Search for $D^0 \to \ell^+\ell^-$ and $D^0 \to \gamma\gamma$ at *BABAR* and BES III

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on behalf of *BABAR* and BESIII

Outline

- Search for $D^0 \to \ell^+\ell^-$
  - ***BABAR*** Phys. Rev. D 86, 032001, **Aug 2012** (arXiv:1206.5419 [hep-ex])
    "Search for the decay modes $D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$, and $D^0 \to e^\pm\mu^\mp$"
- Search for $D^0 \to \gamma\gamma$
  - ***BABAR*** Phys. Rev. D 85, 091107(R), **Jul 2012** (arXiv:1110.6480 [hep-ex])
    "Search for the Decay $D^0 \to \gamma\gamma$ and Measurement of the Branching Fraction for $D^0 \to \pi^0\pi^0$"
  - **BESIII** prelim. (**Charm 2012**), arXiv:1208.4744 [hep-ex]
    "Search for $D^0 \to \gamma\gamma$ at BES III"

Motivation

- all modes **very suppressed in Standard Model (SM)** (FCNC, GIM, small mass down quarks, LFV)
- **New Physics (NP) models enhancements** by several orders of magnitude are possible

Search for $D^0 \to \ell^+\ell^-$, motivation

- **SM predictions** G.Burdman *et al.*, Phys.Rev.D66:014009,2002, arXiv:hep-ph/0112235
  - BF($D^0 \to \mu^+\mu^-$) $\simeq 10^{-13}$ BF($D^0 \to e^+e^-$) $\simeq 10^{-23}$
    - dominated by uncertain long-distance contributions (short-distance BF($D^0 \to \mu^+\mu^-$) $\simeq 10^{-18}$)
  - BF($D^0 \to e^\pm\mu^\mp$) forbidden in SM (can go via **LFV** neutrino mixing at extremely low rates)
- **NP models enhancements**
  - e.g. RPV SUSY, E.Golowich *et al.*, Phys.Rev.D79:114030,2009 arXiv:0903.2830 [hep-ph]

    BF($D^0 \to \mu^+\mu^-$) $\simeq 4.8{\cdot}10^{-9} \left(\frac{300\,\text{GeV}}{m_{\tilde{d}_K}} \right)^2$ ($\tilde{d}_K$ denotes down-type s-quarks)

BABAR $D^0 \to \ell^+\ell^-$ analysis

- search all combinations: $D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$, $D^0 \to e^+\mu^-$, $D^0 \to e^-\mu^+$
- full *BABAR* data sample at or near Y(4*S*) peak, $468\,\text{fb}^{-1}$
- signal yield with **cut&count** approach
- signal normalized relative to $D^0 \to \pi^+\pi^-$ to reduce efficiency-related systematics
- **combinatoric bkg** estimated from upper D^0 mass sideband
- **peaking bkg** from $D^0 \to \pi^+\pi^-$ estimated using pion mis-id probabilities measured in data

BABAR $D^0 \to \ell^+\ell^-$: selection

prompt D^0 candidates selection

- require $D^*(2010)^+ \to D^0\pi^+(\text{slow})$, $D^0 \to \ell^+\ell^-$ decay chain
- $m(D^0) \in [1.65, 2.05]\,\text{GeV}$, $\Delta m \in [0.141, 0.149]\,\text{GeV}$, $p(D^0) > 2.4\,\text{GeV}$
  - ► improve $m(D^{*+})$ resolution by constraining slow pion to beam spot
- vertex probability of D^0 and D^{*+} must be $> 1\%$

QED background (Bhabha, di-muons) suppression

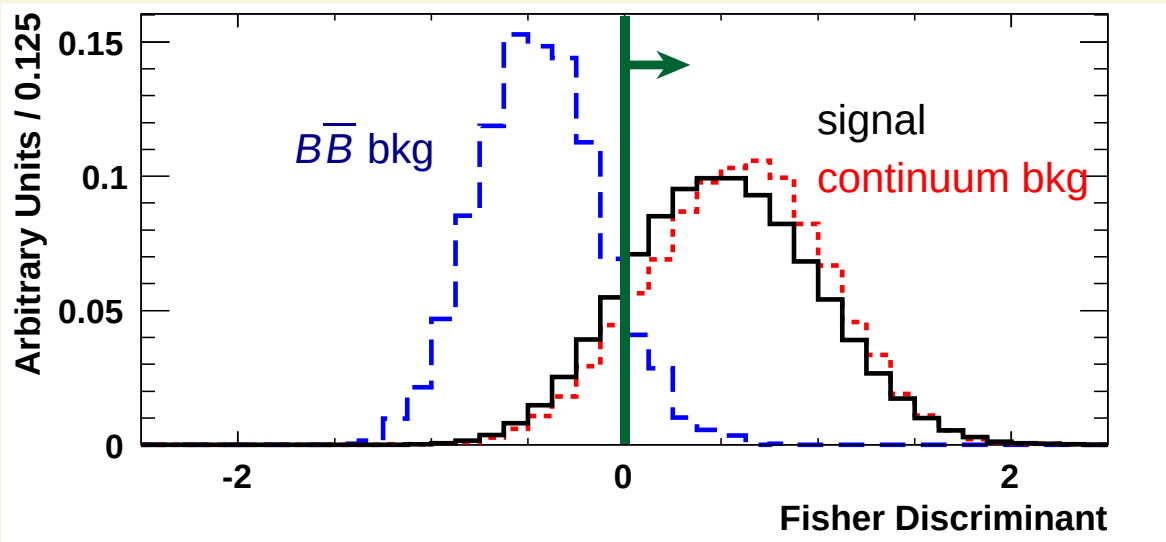
- **track multiplicity** ≥ 5 for $D^0 \to e^+e^-$, ≥ 4 for $D^0 \to \mu^+\mu^-$ and $D^0 \to e^\pm\mu^\mp$
- no more than 3 **electron candidates** in the event
- slow pion and leptons cannot belong to track pairs that are **photon conversion** candidates

BABAR $D^0 \to \ell^+\ell^-$: $B\overline{B}$ background suppression

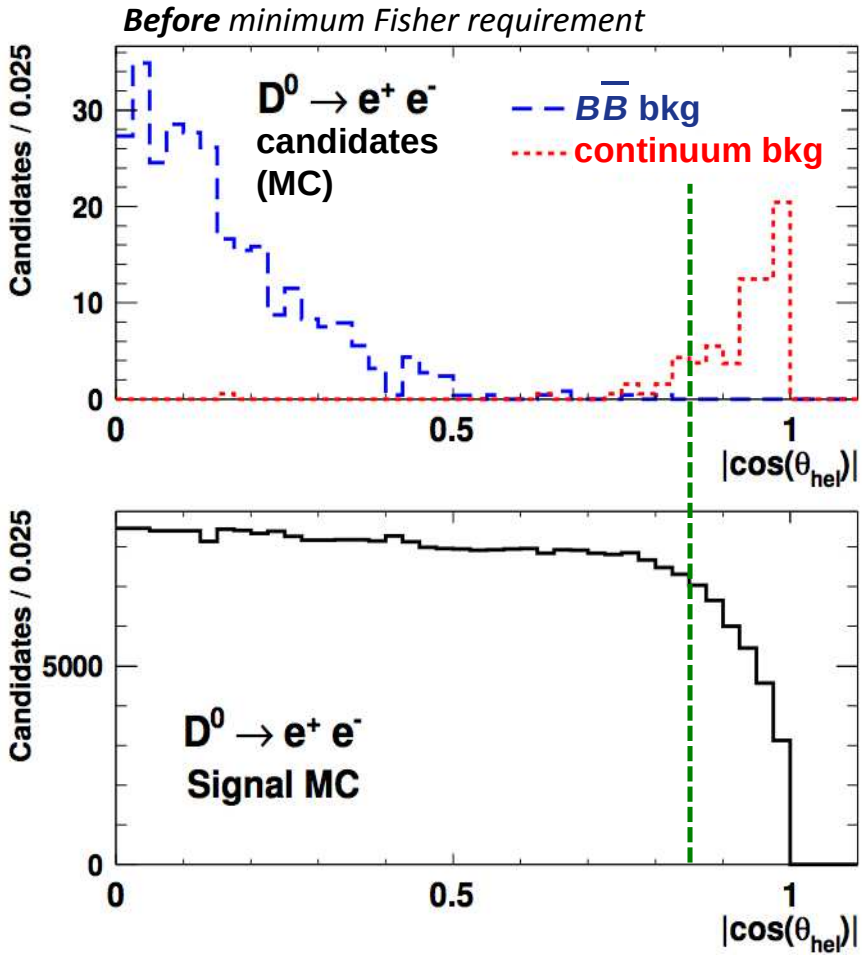
Fisher discriminant

- ratio of 2nd and 0th Fox-Wolfram moments
- missing transverse momentum wrt beam axis
- center-of-mass frame D^0 momentum
- D^0 flight length significance $[\lambda/\sigma(\lambda)]$
- $|\cos\theta_{\text{helicity}}|$, where θ_{helicity} is $D^0 \to \ell^+\ell^-$ decay helicity

Monte Carlo $D^0 \to \mu^+\mu^-$ candidates



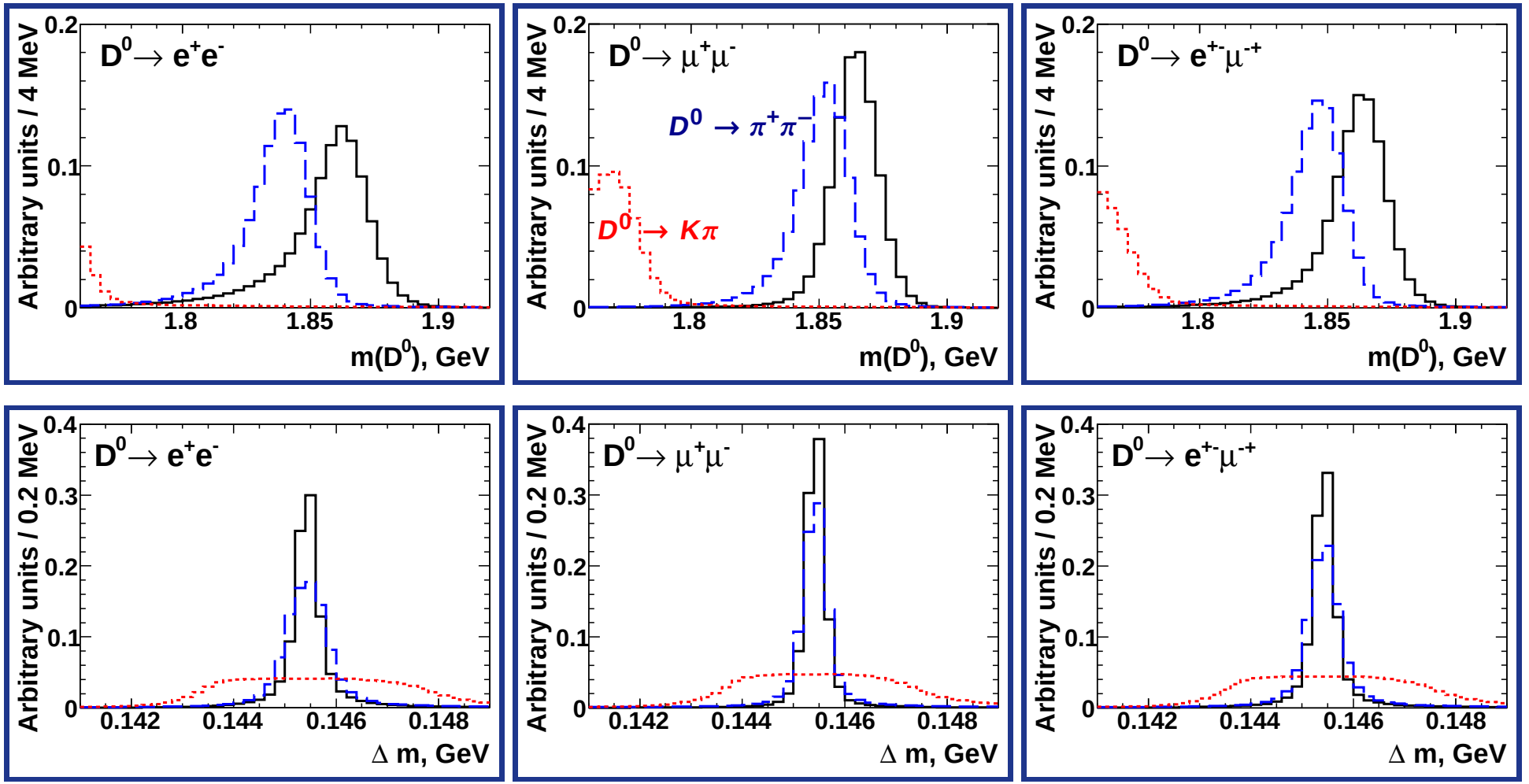
BABAR $D^0 \to \ell^+\ell^-$: cut on $D^0 \to \ell^+\ell^-$ decay helicity angle



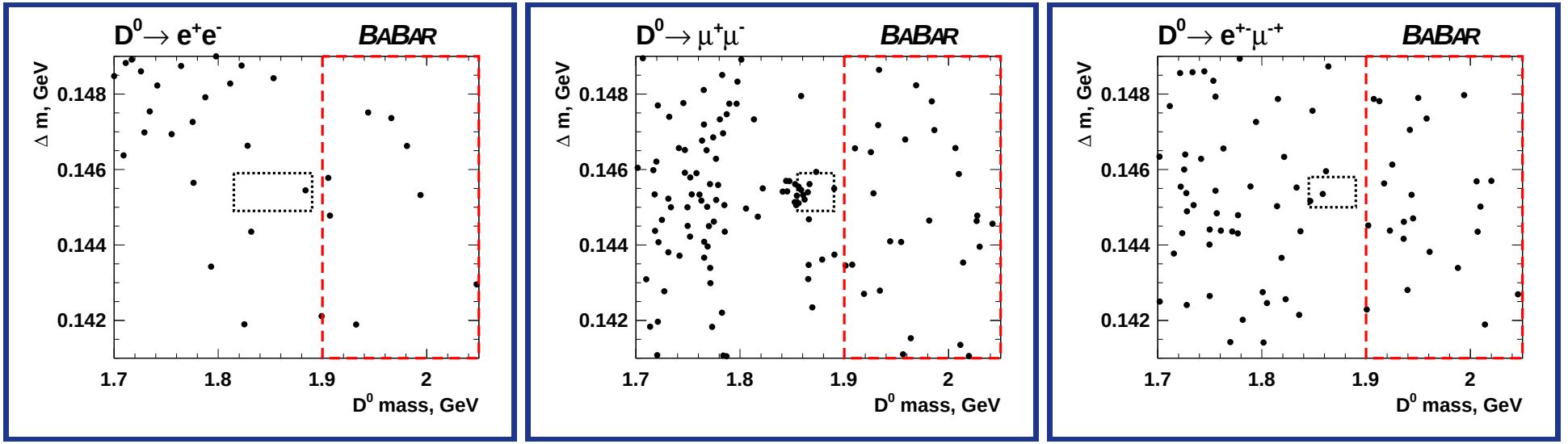
- Combinatoric BG in continuum events peaks sharply near $|\cos\theta_{hel}|$ of 1.
- Signal $|\cos\theta_{hel}|$ distribution uniform.
  - shoulder near 1 from acceptance effects.
- Maximum $|\cos\theta_{hel}|$ requirement optimized in final selection separately for *ee*, $\mu\mu$, and $e\mu$ modes.

$|\cos\theta_{hel}| < 0.85$ requirement: removes 86% of continuum BG, keeps 89% of signal.

BABAR $D^0 \to \ell^+\ell^-$: $D^0 \to \pi^+\pi^-$ peaking bkg $m(D^0)$ and Δm MC distributions



BABAR $D^0 \to \ell^+\ell^-$: results



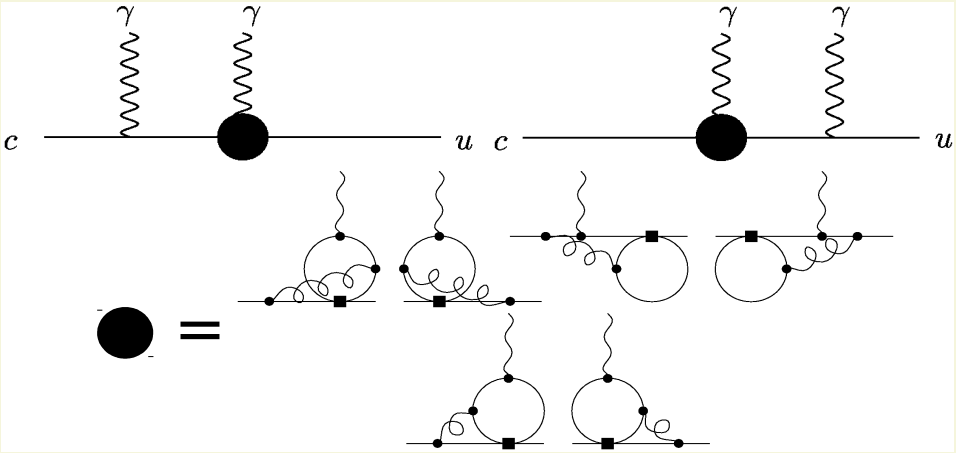
- **no statistically significant excess over expected background**
  - Observed 1 event for $D^0 \to e^+e^-$ with expected bkg 1.0 ± 0.5
  - Observed 2 events for $D^0 \to e^\pm\mu^\mp$ with expected bkg 1.4 ± 0.3
  - Observed 8 events for $D^0 \to \mu^+\mu^-$ with expected bkg 3.9 ± 0.6
- 90% CL intervals using the Feldman-Cousins method:

  $D^0 \to e^+e^- < 1.7 \cdot 10^{-7}$ $D^0 \to e^\pm\mu^\mp < 3.3 \cdot 10^{-7}$ $D^0 \to \mu^+\mu^- \in [0.6, 8.1] \cdot 10^{-7}$
- **Phys. Rev. D 86, 032001 (Aug 2012)** arXiv:1206.5419 [hep-ex]

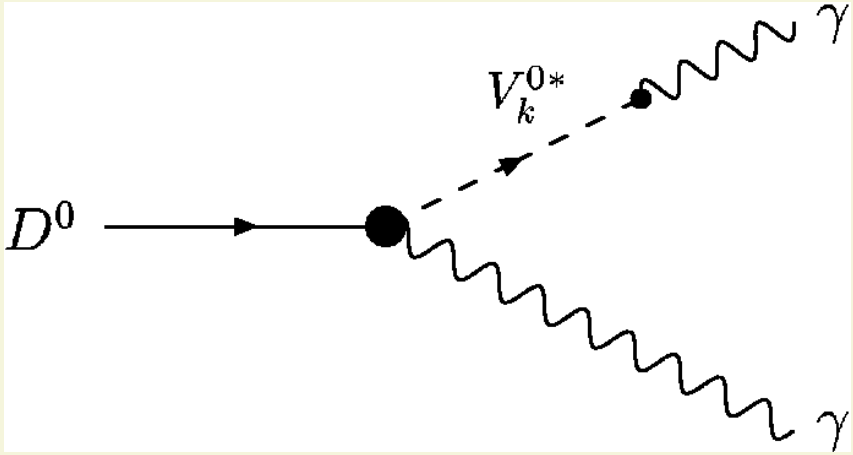
Search for $D^0 \to \gamma\gamma$, motivation

- **very suppressed in SM** (FCNC, GIM, small mass down quarks)
- G.Burdman *et al.*, Phys.Rev.D66:014009,2002, arXiv:hep-ph/0112235
  - BF($D^0 \to \gamma\gamma$) $\simeq 3 \cdot 10^{-11}$ short-distance
  - BF($D^0 \to \gamma\gamma$) $\simeq 3.5 \cdot 10^{-8}$ long-distance

short distance



long distance



- **NP models enhancements** by two orders of magnitude possible
  - BR $\simeq 6 \cdot 10^{-6}$ via MSSM gluino exch., S. Prelovsek & D. Wyler, hep-ph/0012116v1 11 Dec 2000

BABAR $D^0 \to \gamma\gamma$ analysis

- full *BABAR* data sample at Y(4*S*) peak (10.58 GeV) and at 10.54 GeV, 470.5 fb^{-1}
- signal yield from **fit to $\gamma\gamma$ invariant mass distribution**
- signal normalized relative to $D^0 \to K^0_S\pi^0$ = (1.22 ± 0.05)% to reduce efficiency-related systematics
- major background $D^0 \to \pi^0\pi^0$ BF also measured
- suppress $D^0 \to \pi^0\pi^0$ with **π^0 veto**: 95% bkg removed, 66% signal retained

BABAR $D^0 \to \gamma\gamma$: selection

prompt D^0 candidates selection

- require $D^*(2010)^+ \to D^0\pi^+(\text{slow})$, $D^0 \to \gamma\gamma$ decay chain
- $m(D^0) \in [1.7, 2.1]\,\text{GeV}$, $\Delta m \in [0.1445, 0.1463]\,\text{GeV}$, $p(D^{*+}) > 2.85\,\text{GeV}$
  - ► improve $m(D^{*+})$ resolution by constraining slow pion to beam spot

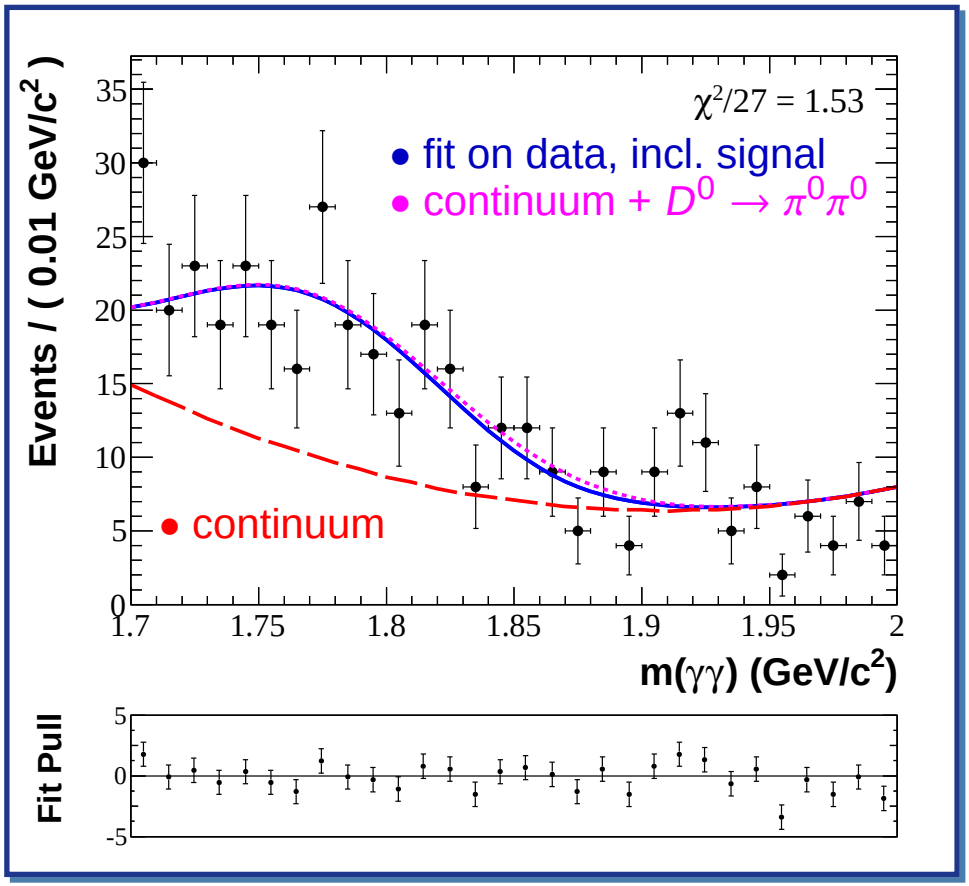
QED background suppression

- ≥ 4 tracks and ≥ 4 photon candidates
- photon momenta $< 4\,\text{GeV}$

BABAR $D^0 \to \gamma\gamma$: selection optimization

- optimization on 3 variables
  - Δm
  - $p(D^{*+})$
  - minimum $p(\gamma)$
- optimize for maximum significance $N_S/\sqrt{N_S + N_B}$, where S = signal, B = bkg
  - assumed BF($D^0 \to \gamma\gamma$) = 5.4×10^{-6} (five times less than the CLEO collaboration upper limit)
- signal efficiency: $(5.9 \pm 0.2)\%$

BABAR $D^0 \to \gamma\gamma$: results



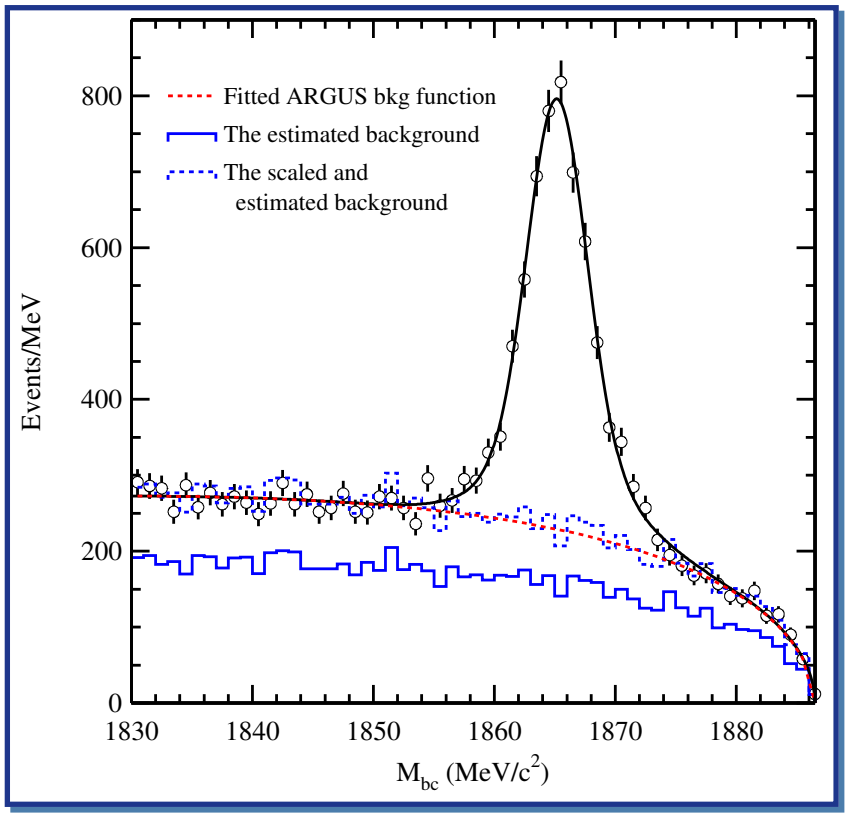
- unbinned maximum likelihood fit, PDF includes:
  - continuum bkg
  - $D^0 \to \pi^0\pi^0$ bkg
  - $D^0 \to \gamma\gamma$ signal
- shapes fixed on simulated events
- components' normalizations fit on data
- yield: -6 ± 15 events
- largest systematics:
  - K_S selection and tracking for $D^0 \to K^0_S\pi^0$
  - photon reconstruction
- BF($D^0 \to \gamma\gamma$) $< 2.2 \cdot 10^{-6}$ at 90% CL
  (×10 improvement w.r.t. PDG 2012)
- **Phys. Rev. D 85, 091107(R) (Jul 2012)**
  arXiv:1110.6480 [hep-ex]

BES III $D^0 \to \gamma\gamma$ analysis

- 2010 – 2011 data sample, 2.9 fb^{-1} at $\psi(3770)$ peak
- measure also major background mode $D^0 \to \pi^0\pi^0$ and use for normalization

BES III $D^0 \to \gamma\gamma$: $D^0 \to \pi^0\pi^0$ selection and yield

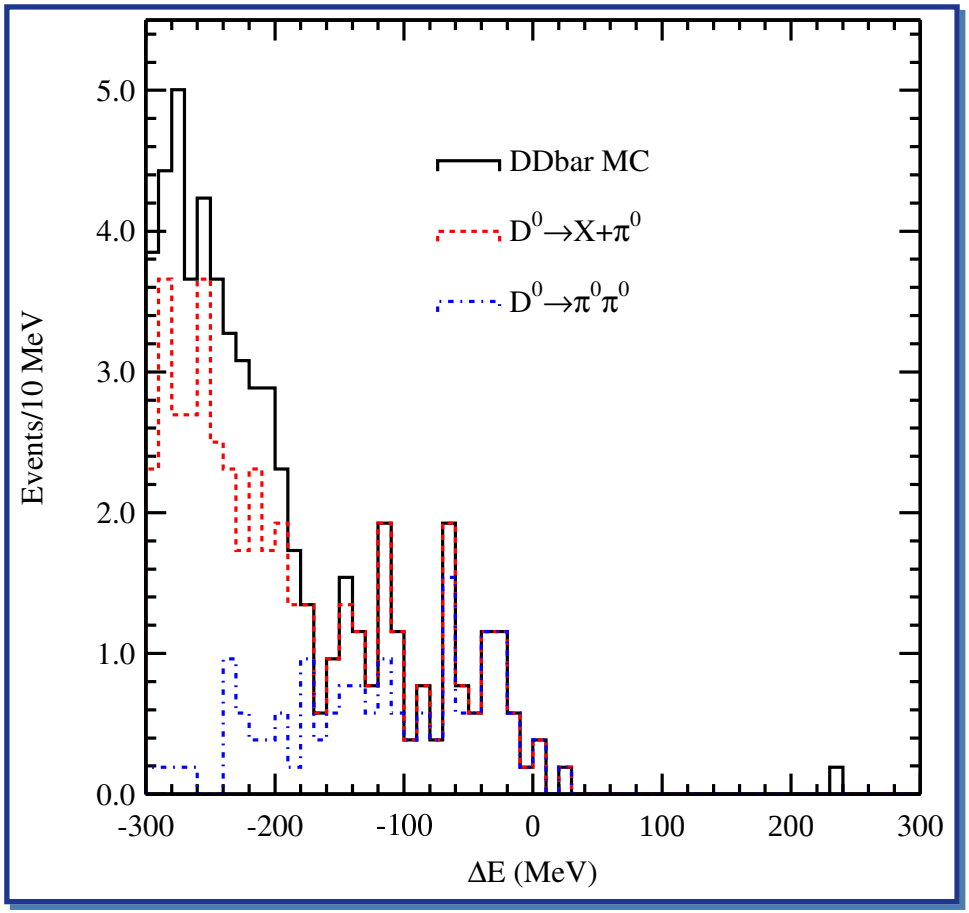
- γ candidates from CsI calorimeter energy deposits
  - ► > 25 MeV in barrel, > 50 MeV endcap
- π^0 candidates: γ pairs with $m(\gamma\gamma) \in [110, 150]$ MeV
  - ► π^0 mass constrained to known value
- D^0 candidates from π^0 pairs
  with $\Delta E = E_{\pi^0\pi^0} - E_{\text{beam}} \in [-60, 30]$ MeV
- fit beam-constrained mass
  $m(D^0) = \sqrt{E^2_{\text{beam}} - p^2_{\pi^0\pi^0}}$ distribution
- efficiency $(23.3 \pm 0.1)\%$
- **yield: 4081 ± 117 events** (preliminary)
- compatible with PDG and *BABAR* measurement
- largest systematic: signal shape
  (double Gaussian fixed on MC)
- must scale MC bkg up by ~50%



BES III $D^0 \to \gamma\gamma$: $D^0 \to \gamma\gamma$ selection

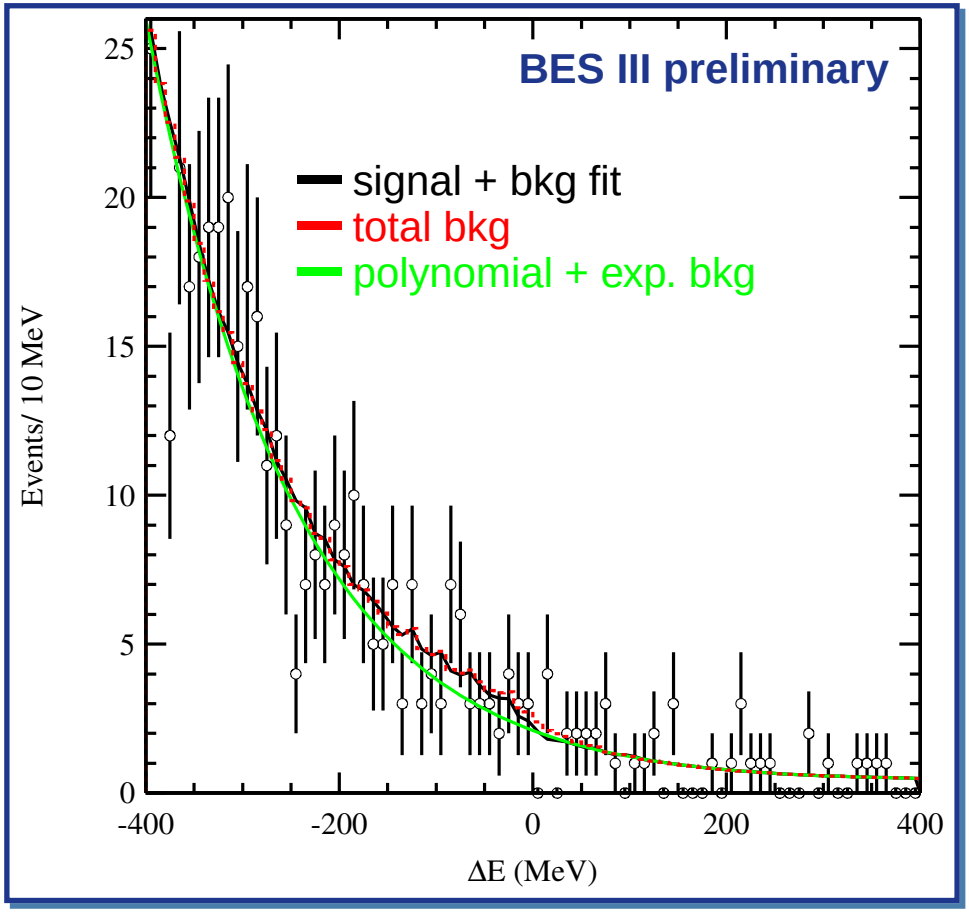
- two highest energy photons (E_γ from D^0 decay mostly $> 700\,\text{MeV}$)
- veto photons compatible with π^0 decay
- veto events containing tracks with $E_{\text{EMC}}/p \sim 1$ $(e^\pm)$
- require at least one kaon candidate
- require D^0 candidates from photon pairs with $m_{\gamma\gamma} \in [1860, 1870]\,\text{MeV}$
- selection efficiency $(12.02 \pm 0.1)\%$

BES III $D^0 \to \gamma\gamma$: ~peaking $D^0 \to \pi^0\pi^0$ bkg in ΔE distribution



- $D\overline{D}$ bkg MC expectations
- signal expected at $\Delta E \simeq 0$

BES III $D^0 \to \gamma\gamma$: results



- **fit data Δ*E* distribution**
- $D^0 \to \gamma\gamma$ signal shape determined by MC
- bkg components:
  - $D^0 \to \pi^0\pi^0$
    - shape from MC
    - size from this analysis yield
  - Bhabha 1st order polyn. from MC
  - remaining bkg 1st order exp. from MC
- yield -2.9 ± 7.1 events
- largest systematics from $D^0 \to \pi^0\pi^0$
- 90% CL bayesian upper limit

  $\mathrm{BF}(D^0 \to \gamma\gamma)/\mathrm{BF}(D^0 \to \pi^0\pi^0) < 5.8 \cdot 10^{-3}$
- using BF $(D^0 \to \pi^0\pi^0)$ from PDG 2012

  $\mathrm{BF}(D^0 \to \gamma\gamma) < 4.7 \cdot 10^{-6}$ at 90% CL

  BESIII preliminary, **Charm 2012**

BES III $D^0 \to \gamma\gamma$: prospects

- with respect to the *BABAR* result
  - less bkg (~1/2)
  - larger efficiency (~2×)
  - less produced D^0's ~1/10
- future improvements
  - $D^0 \to \pi^0\pi^0$ measurement to reduce $D^0 \to \pi^0\pi^0$-related systematics
  - require other D^0 reconstructed in known modes to reduce non $D\overline{D}$ bkgs
  - more data

Conclusions

$D^0 \to \ell^+\ell^-$

- *BABAR* 468 fb^{-1}, Phys. Rev. D 86, 032001, Aug 2012, arXiv:1206.5419 [hep-ex]
  90% CL limits: $D^0 \to e^+e^- < 1.7\cdot10^{-7}$ $D^0 \to e^\pm\mu^\mp < 3.3\cdot10^{-7}$ $D^0 \to \mu^+\mu^- \in [0.6, 8.1]\cdot10^{-7}$
- Belle 660 fb^{-1}, Phys. Rev. D 81, 091102 (2010) **(not described here)**
  90% CL limits: $D^0 \to e^+e^- < 0.79\cdot10^{-7}$ $D^0 \to e^\pm\mu^\mp < 2.6\cdot10^{-7}$ $D^0 \to \mu^+\mu^- < 1.4\cdot10^{-7}$
- Belle can update to full collected data sample
- LHC experiments have best results on $D^0 \to \mu^+\mu^-$ and will improve

$D^0 \to \gamma\gamma$

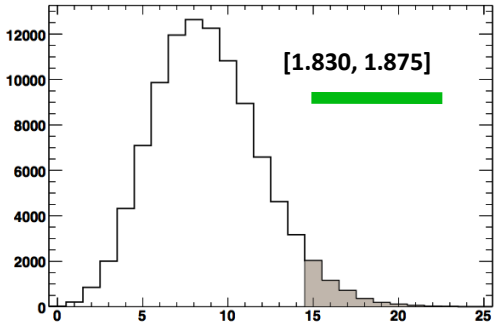
- *BABAR* 470.5 fb^{-1}, Phys. Rev. D 85, 091107(R), Jul 2012, (arXiv:1110.6480 [hep-ex])
  - **BF($D^0 \to \gamma\gamma$) < $2.2\cdot10^{-6}$ at 90% CL**
- BES III 2.9 fb^{-1}, Charm 2012, preliminary
  - **BF($D^0 \to \gamma\gamma$) < $4.7\cdot10^{-6}$ at 90% CL**
- improvements expected first by BES III and later by Super B-factories

extra backup slides

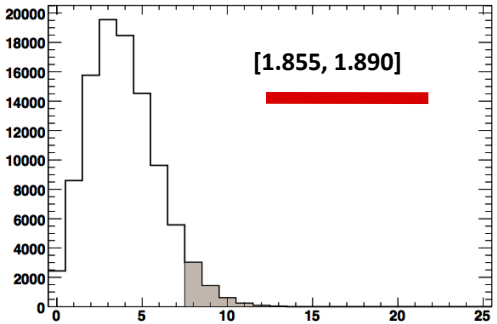
Toy MC study: $D^0 \to \mu^+\mu^-$ excess not statistically significant

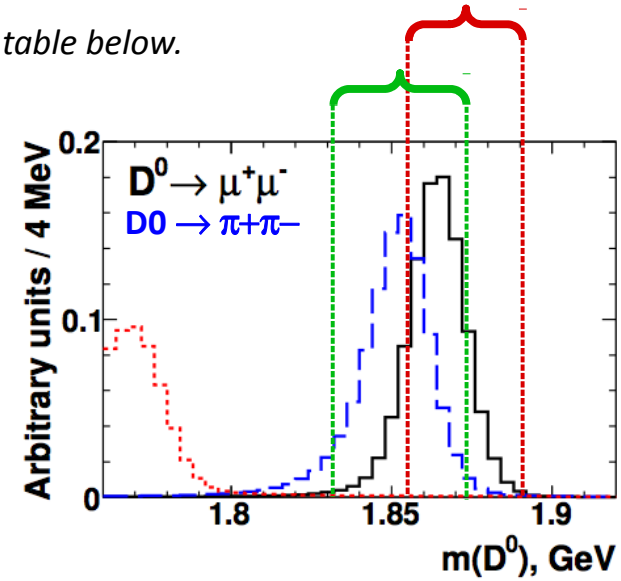
Poisson distributions generated with Gaussian uncertainties on mean from table below.

Window around ππ peak



Signal window for μμ





Quantity \ *D0* interval	[1.830, 1.875]	[1.855, 1.890]
Nππ	7.0 ± 0.6 ± 0.6	2.6 ± 0.2 ± 0.4
Ncomb	1.8 ± 0.2 ± 0.6	1.2 ± 0.3 ± 0.3
NBG	8.8 ± 1.1	3.9 ± 0.6
Nobs	15	8
Prob (Nobs or more)	4.6% (1.7 “sigma”)	5.4% (1.6 “sigma”)

$$\left\{\mathrm{Erf}(1.7/\sqrt{2})+1\right\}/2 = 1-0.046$$

Observed events