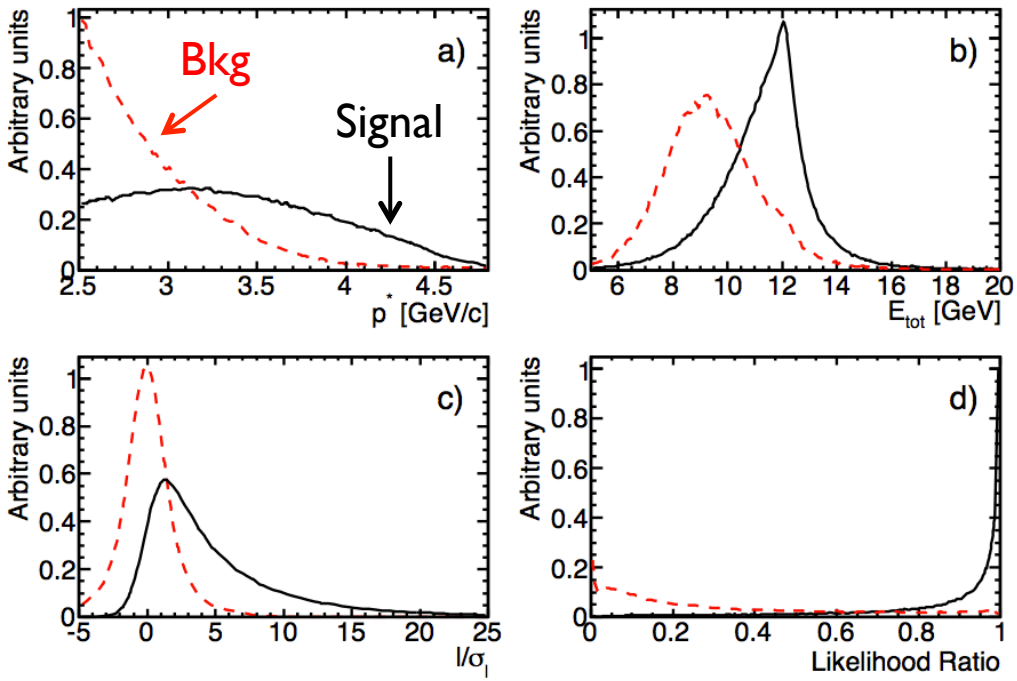


- At current sensitivities only the ϕ resonance contributes
- Can be removed by cutting on ll invariant mass

$X_c \to hll$: Background

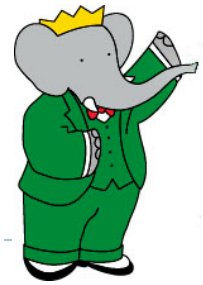


- Main background sources:
  - QED events (Bhabha)
    - Rejected requiring at least 5 tracks
  - Semileptonic B and charm decay
    - Rejected by requiring the two leptons to be consistent with common origin
- Final candidate selection through a Likelihood ratio
  - 3 discriminating variables



a) CoM momentum of the X_c candidate
b) Total energy in the event
c) Flight length significance
d) Likelihood ratio

$X_c \to hll$: Result



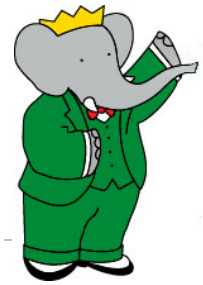
- Unbinned likelihood fit to X_c invariant mass
- Most channels improve upon previous limit

Decay mode	BF UL (10^{-6}) 90% CL		
$D^+ \to \pi^+ e^+ e^-$	1.1	5.9	CLEO-c
$D^+ \to \pi^+ \mu^+ \mu^-$	6.5	3.9	D0
$D^+ \to \pi^+ e^+ \mu^-$	2.9	34	E791
$D^+ \to \pi^+ \mu^+ e^-$	3.6	34	E791
$D_s^+ \to \pi^+ e^+ e^-$	13	22	CLEO-c
$D_s^+ \to \pi^+ \mu^+ \mu^-$	43	26	FOCUS
$D_s^+ \to \pi^+ e^+ \mu^-$	12	610	E791
$D_s^+ \to \pi^+ \mu^+ e^-$	20	610	E791
$D^+ \to K^+ e^+ e^-$	1.0	3.0	CLEO-c
$D^+ \to K^+ \mu^+ \mu^-$	4.3	9.2	FOCUS
$D^+ \to K^+ e^+ \mu^-$	1.2	68	E791
$D^+ \to K^+ \mu^+ e^-$	2.8	68	E791
$D_s^+ \to K^+ e^+ e^-$	3.7	52	CLEO-c
$D_s^+ \to K^+ \mu^+ \mu^-$	21	36	FOCUS
$D_s^+ \to K^+ e^+ \mu^-$	14	630	E791
$D_s^+ \to K^+ \mu^+ e^-$	9.7	630	E791
$\Lambda_c^+ \to p e^+ e^-$	5.5	340	E653
$\Lambda_c^+ \to p \mu^+ \mu^-$	44		
$\Lambda_c^+ \to p e^+ \mu^-$	9.9		
$\Lambda_c^+ \to p \mu^+ e^-$	19		

Decay mode	BF UL (10^{-6}) 90% CL		
$D^+ \to \pi^- e^+ e^+$	1.9	1.1	CLEO-c
$D^+ \to \pi^- \mu^+ \mu^+$	2.0	4.8	FOCUS
$D^+ \to \pi^- \mu^+ e^+$	2.0	50	E791
$D_s^+ \to \pi^- e^+ e^+$	4.1	18	CLEO-c
$D_s^+ \to \pi^- \mu^+ \mu^+$	14	29	FOCUS
$D_s^+ \to \pi^- \mu^+ e^+$	8.4	730	E791
$D^+ \to K^- e^+ e^+$	0.9	3.5	CLEO-c
$D^+ \to K^- \mu^+ \mu^+$	10	13	FOCUS
$D^+ \to K^- \mu^+ e^+$	1.9	130	E687
$D_s^+ \to K^- e^+ e^+$	5.2	17	CLEO-c
$D_s^+ \to K^- \mu^+ \mu^+$	13	13	FOCUS
$D_s^+ \to K^- \mu^+ e^+$	6.1	680	E791
$\Lambda_c^+ \to \overline{p} e^+ e^+$	2.7		
$\Lambda_c^+ \to \overline{p} \mu^+ \mu^+$	9.4		
$\Lambda_c^+ \to \overline{p} \mu^+ e^+$	16		

BABAR
preliminary

Conclusions



- BaBar ended data taking in 2008 but analysis still ongoing
- BaBar was not only a B-factory but many new results also on charm and tau physics
- Many rare decay sensible to NP: BaBar high statistics consent to have great sensibility to NP
  - BF($B \to \gamma\gamma$) upper limit lowered by a factor 2
  - No evidence of BNV found in the search for $B \to \Lambda_{(c)} l$
  - The BF($D \to \gamma\gamma$) improved by 1 order of magnitude, down to 10^{-6}
  - Most of $X_c \to hll$ channels BF upper limit down of 1 order of magnitude