

# Rediscovery of $\eta'$ in Phase III (and II)

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INFN Padova

35th B2GM,  
KEK, 03/02/2020

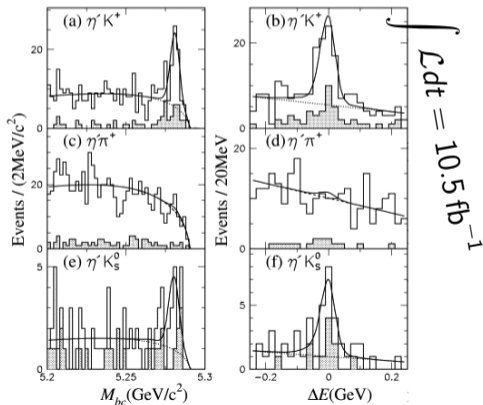
- Goal is TDCPV for charmless  $B^0 \rightarrow \eta' K_S^0$  decay
- From PDG:
  - ▶  $\mathcal{B}(B^0 \rightarrow \eta' K_S^0) = (6.6 \pm 0.4) \cdot 10^{-5}$
  - ▶  $\mathcal{B}(B^\pm \rightarrow \eta' K^\pm) = (7.06 \pm 0.25) \cdot 10^{-5}$
- Can it be seen with  $10 \text{ fb}^{-1}$ ?
- Belle did it with  $10.5 \text{ fb}^{-1}$  [PLB 517 (Oct, 2001) 309-318]
  - ▶  $\mathcal{B}(B^0) = (55_{-16}^{+19} \pm 9) \cdot 10^{-6} \quad N_{B^0} = 28.9_{-5.7}^{+6.5}$
  - ▶  $\mathcal{B}(B^\pm) = (79_{-11}^{+12} \pm 8) \cdot 10^{-6} \quad N_{B^\pm} = 42.5_{-8.3}^{+9.1}$
  - ▶ Upper limit for  $B^+ \rightarrow \eta' \pi^+$
- First step is to rediscover  $\eta'$  in Data and study its features
- B2Note [BELLE2-NOTE-PH-2018-038](#)
  - ▶ Seeking approval for Moriond
  - ▶ review committee: Bryan (chair), Sasha, Torben



Physics Letters B  
Volume 517, Issues 3-4, 4 October 2001, Pages 309-318



Measurement of the branching fraction for  $B \rightarrow \eta' K$  and search for  $B \rightarrow \eta' \pi^+$



- Data and MC

- ▶ proc9 + prompt for exp 3 (phase II) and 7+8 (phase III)
- ▶ proc10 for exp 7+8
  - ★ for exp8 use 4S+Scan+Continuum
  - ★ GoodRuns only
- ▶ MC12d (run dependent MC)  $L = 10 \text{ fb}^{-1}$  (rel-03)
  - ★ MC13b not yet used
- ▶ Comparison also with Belle ( $10.5 \text{ fb}^{-1}$ ) when available

- release-04-01-01

Final state	BR	sub-decay	BR	BR <sub>total</sub>
$\eta \rightarrow \gamma\gamma$	0.394			
$\eta \rightarrow \pi^0\pi^0\pi^0$	0.327			
$\eta \rightarrow \pi^+\pi^-\pi^0$	0.229			
$\eta \rightarrow \pi^+\pi^-\gamma$	0.042			
$\eta' \rightarrow \eta\pi^+\pi^-$	0.426	$\eta \rightarrow \gamma\gamma$	0.394	0.168
		$\eta \rightarrow \pi^+\pi^-\pi^0$	0.229	0.098
$\eta' \rightarrow \rho\gamma$	0.289	$\rho \rightarrow \pi^-\pi^+$	1	0.289
$\eta' \rightarrow \eta\pi^0\pi^0$	0.228			

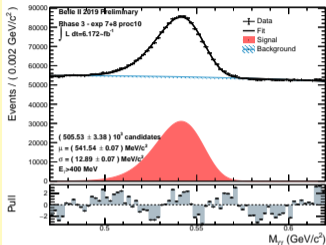
- ✓  $\pi^0 \rightarrow \gamma\gamma$
- ✓  $\eta \rightarrow \gamma\gamma$
- ✓  $\eta \rightarrow \pi^+\pi^-\pi^0$
- ✓  $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$
- ✓  $\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$
- ✓  $\rho \rightarrow \pi^+\pi^-$
- ✓  $f_0(975) \rightarrow \pi^+\pi^-$
- ✓  $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-\gamma)$

Detailed selection and fit model in the B2Note and in backup slides

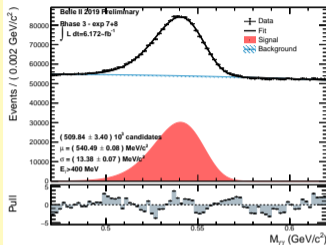
## Building blocks:

- $\gamma$ 
  - ▶  $\gamma$  gamma:tight from stdPhotons
  - ▶ in the CDC acceptance:  
 $0.296706 < \theta_\gamma < 2.61799$
  - ▶ Cluster:  $N_{hits} > 1.5, E_9/E_{21} > 0.7$
- Pions:  $\pi^\pm$ 
  - ▶  $d_r(\pi) < 0.5 \text{ cm}, |d_z(\pi)| < 2 \text{ cm}$
  - ▶  $P(\chi^2) > 0.0001$
- $\eta(\rightarrow \gamma\gamma)$ 
  - ▶  $E_\gamma > 400 \text{ MeV}$
- $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$ 
  - ▶  $p_{\pi^\pm} > 400 \text{ MeV}$
  - ▶  $p_\eta > 400 \text{ MeV}$
  - ▶  $0.48 < M_{\gamma\gamma} < 0.58 \text{ GeV}$
  - ▶  $0.9 < M_{\gamma\gamma\pi^\pm} < 1.1 \text{ GeV}$
- TreeFitter with  $\eta$  mass constraint

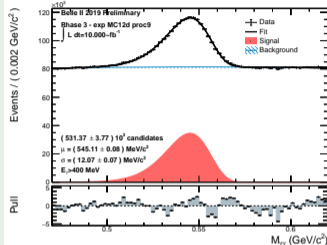
### proc10 exp 7+8



### proc9+prompt exp 7+8



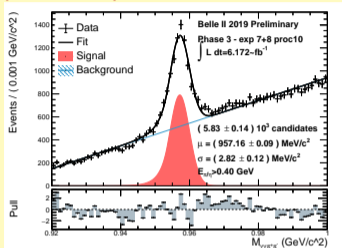
### proc9 MC12d



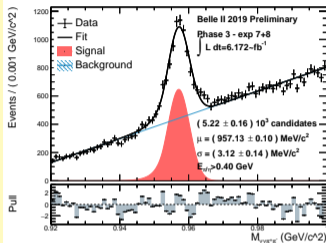
	Proc	Yield ( $10^3 / \text{fb}^{-1}$ )	$\mu$ (MeV)	$\sigma$ (MeV)
Phase III	proc10	81.6	541.5	12.9
Phase III	proc9	82.6	540.5	13.4
MC12d	Rel 3	53	545.1	12.1

- $E_\gamma > 400$  MeV in all regions
- Significant less yield in MC
  - ▶ same in MC12d bucket8
- Data - MC  $\Delta\mu \sim 4$  MeV  $\sim 1\%$
- $\sigma$  proc10 improved wrt proc9
- At Belle ( $10.5 \text{ fb}^{-1}$ ) 12 MeV

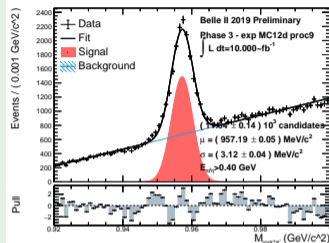
### proc10 exp 7+8



### proc9+prompt exp 7+8



### proc9 MC12d



	Proc	Yield (10 <sup>3</sup> / fb <sup>-1</sup> )	$\mu$ (MeV)	$\sigma$ (MeV)
Phase III	proc10	0.95	957.16	2.8
Phase III	proc9	0.85	957.13	3.2
MC12d	Rel 3	1.16	957.19	3.1

- $E_{\eta/\pi} > 400 \text{ MeV}$
- Yield +10% in proc10, still less than MC
- $\sigma$ : improvement in proc10
  - ▶ better than MC
- in Belle (10.5 fb<sup>-1</sup>) 2.7 MeV
- fit model can be improved

## Building blocks:

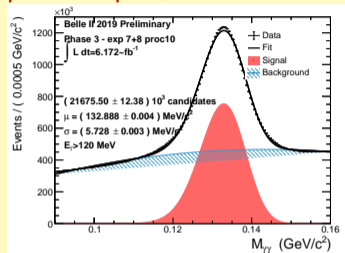
### Same as before

- $\gamma$ 
  - ▶ `gamma:tight` from `stdPhotons`
  - ▶ in the CDC acceptance:  
 $0.296706 < \theta_\gamma < 2.61799$
  - ▶ Cluster:  $N_{hits} > 1.5, E_9/E_{21} > 0.7$
- Pions:  $\pi^\pm$ 
  - ▶  $d_r(\pi) < 0.5 \text{ cm}, |d_z(\pi)| < 2 \text{ cm}$
  - ▶  $P(\chi^2) > 0.0001$

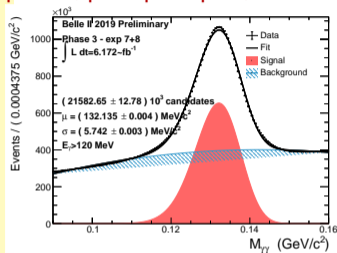
Channel not used in Belle ( $10.5 \text{ fb}^{-1}$ )

- $\pi^0 \rightarrow \gamma\gamma$ 
  - ▶  $E_\gamma > 120$
- $\eta \rightarrow \pi^+ \pi^- \pi^0$ 
  - ▶  $110 < M_{\pi^0} < 150 \text{ MeV}$
  - ▶  $p_\pi > 300 \text{ MeV}$
- $\eta' \rightarrow \eta(\rightarrow \pi^+ \pi^- \pi^0) \pi^+ \pi^-$ 
  - ▶  $\pi^0 \rightarrow \gamma\gamma$ 
    - ★  $E_\gamma > 200 \text{ GeV}$
  - ▶  $p_\pi > 400 \text{ MeV}$
  - ▶  $510 < M_\eta < 580 \text{ MeV}$
  - ▶  $0.9 < M_{\eta'} < 1.1 \text{ GeV}$
- TreeFitter with  $\eta$  and  $\pi^0$  mass constraint

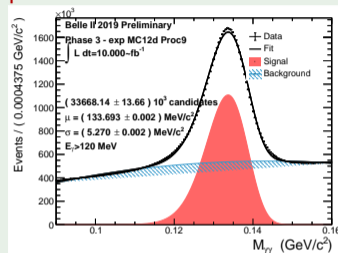
### proc10 exp 7+8



### proc9+prompt exp 7+8



### proc9 MC12d - rel 3

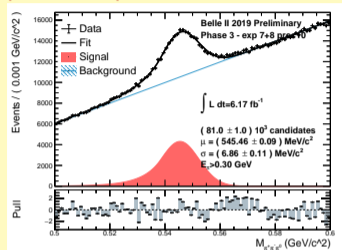


	Proc	Yield ( $10^6 / \text{fb}^{-1}$ )	$\mu$ (MeV)	$\sigma$ (MeV)
Phase III	proc10	3.6	132.9	5.7
Phase III	proc9	3.5	132.1	5.7
MC12d	Rel 3	3.4	133.7	5.3

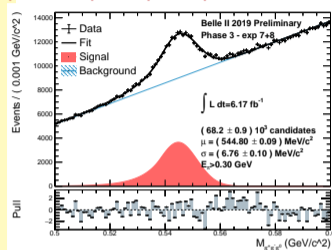
- NB: **not** the official  $\pi^0$  selection
- $E_\gamma > 120$  MeV in all regions
- poor fit: Novosibirsk1 + Chebychev(2)
- $\mu$  shifted by 1 MeV Data-MC ( $\sim 1\%$ )
- $\sigma$  stable and larger than MC



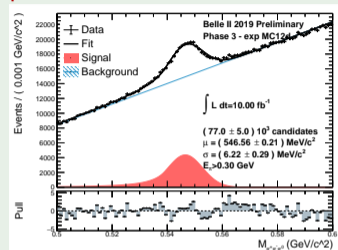
### proc10 exp 7+8



### proc9+prompt exp 7+8



### proc9 MC12d



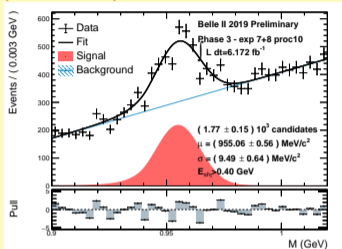
	Proc	Yield ( $10^3 / \text{fb}^{-1}$ )	$\mu$ (MeV)	$\sigma$ (MeV)
Phase III	proc10	13.1	545.5	6.9
Phase III	proc9	11.0	544.8	6.8
MC12d	Rel 3	6.9	546.6	6.2

Relative efficiency:  $\frac{\varepsilon(\eta \rightarrow 3\pi)}{\varepsilon(\eta \rightarrow \gamma\gamma)} \approx 28\%$

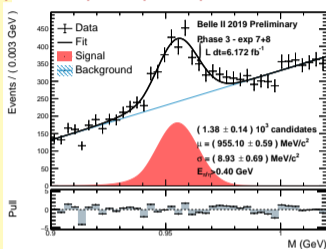
Could be used to test tracking efficiency?

- $E_{\pi} > 300 \text{ MeV}$
- Also low yield in MC
  - ▶ +20% in proc10
- $\mu$  proc10 vs proc9 +0.7 MeV
- Data - MC  $\Delta\mu \sim 1 \text{ MeV}$
- Not used in Belle ( $10.5 \text{ fb}^{-1}$ )

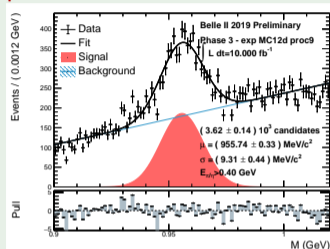
### proc10 exp 7+8



### proc9+prompt exp 7+8



### proc9 MC12d



	Proc	Yield (10 <sup>3</sup> / fb <sup>-1</sup> )	$\mu$ (MeV)	$\sigma$ (MeV)
Phase III	proc10	0.29	955.1	9.5
Phase III	proc9	0.22	955.1	8.9
MC12d	Rel 3	0.36	955.7	9.3

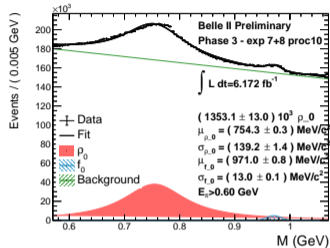
- $E_{\eta\pi} > 400 \text{ MeV}$
- very poor peak
- Yield  $\sim 1/3$  of  $\eta' \rightarrow \eta(\rightarrow \gamma\gamma) \pi^+ \pi^-$
- relative eff:  $\varepsilon(3\pi/2\gamma) = 0.52 \pm 0.05$
- Not used in Belle (10.5 fb<sup>-1</sup>)

## Building blocks:

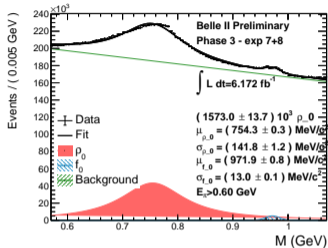
### Same as before

- $\gamma$ 
  - ▶  $\gamma$  gamma: tight from stdPhotons
  - ▶ in the CDC acceptance:
 
$$0.296706 < \theta_\gamma < 2.61799$$
  - ▶ Cluster:  $N_{hits} > 1.5, E_9/E_{21} > 0.7$
- Pions:  $\pi^\pm$ 
  - ▶  $d_r(\pi) < 0.5 \text{ cm}, |d_z(\pi)| < 2 \text{ cm}$
  - ▶  $P(\chi^2) > 0.0001$
- $\rho \rightarrow \pi^+\pi^-$ 
  - ▶  $p_\pi > 0.6 \text{ GeV}$
  - ▶  $0.57 < M_\rho < 0.95 \text{ GeV}$
- $\gamma$  gamma: all from stdPhotons
  - ▶  $0.296706 < \theta < 2.61799$
  - ▶ Cluster:  $N_{hits} > 1.5, E_9/E_{21} > 0.9$
  - ▶  $E_\gamma > 0.6 \text{ GeV}$
- $\pi^0$  veto
  - ▶ select one  $\gamma$  from ROE and build  $M_{\gamma\gamma}$
  - ▶  $M_{\pi^0\text{-veto}} < 120 \text{ or } > 145 \text{ MeV}$
- TreeFitter w/o any mass constraint

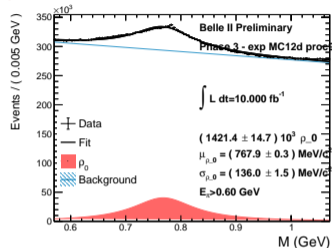
proc10 exp 7+8



proc9+prompt exp 7+8



proc9 MC12d



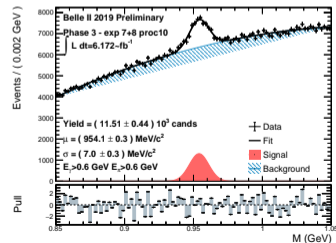
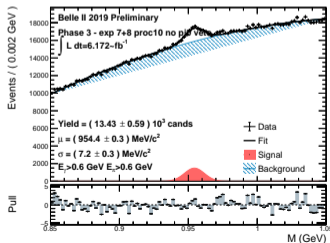
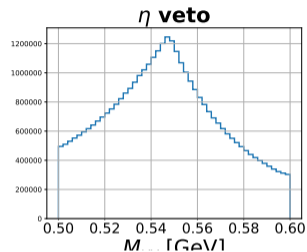
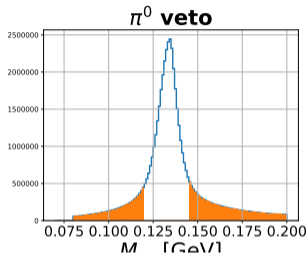
Dataset	Yield ( $10^6 / \text{fb}^{-1}$ )	$\rho$		$f_0$	
		$\mu$ (MeV)	$\sigma$ (MeV)	$\mu$ (MeV)	$\sigma$ (MeV)
Phase III proc10	1.35	754.3	139	971	13
Phase III proc9	1.57	754.3	142	972	13
MC12d Rel 3	1.42	767.9	136		

fit model:

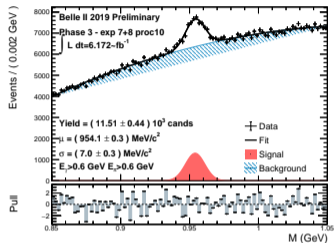
- Breit-Wigner ( $\rho$ ) + Gauss ( $f_0$ ) + Cheb(1) background
- not very good to model data, especially for  $\rho$

- $p_{\pi^\pm} > 600 \text{ MeV}$
- $f_0$  peak well visible on Data
  - ▶ not simulated in MC
- Peak features stable
- Yield lower in proc10 but might due to fit model

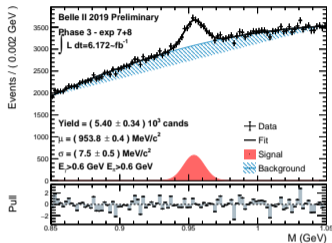
- reconstruct  $M_{\gamma\gamma}$  for  $\pi^0/\eta$  candidate from
  - the  $\gamma$  from  $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$
  - a  $\gamma$  from Rest of Event
- look at the candidate closest to  $M_{PDG}$
- Clear  $\pi^0$  peak, only biased  $M_{\gamma\gamma}$  for  $\eta$ 
  - yield ( $\pi^0/\eta$ )  $\rightarrow \gamma\gamma \sim 50$
- Reject candidate if  $120 < M_{\gamma\gamma}^{\text{veto}} < 145 \text{ MeV}$
- Impact of  $\pi^0$  veto is significant
  - background level reduced by factor 2
  - Signal/Background significantly improves
  - $\eta'$  peak more visible



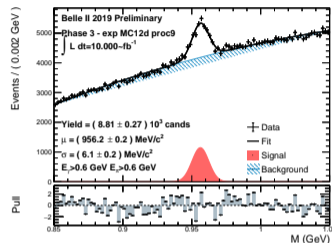
### proc10 exp 7+8



### proc9+prompt exp 7+8



### proc9 MC12d

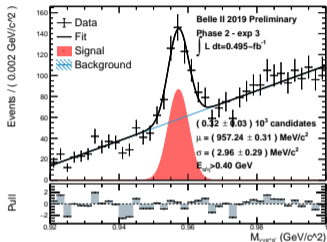


	Proc	Yield ( $10^3 / \text{fb}^{-1}$ )	$\mu$ (MeV)	$\sigma$ (MeV)
Phase III	proc10	1.9	954	7.0
Phase III	proc9	0.9	954	7.4
MC12d	Rel 3	0.9	956	6.1

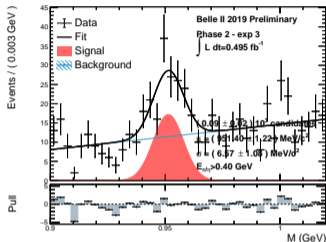
Relative efficiency:  $\varepsilon(\rho\gamma/\eta_{\gamma\gamma} 2\pi) = 1.1 \pm 0.06$

- $E_{\rho\gamma} > 600 \text{ MeV}$
- Large yield increase wrt proc9+prompt
  - ▶ was  $1.45 \cdot 10^3$  per proc9,  $0.8 \cdot 10^3$  for prompt
  - ▶ large increase also for background same S/B
- Belle ( $10.5 \text{ fb}^{-1}$ )  $\sigma = 8.8 \text{ MeV}$

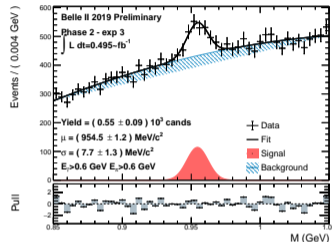
$$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$$



$$\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$$



$$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$$



channel	Exp-Phase-proc	Yield ( $10^3 \text{ cand}/\text{fb}^{-1}$ )	$\mu$ (MeV)	$\sigma$ (MeV)
$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$	3 - II - proc9	$0.65 \pm 0.06$	$957.24 \pm 0.31$	$2.96 \pm 0.29$
	7+8 - III - proc10	$0.95 \pm 0.02$	$957.16 \pm 0.09$	$2.82 \pm 0.12$
$\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$	3 - II - proc9	$0.19 \pm 0.03$	$951.40 \pm 1.22$	$6.57 \pm 1.08$
	7+8 - III - proc10	$0.95 \pm 0.02$	$957.16 \pm 0.09$	$2.82 \pm 0.12$
$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$	3 - II - proc9	$1.12 \pm 0.19$	$954.50 \pm 1.16$	$7.73 \pm 1.29$
	3 - III - proc10	$1.86 \pm 0.07$	$954.06 \pm 0.26$	$7.02 \pm 0.28$

	Proc	Yield ( $10^3 \text{ cand}/\text{fb}^{-1}$ )	$\mu$ (MeV)	$\sigma$ (MeV)
$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$				
Phase II	proc9	$0.65 \pm 0.06$	$957.24 \pm 0.31$	$2.96 \pm 0.29$
Phase III		$0.85 \pm 0.03$	$957.13 \pm 0.10$	$3.12 \pm 0.14$
Phase III	proc10	$0.95 \pm 0.02$	$957.16 \pm 0.09$	$2.82 \pm 0.12$
MC12d	proc9	$1.16 \pm 0.01$	$957.19 \pm 0.05$	$3.12 \pm 0.04$
Belle ( $10.5 \text{ fb}^{-1}$ )				2.7
$\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$				
Phase II	proc9	$0.19 \pm 0.03$	$951.40 \pm 1.22$	$6.57 \pm 1.08$
Phase III		$0.22 \pm 0.02$	$955.10 \pm 0.59$	$8.93 \pm 0.69$
Phase III	proc10	$0.29 \pm 0.02$	$955.06 \pm 0.56$	$9.49 \pm 0.64$
MC12d	proc9	$0.36 \pm 0.01$	$955.74 \pm 0.33$	$9.31 \pm 0.44$
$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$				
Phase II	proc9	$1.12 \pm 0.19$	$954.50 \pm 1.16$	$7.73 \pm 1.29$
Phase III		$0.88 \pm 0.05$	$953.83 \pm 0.41$	$7.46 \pm 0.47$
Phase III	proc10	$1.86 \pm 0.07$	$954.06 \pm 0.26$	$7.02 \pm 0.28$
MC12d	proc9	$0.88 \pm 0.03$	$956.23 \pm 0.22$	$6.12 \pm 0.18$
Belle ( $10.5 \text{ fb}^{-1}$ )				8.8



- Rediscovery of  $\eta'$  in phase III (and phase II)
  - ▶ proc10 has generally better yield and  $\sigma$
- Comparison with MC generally good
  - ▶ some difference on yield and peak values.
- Comparison with Belle with similar luminosity ( $10.5 \text{ fb}^{-1}$ ) shows similar or better results
- TODO list
  - ▶ Update note with proc10 results
  - ▶ look at MC13b (run dependent)
- Review process can proceed with current note
- Goal is to have  $\eta'$  plots (pdf) approved for Moriond
  - ▶ exp3 proc9
  - ▶ exp7+8 proc10

## Light meson rediscovered

- ✓  $\pi^0 \rightarrow \gamma\gamma$
- ✓  $\eta \rightarrow \gamma\gamma$
- ✓  $\eta \rightarrow \pi^+\pi^-\pi^0$
- ✓  $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$
- ✓  $\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$
- ✓  $\rho \rightarrow \pi^+\pi^-$
- ✓  $f_0(975) \rightarrow \pi^+\pi^-$
- ✓  $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$

Additional or backup slides

$$\pi^0/\eta \rightarrow \gamma \gamma$$

- **Preselection:**

- `gamma:tight`

- ▶ in the CDC acceptance  
 $0.296706 < \theta_\gamma < 2.61799$
- ▶ `clusterErrorTiming` < 1e6
- ▶  $E_\gamma > 50$  MeV in barrel and forward region
- ▶  $E_\gamma > 75$  MeV in backward region
- ▶  $N_{hits} > 1.5$
- ▶  $E_9/E_{25} > 0.7$

- **Selection:**

- ▶  $E_9/E_{21} > 0.9$
- ▶  $E_\gamma > 120$  MeV ( $\pi^0$ )
- ▶  $E_\gamma > 400$  MeV ( $\eta$ )

- TreeFitter

$$\eta \rightarrow \pi^+ \pi^- \pi^0$$

- **Preselection:**

- `pi:all`

- ▶ in the CDC acceptance
- ▶  $\chi^2 > 0.0001$
- ▶  $dr < 0.5$  and  $|dz| < 2$  cm

- **Selection:**

- ▶  $\gamma$  as in  $\pi^0$
- ▶  $E_\gamma > 200$  MeV
- ▶  $110 < M_{\gamma\gamma} < 150$  MeV.

- TreeFitter with  $\pi^0$  mass constraint

$$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$$

- $\eta \rightarrow \gamma\gamma$ 
  - ▶ `gamma:tight` from `stdPhotons`
  - ▶ in the CDC acceptance:  
 $0.296706 < \theta_\gamma < 2.61799$
  - ▶ Cluster:  $N_{hits} > 1.5$ ,  $E_9/E_{21} > 0.7$
  - ▶  $E_\gamma > 400$  MeV
- $\pi^\pm$ 
  - ▶  $d_r(\pi) < 0.5$  cm,  $|d_z(\pi)| < 2$  cm
  - ▶  $P(\chi^2) > 0.0001$
  - ▶  $p_\pi > 400$  MeV
- $\eta$ 
  - ▶  $0.48 < M_{\gamma\gamma} < 0.58$  GeV
  - ▶  $p_\eta > 400$  MeV
- $\eta'$ :  $0.9 < M_{\gamma\gamma\pi^\pm} < 1.1$  GeV
- TreeFitter with  $\eta$  mass constraint

$$\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$$

- $\pi^0 \rightarrow \gamma\gamma$ 
  - ▶ `gamma:gamma:tight` from `stdPhotons`
  - ▶ in the CDC acceptance  
 $0.296706 < \theta_\gamma < 2.61799$
  - ▶ Cluster:  $N_{hits} > 1.5$ ,  $E_9/E_{21} > 0.7$
  - ▶  $E_\gamma > 200$  GeV
  - ▶  $110 < M_{\pi^0} < 150$  MeV
  - ▶  $p_{\pi^0} > 400$  MeV
- $\pi^\pm$ 
  - ▶  $d_r(\pi) < 0.5$  cm,  $|d_z(\pi)| < 2$  cm
  - ▶  $p_\pi > 400$  MeV
- $\eta$ :  $510 < M_\eta < 580$  MeV
- $\eta'$ :  $0.9 < M_{\eta'} < 1.1$  GeV
- TreeFitter with  $\eta$  and  $\pi^0$  mass constraint

- $\rho \rightarrow \pi^+\pi^-$ 
  - ▶  $p_\pi > 0.6 \text{ GeV}$
  - ▶  $0.57 < M_\rho < 0.95 \text{ GeV}$
- $\gamma$  gamma: all from stdPhotons
  - ▶  $0.296706 < \theta < 2.61799$
  - ▶ Cluster:  $N_{hits} > 1.5$ ,  $E_9/E_{21} > 0.9$
  - ▶  $E_\gamma > 0.6 \text{ GeV}$
- $\pi^0$  veto
  - ▶ select one  $\gamma$  from ROE and build  $M_{\gamma\gamma}$
  - ▶  $M_{\pi^0\text{-veto}} < 120$  or  $> 145 \text{ MeV}$
- TreeFitter w/o any mass constraint

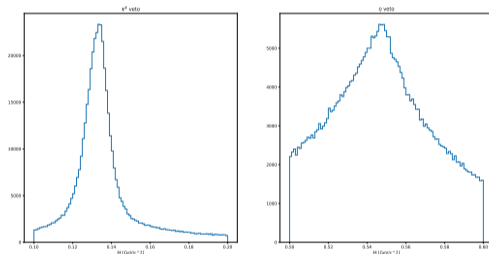


Figure: Distribution of invariant mass of  $\gamma\gamma$  candidates for  $\pi^0/\eta$  veto.

- $\pi^0 \rightarrow \gamma\gamma$ 
  - ▶ Novosibirskl + Chebychev(2)
- $\eta \rightarrow \gamma\gamma$ 
  - ▶ Novosibirskl + Chebychev(2)
- $\eta \rightarrow \pi^+\pi^-\pi^0$ 
  - ▶ Crystal Ball + Chebychev(1)
- $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$ 
  - ▶ Crystal Ball + Chebychev(1)
- $\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$ 
  - ▶ Crystal Ball + Chebychev(1)
- $\rho \rightarrow \pi^+\pi^-$ ,  $f_0(975) \rightarrow \pi^+\pi^-$ 
  - ▶ Breit-Wigner for  $\rho$  + Gaussian for  $f_0$  + Chebychev(1)
- $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$ 
  - ▶ Gaussian + Chebychev(2)