Search for $D^0 \to \gamma + \gamma$

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for the BESIII collaboration

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Outline

- (brief) Introduction
- Preliminary results from BESIII
  - $D^0 \rightarrow \pi^0\pi^0$
  - $D^0 \rightarrow \gamma + \gamma$
- Prospects & Summary

$D^0 \rightarrow \gamma\gamma$

- It is a FCNC transition (i.e., $c \rightarrow u + \gamma$) and is forbidden at tree level.
  Besides, the ubar quark also needs to annihilate with the u quark to produce the other photon.
- Extremely suppressed: Unlike FCNC processes in decays of K and B mesons (i.e., $s \rightarrow d\, l^+ l^-$, $b \rightarrow s\, \gamma$),
  in decays of the D mesons, the transitions are mediated by the lighter down-quark sector → larger GIM suppression.
- But such short-distance contributions are usually diluted by (very) large long-distance contributions.
- The radiative decay, $D^0 \rightarrow \gamma\gamma$, is indeed such case.

How small (large) $B(D^0 \rightarrow \gamma\gamma)$ is?

- This small transition rate due to the short distance effect is enhanced by long distance effect, bringing the overall $B(D^0 \rightarrow \gamma\gamma)$ larger.
  SM: $B(D^0 \rightarrow \gamma\gamma) \sim 10^{-8}$ or less (i.e., see Fajfer et al. PRD64, 074008 (2001)).

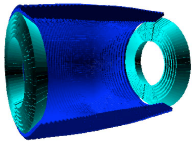
- But, for instance, the minimal super-symmetric standard model predicts the rate could be enhanced by a factor of 100 by exchanging gluino
  (i.e., see Prelovsek and Wyler, PLB500, 304 (2001)) or $BR(D^0 \rightarrow \gamma\gamma) \sim 10^{-6}$.

Three experimental results so far and they are all Upper Limits

- **CLEO2** looked for this with 13.8/fb taken around Υ(4S).
  → $B(D^0 \rightarrow \gamma\gamma) < 2.9\times10^{-5}$ @ 90% CL (PRL90, 101801 (2003)).

- **CLEO-c** also looked for based on 818/pb taken at ψ(3770) [~6 M D^0 produced]
  → Preliminary result: $B(D^0 \rightarrow \gamma\gamma) < 8.63\times10^{-6}$ @ 90% CL (Charm 2010).

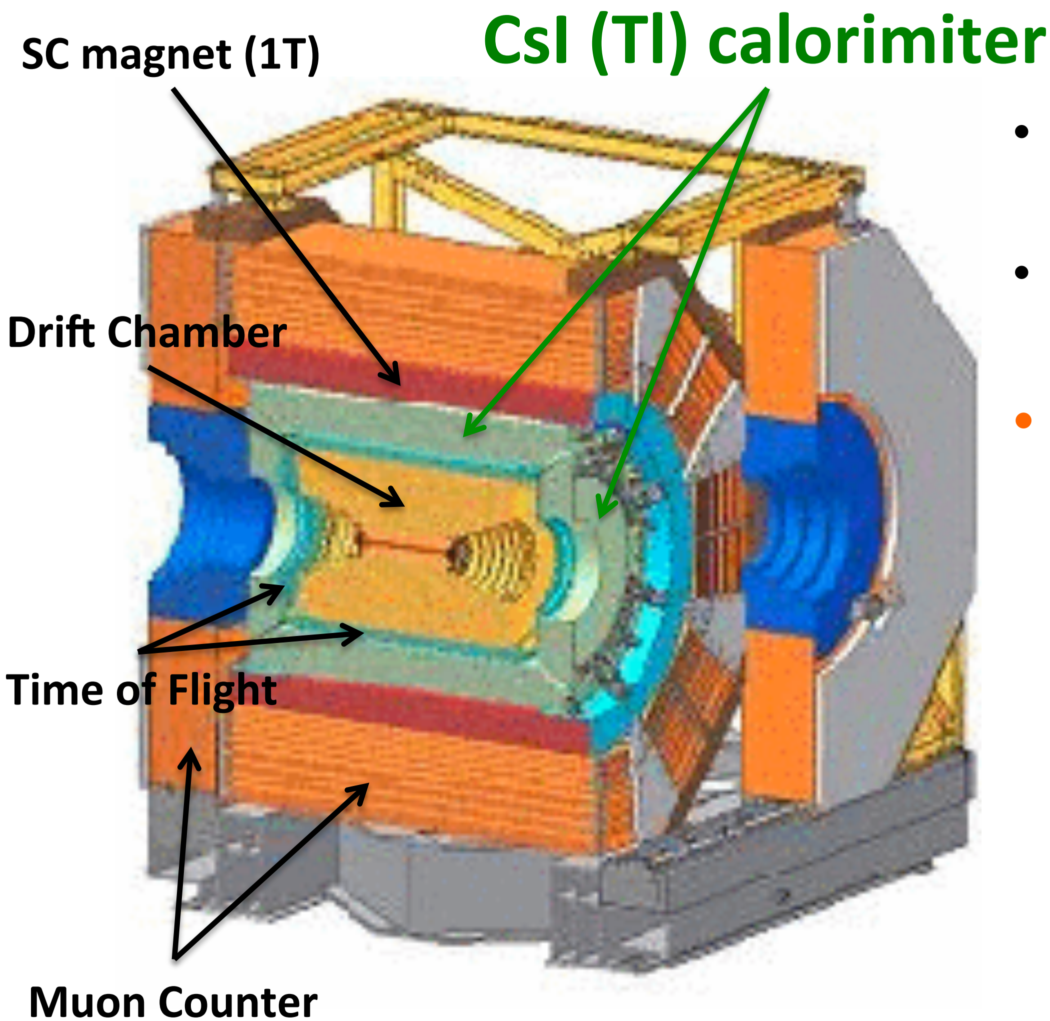
- **BaBar** also has a result with 470.5/fb taken around Υ(4S) [~201 M D^0 produced].
  → $B(D^0 \rightarrow \gamma\gamma) < 2.2\times10^{-6}$ @ 90% CL (hep-ex:1110.6480).



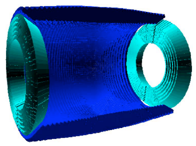
Now it's BESIII's turn

- BEPCII: symmetric e^+e^- collider, operates at $\sqrt{s}$ ~ 2.0 ~4.6 GeV.
  BESIII detector: all purpose detector, equipped with ~6000 CsI crystals (see the next slide).
- Today's preliminary results are based on a sample taken in 2010-2011.
  2.9 fb^{-1} at $\sqrt{s}$ = 3.773 GeV [~ 21 M D^0 produced]
  or ~ 3.5 × CLEO-c (0.818 fb^{-1})
- Not for today: We also have some Onia data sets:
  The largest samples of ψ(2S) and J/ψ
  - 225 M J/ψ (2009)
  - 106 M ψ(2S) (2009)
  - 0.5 fb^{-1} at $\sqrt{s}$ = 4.01GeV (one month in 2011)

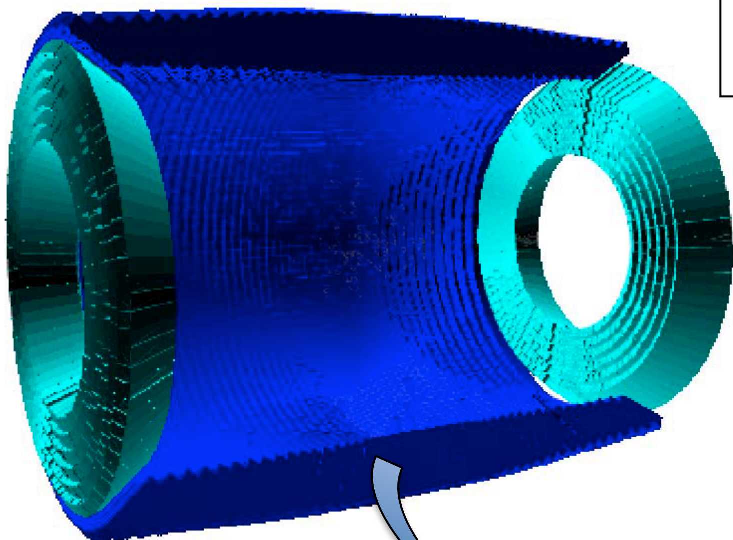
BESIII detector



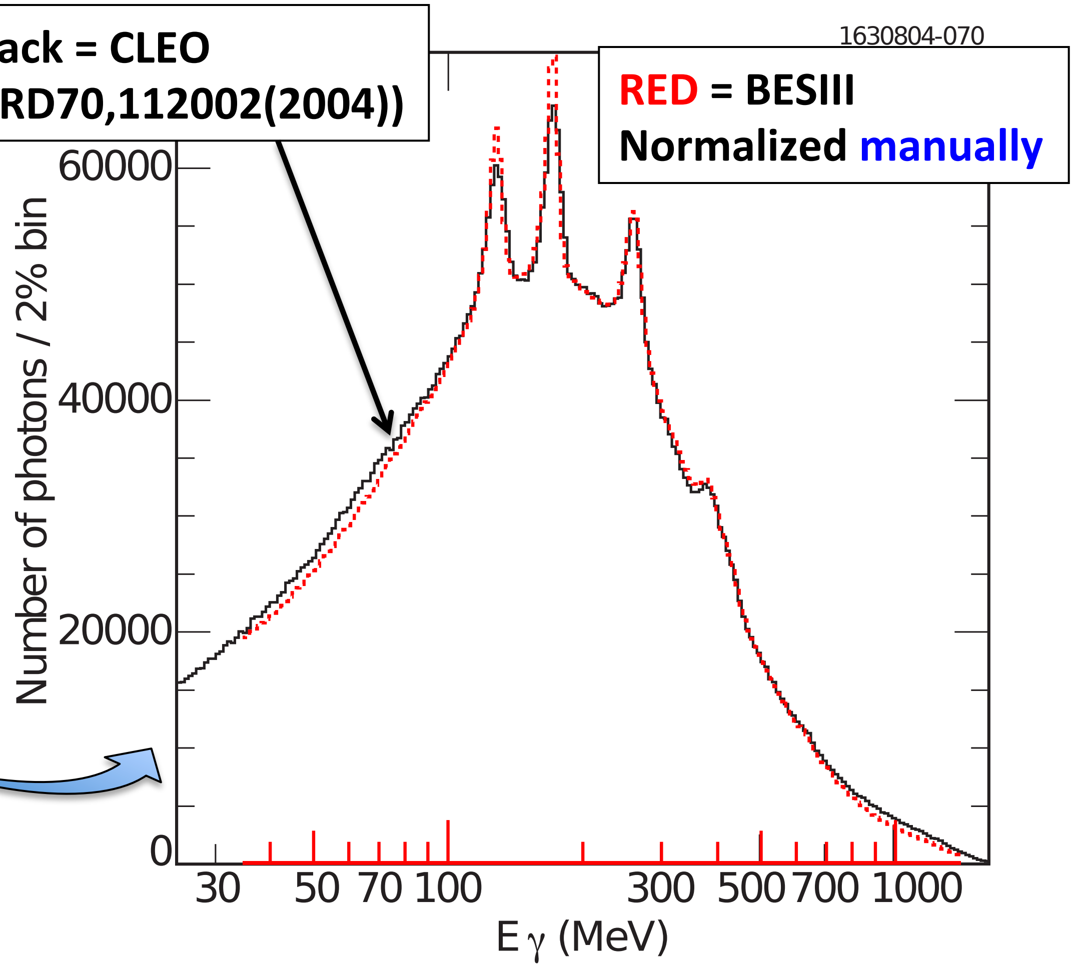
- Excellent charged particle detection (σ_p/p ~ 0.6% @ 1 GeV/c)
- Excellent particle identification (ToF and dE/dx)
- EM calorimeter
  - Essential for this analysis
  - 6240 CsI (Tl) crystals (5280 in Barrel, 960 in Endcaps)
  - Crystal sizes are very similar to CLEO's
  - σ_E/E ~ 2.5% @ 1 GeV



Similar to the CLEO-III(c) detector



Based on the photons detected in the Barrel section



Comparison of

inclusive photon energy spectrum based on ψ(2S) data.

Three monochromatic photon lines are seen due to ψ(2S)→ γ χ_{cJ}.

Analysis of $D^0 \rightarrow \gamma\gamma$

- What we are after is to measure $B(D^0 \rightarrow \gamma\gamma)$.
- We also study events from $D^0 \rightarrow \pi^0\pi^0$ decays which share some of the common backgrounds (i.e., continuum such as $e^+e^- \rightarrow \gamma^* \rightarrow$ qqbar).
- In the end, we present our preliminary result in a form of

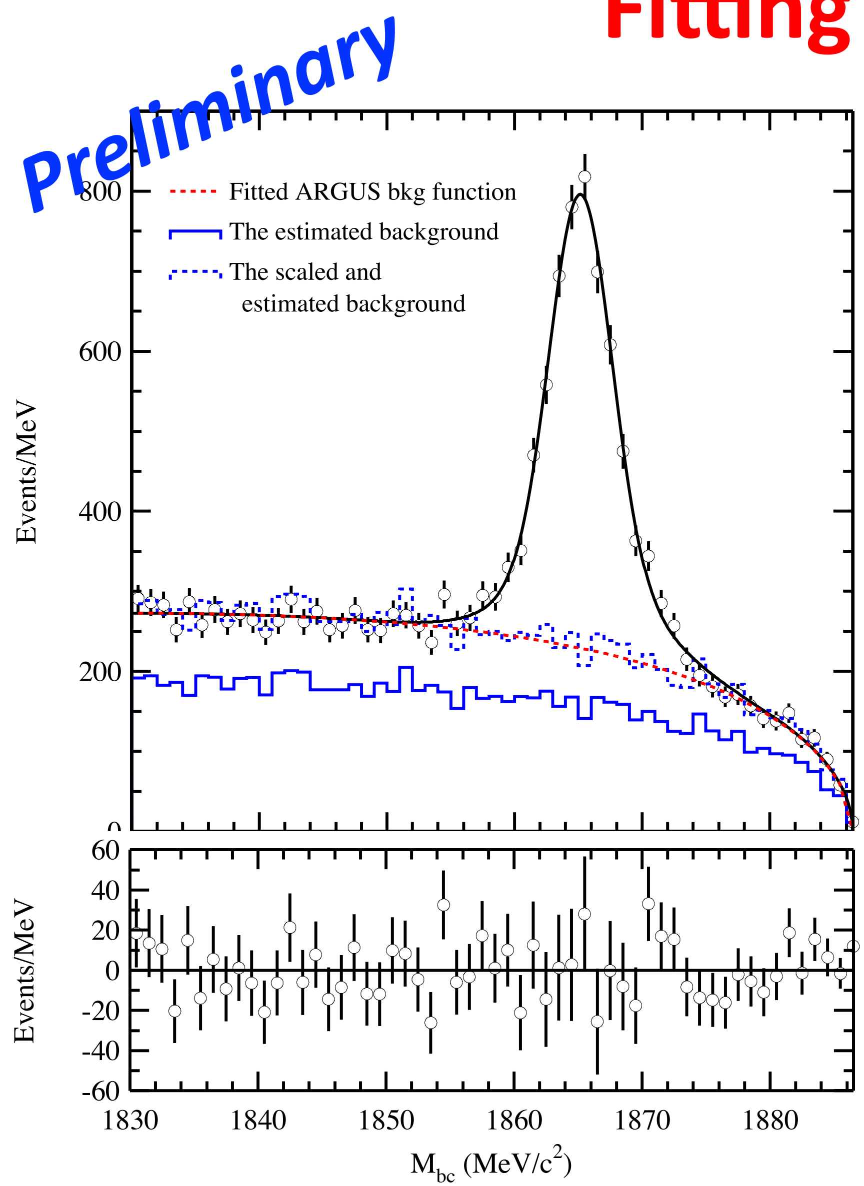
$$B(D^0 \rightarrow \gamma\gamma)/B(D^0 \rightarrow \pi^0\pi^0).$$

- Will start with $D^0 \rightarrow \pi^0\pi^0$ first.

$D^0 \rightarrow \pi^0\pi^0$

- **Analysis method is very straight forward.**
  - **The produced ψ(3770) decays into D^0 and D^0bar.**
  - **Reconstruct only one of the two D^0s with two π^0s from 4 photon candidates.**
  - **Demand $M_{\gamma\gamma}$ is consistent with $M_{\pi 0}$**
  - **Require conservation of energies and momenta:**
    - **$\Delta E = E_{\pi 0 \pi 0} - E_{Beam}$ should be consistent with zero**
    - **Extract signal yields from Beam-constrained mass, $M_{bc} = \sqrt{(E_{Beam}{}^2 - p_{\pi 0 \pi 0}{}^2)}$ which should be consistent with $M(D^0)$.**
- **Detail selection criteria are tuned based on MC.**
- **Overall recon. eff. = 23%.**

Fitting to data



- **4081±117 signal events.**
- **The resultant preliminary $B(D^0 \rightarrow \pi^0\pi^0)$ is consistent with the known value (PDG and the latest result from BaBar).**

- **The total MC-based background (solid-blue) underestimates the one seen in data:**
  Needed to scale it UP(dashed-blue) by (49±2)% to match to data!
  We attribute this to poor simulation of "non-DDbar" components.

of events from $D^0 \to \pi^0\pi^0$

Our preliminary result on efficiency-corrected # of events are:

17521±500(stat.)±1559(syst.) events

The systematic uncertainty is dominated by the MC-based signal line shape which is currently under investigation.

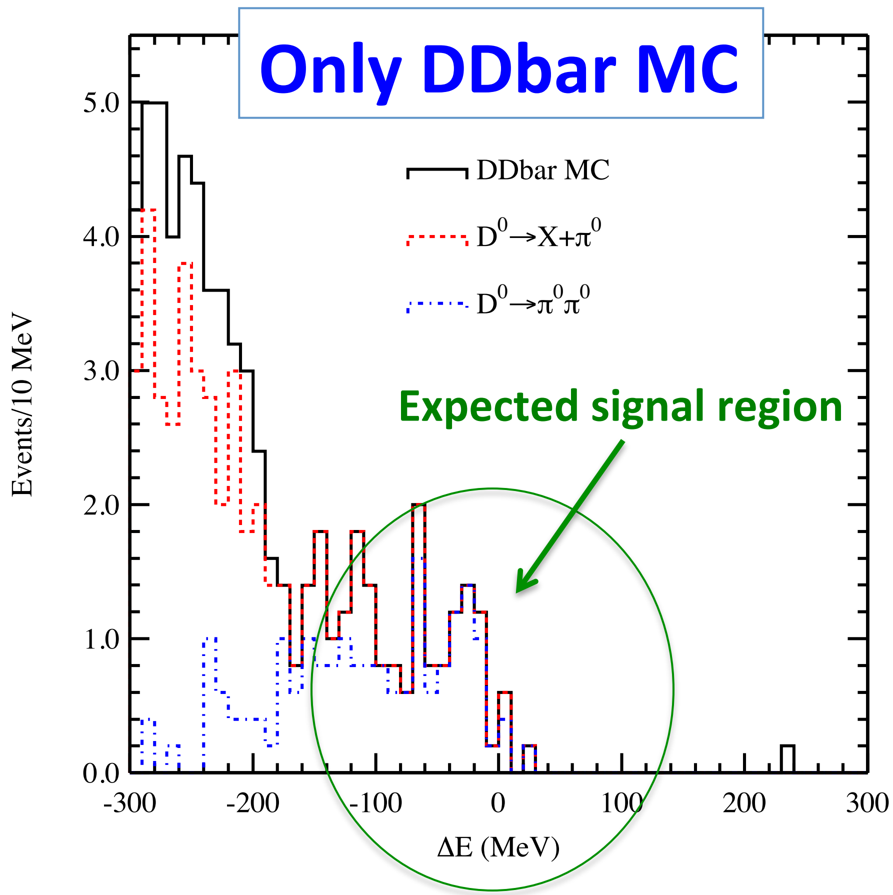
$D^0 \rightarrow \gamma\gamma$

The analysis procedure is very similar to that for $D^0 \rightarrow \pi^0\pi^0$.

- **Reconstruct two photons with the two most energetic photon candidates.**
- **Extract signals from a ΔE distribution.**
- **The main source of backgrounds:**
  - **qqbar**
  - **$D^0 \rightarrow \pi^0\pi^0$ (which we just measured)**
  - **Radiative returns to ψ(1S,2S)**
  - **Radiative Bhabha**
- **Selection criteria are tuned based on MC.**
- **Overall recon. eff. = 12%**

  (hard continuum suppressions are imposed: See extra slide for more detail).

Peaking Background from D^0 decay

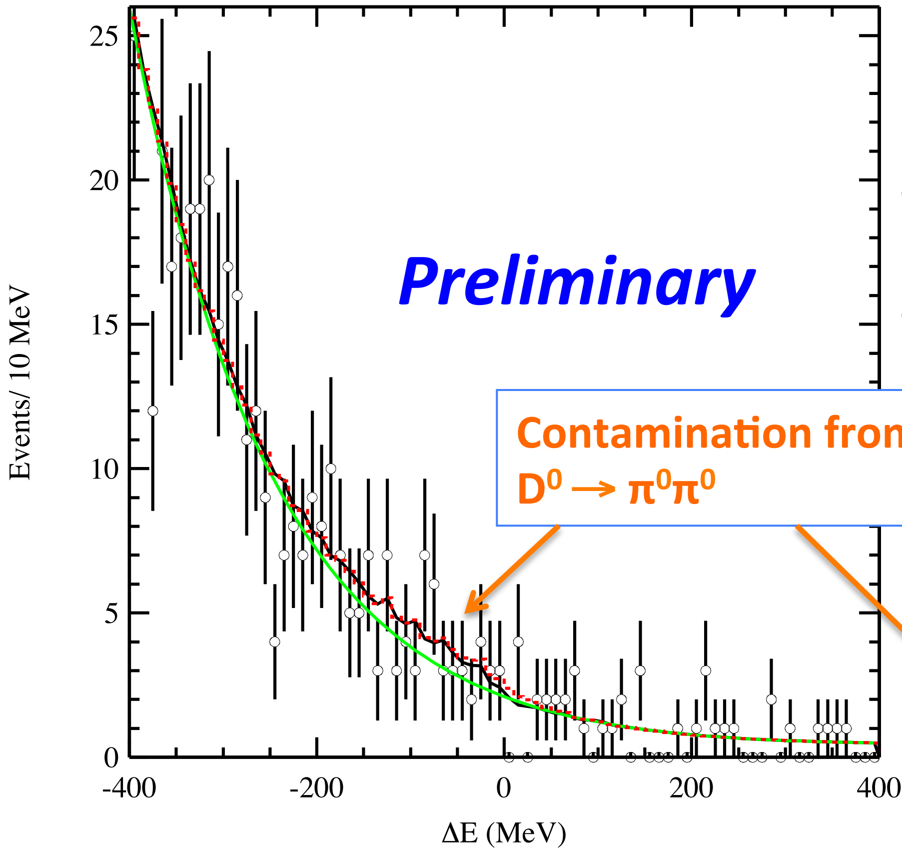


- $D^0 \rightarrow \pi^0\pi^0$ dominates near $\Delta E \sim 0$ in DDbar decays.
- When the energetic π^0 decays asymmetrically, one of the photon turns into a good signal candidate.
  The other photon candidate has much lower energy
  → negative $\Delta E = E_{\gamma\gamma} - E_{beam}$.

- In our fit,
  we fix this $D^0 \rightarrow \pi^0\pi^0$ component based on MC.

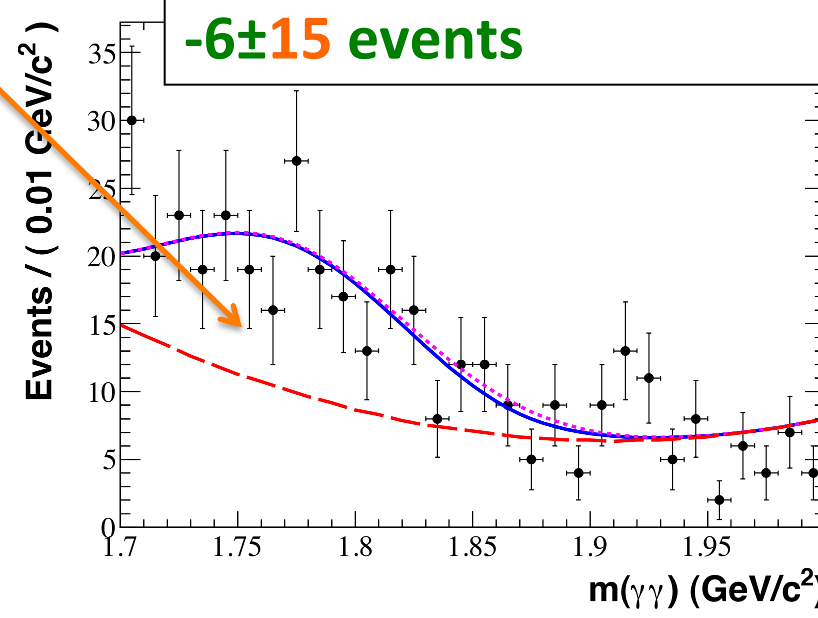
Fit to DATA

- Gives: -2.9±7.1 events
- No significant signals.



Contamination from $D^0 \to \pi^0\pi^0$

BaBar:hep-ex:1110.6480
-6±15 events



W.r.t. the BaBar's result:

- BKG_{BESIII}/BKG_{BaBar} ~ 0.5
- $\varepsilon_{BESIII}/\varepsilon_{BaBar}$ ~ 2
- BUT, $N_{BESIII}(D^0)/N_{BaBar}(D^0)$ ~ 0.1

Result on $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0)$

Preliminary

- With the efficiency-corrected yields of $D^0 \to \pi^0\pi^0$ events, 17521 events, we have:

  $B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8\times10^{-3}$ UL @ 90% CL,

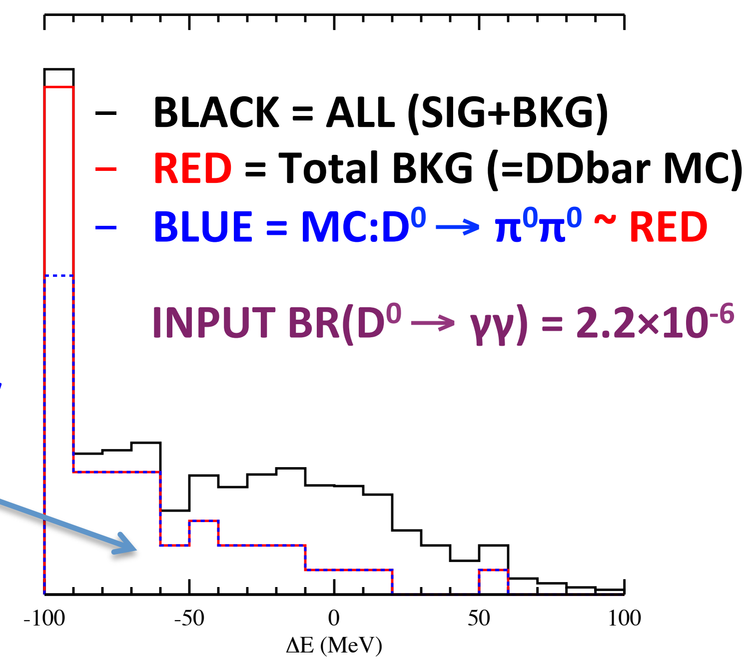
  including its systematic uncertainty (rel. 12%) which is added to the Bayesian upper limit (see the extra slide for more detail).

- With the PDG value of $B(D^0 \to \pi^0\pi^0) = 8.0\times10^{-4}$, this UL corresponds to $B(D^0 \to \gamma\gamma) < 4.6\times10^{-6}$ UL @ 90% CL.
  This is looser UL than the latest result from BaBar:
  $B(D^0 \to \gamma\gamma) < 2.2\times10^{-6}$ @ 90% CL (hep-ex:1110.6480).

Prospects

- Should have improved results (i.e., systmatics) on $B(D^0 \rightarrow \gamma\gamma)$ soon along with a measurement on $B(D^0 \rightarrow \pi^0\pi^0)$.

- Another possible method which takes real advantage of our unique data set:
  - Our D^0s from $\psi(3770)$ are always produced in pairs.
  - Reconstruct one D^0 with known channels while looking for $D^0 \rightarrow \gamma\gamma$ on the other.
  - This double-tag method might leave us only the irreducible background from $D^0 \rightarrow \pi^0\pi^0$ (i.e., no Bhabha, qqbar contaminations) which we measure.



- Intend to look for other radiative decays of D^+, D^0, and D_s^+ as well.

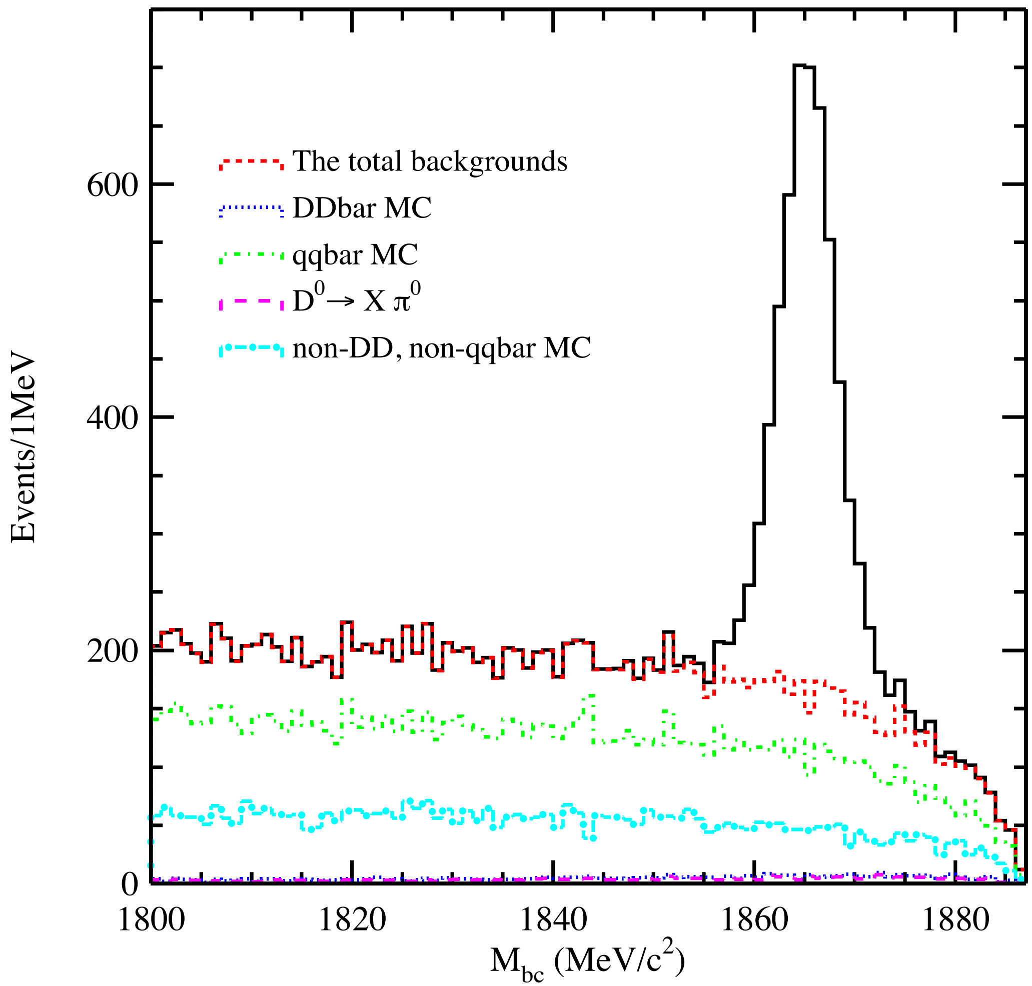
Summary

Based on the 2.9 fb^{-1} data taken at $\sqrt{s}$=3.773 GeV, we have searched for $D^0 \to \gamma\gamma$ with a single tag method.

We did not see significant signals, confirming the latest result from BaBar collaboration, and set a preliminary UL,
$BR(D^0 \to \gamma\gamma)/BR(D^0 \to \pi^0\pi^0) < 5.8\times10^{-3}$ UL @ 90% CL.

Extras

MC with the nominal selection criteria



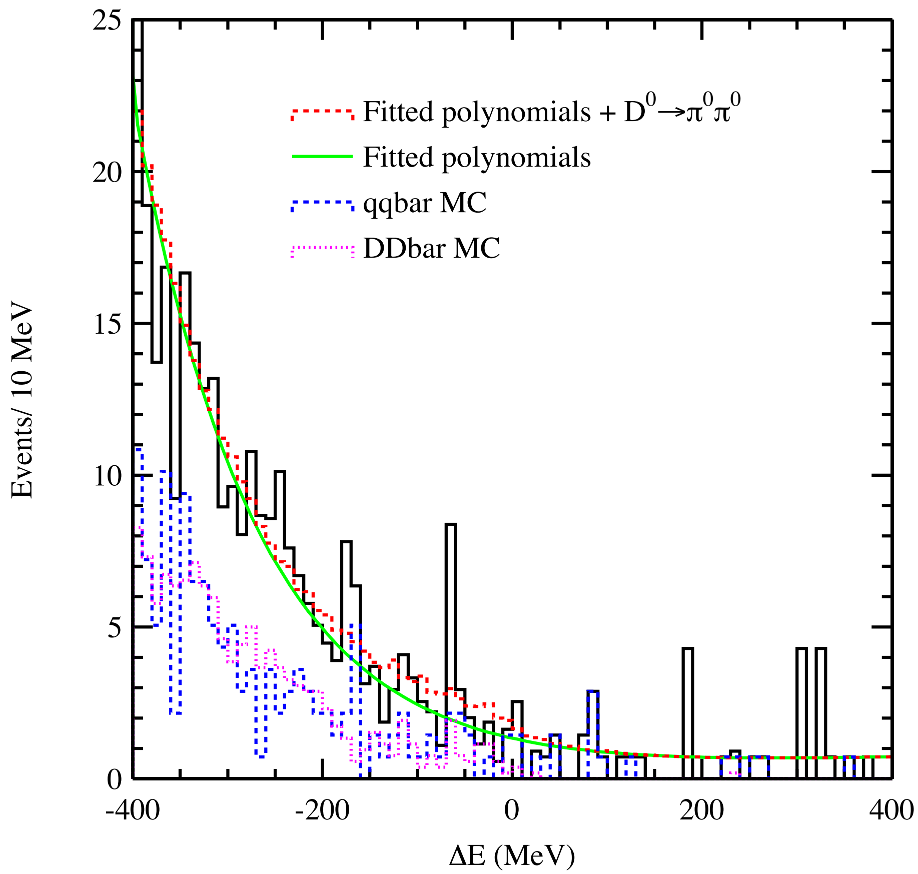
- The "DDbar background" is almost non-existent.
- The background is dominated by qqbar and R.R. to ψ(1S,2S) (similar to what we'll see in $D^0 \to \gamma\gamma$), leaving a smooth background shape
  → easy to describe by ARGUS bkg function.
- Overall recon. eff. = 23%.

Selection criteria for $D^0 \rightarrow \gamma\gamma$ events

All selection criteria are tuned based on MC samples:

- **Use showers detected in the Barrel section only.**
- **π^0 suppression on both photons.**
- **Lateral shower profile should be consistent with that of electromagnetic shower.**
- **The fastest reconstructed charged track should not have $E_{crystal}/p \sim 1$ to suppress radiative Bhabha events.**
- **There must be at least one charged kaon (PID: dE/dx+ ToF) reconstructed in order to suppress contamination from qqbar.**

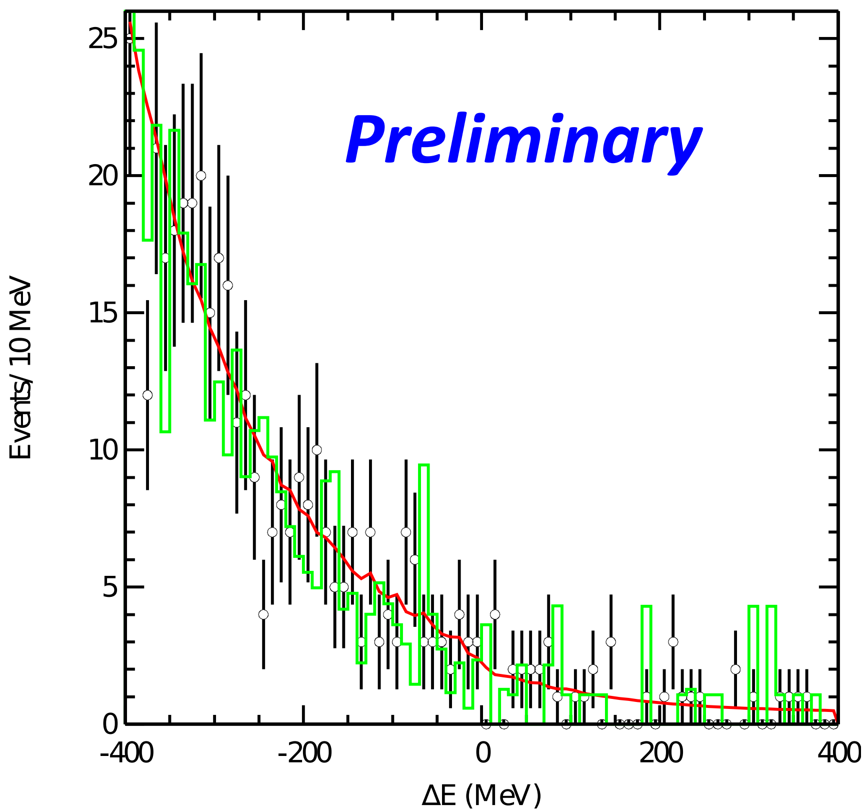
An Example Fit to the cocktail MC, scaled to our data size (w/ no signal)



- **Red = total fitted background shape**
- **Green = bkg without the $D^0 \to \pi^0\pi^0$ shape.**
- **Gives: -5.2±5.0 events.**

- **The background shape is described by an exponential polynomial and a linear polynomial.**

Scaled up MC background shape



- MC : -5.2±5.0 events
- DATA: -2.9±7.1 events

In our $D^0 \to \pi^0\pi^0$ study, we had to scale UP our non-DD MC sample by a factor of 1.49.

Here, similarly we scaled up the MC background (solid green).

Black points are data.

Red line is the fitted curve.

Preliminary

Systematic Uncertainties

The total relative systematic uncertainty of
$B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0)$ is 12%.

This is dominated by:

- **The syst. error from $D^0 \to \pi^0\pi^0$ measurement (~9%).**
  This is currently under investigation and will improve.
  Also, in the future, we may not need to use $B(D^0 \to \pi^0\pi^0)$ to normalize $B(D^0 \to \gamma\gamma)$.
- **Photon reconstructions simulation (~5%).**
  π^0 suppression as well as radiative Bhabha suppression.
- **Continuum (including Bhabha) suppression (~5%).**
  See backup slide for more detail.
  Needed to suppress the most dominant background.