η' rediscovery in phase 3 (and 2) data

Neutrals Physics Performance Meeting
19/12/2019

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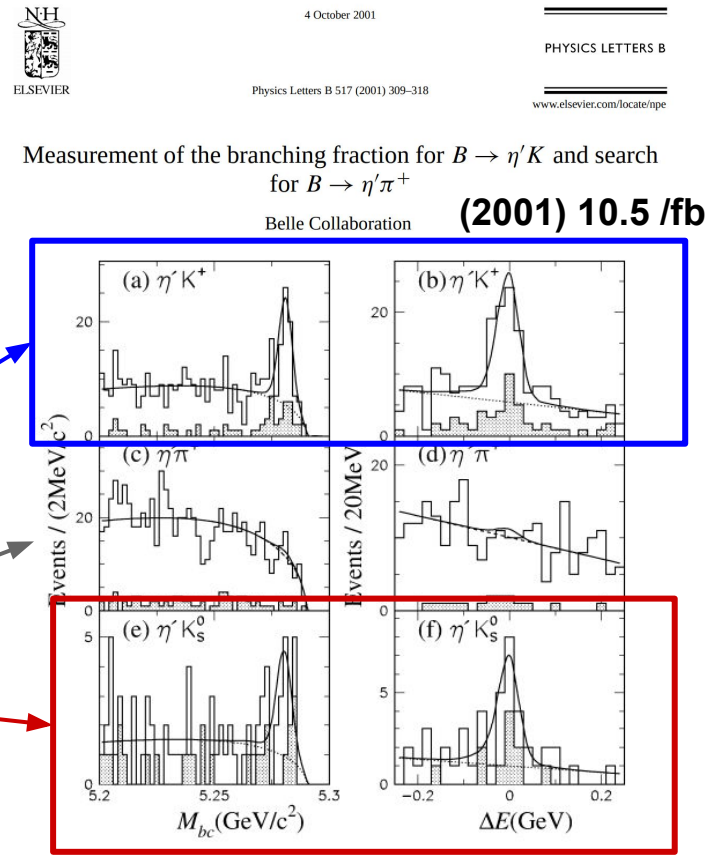
Motivations

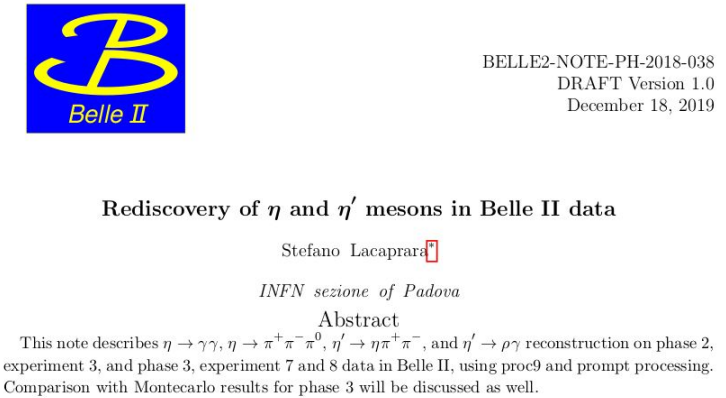
- **TimeDependet CPV study with Charmless B^0 decay: $B^0 \to \eta' K^0_S$**
- From PDG:
- BR($B^0 \to \eta' K^0_S$) = (6.6 ± 0.4) × 10^{-5}
  - C_{CP} ($B^0 \to \eta' K^0$) = −0.06 ± 0.04
  - $-A_{CP}=S_{CP}$ ($B^0 \to \eta' K^0_S$) = 0.63 ± 0.06
- BR($B^+ \to \eta' K^+$) = (7.06 ± 0.25) × 10^{-5}
- Can it be seen with 10/fb?
- It was done at Belle, both for:
  - B^+: BR=$(79^{+12}_{-11} \pm 8) \times 10^{-6}$
  - B^0 : BR=$(55^{+19}_{-16} \pm 9) \times 10^{-6}$
  - Limit for $B^0 \to \eta' \pi^+$
- First step: rediscovery η' in Phase 3 (and 2) Data and study its features



Shaded η'→ηππ, white all (including η'→ργ)

Documentation

- Being documented on BELLE2-NOTE-PH-2018-038
  - https://docs.belle2.org/record/1218?ln=en
- Note started with phase 2 data
  - Was under review
    - Phill, Bryan, Torben
  - Neglected (by me)
  - Now resurrected and updated
- Should be ready before Xmas



BELLE2-NOTE-PH-2018-038
DRAFT Version 1.0
December 18, 2019

Rediscovery of η and η' mesons in Belle II data

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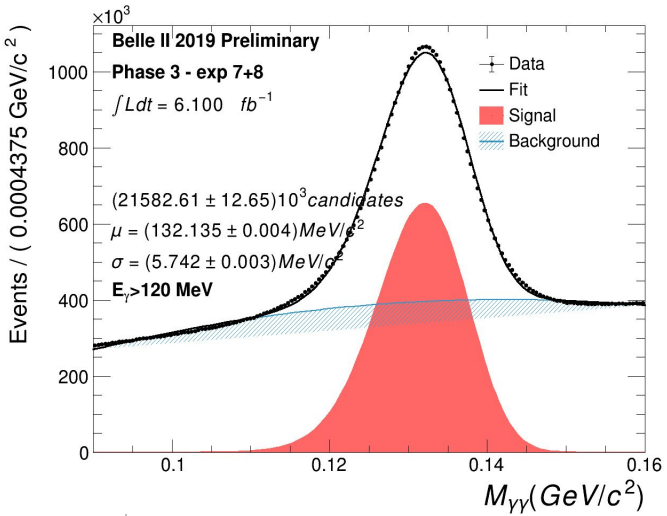
Abstract

This note describes $\eta \to \gamma\gamma$, $\eta \to \pi^+\pi^-\pi^0$, $\eta' \to \eta\pi^+\pi^-$, and $\eta' \to \rho\gamma$ reconstruction on phase 2, experiment 3, and phase 3, experiment 7 and 8 data in Belle II, using proc9 and prompt processing. Comparison with Montecarlo results for phase 3 will be discussed as well.

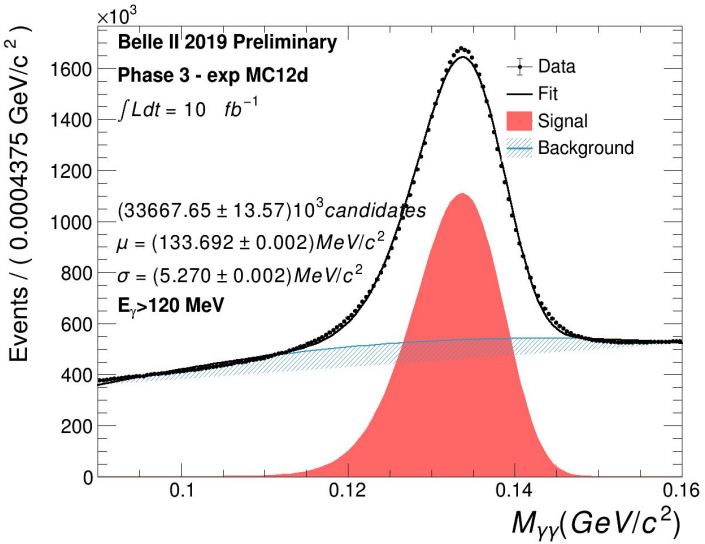
$\pi^0 \to \gamma\gamma$

- γ in CDC volume
- N_{hits}>1.5
- E_9/E_{21}>0.9
- E_γ>120 MeV

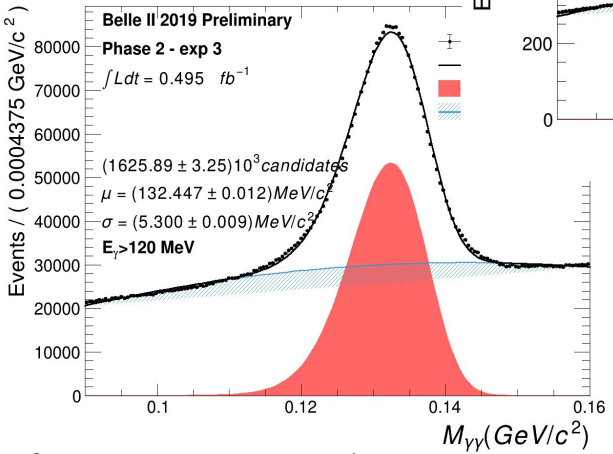
Phase 3



Run Dep MC12d

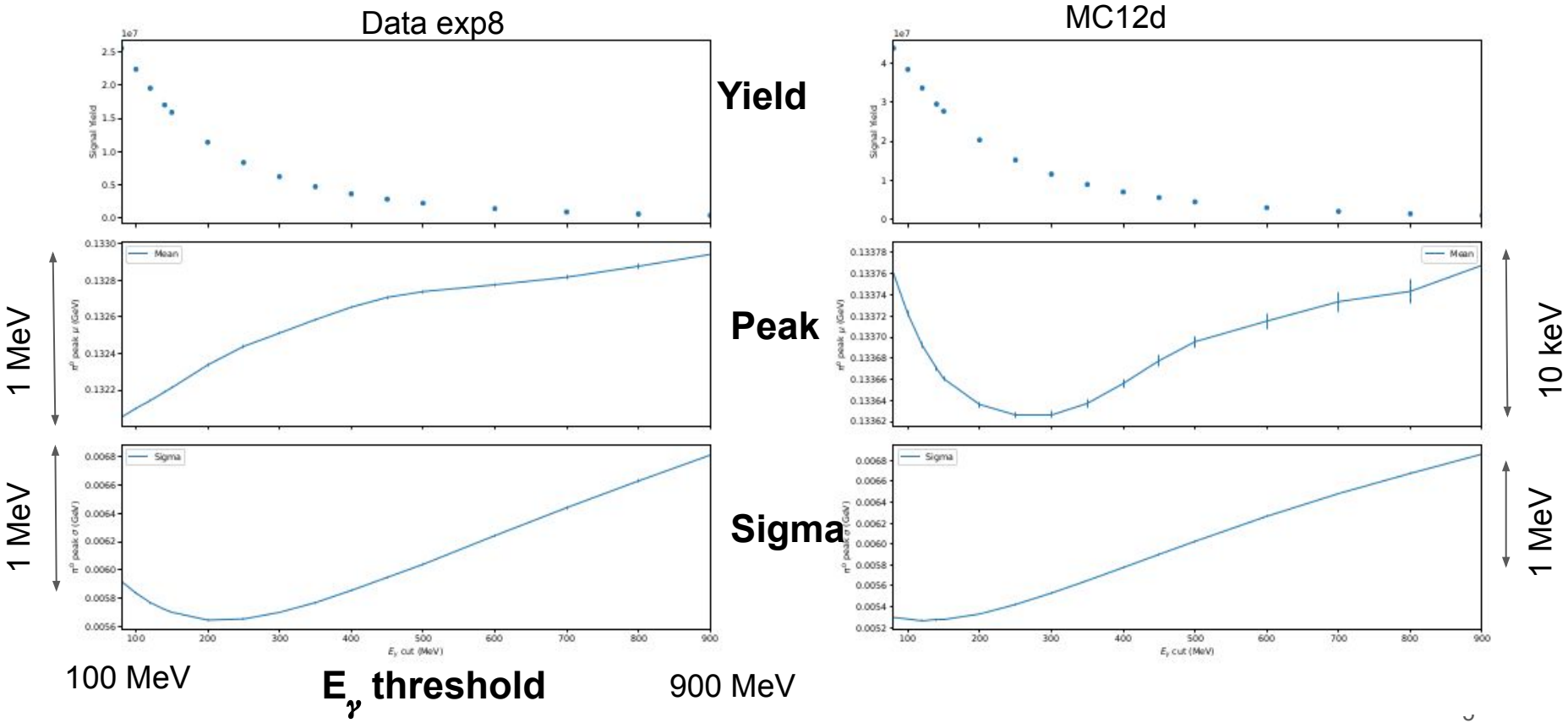


Phase 2



- Fit Novosibirsk + chebichev(2)
  - Not perfect pdf, good enough for peak and sigma.
- Peak Shift 1 MeV between Data and MC12d
- Width 5.3 vs 5.7 vs 5.3 (phase 2, 3, MC)

$\pi^0 \to \gamma\gamma$ vs E_γ threshold



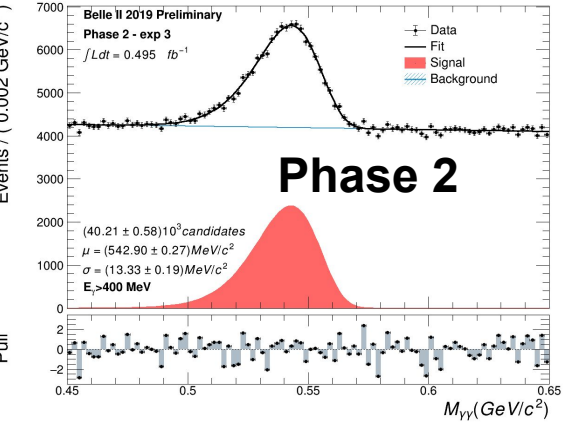
Fit result feature

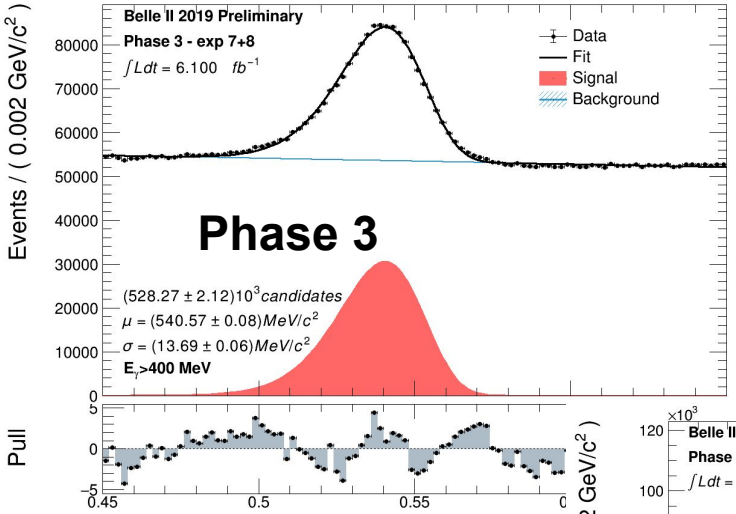
TABLE 1: Features of π^0 peak fit in different datasets. The uncertainties are only statistical.

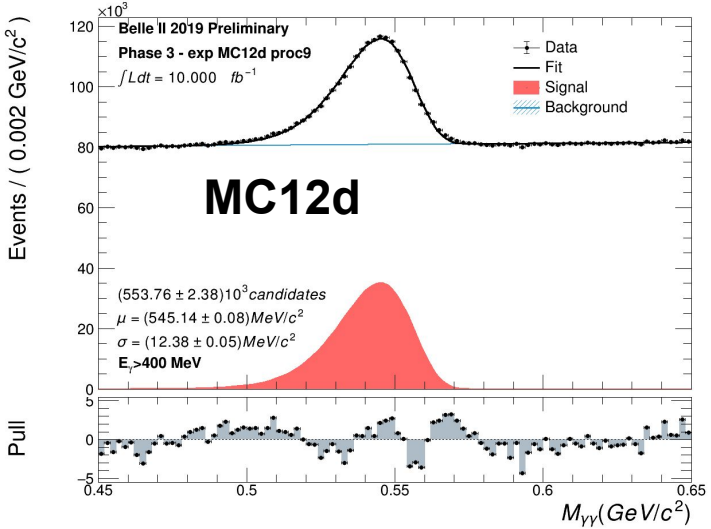
Phase	Exp	proc	yield ($1E6/fb^{-1}$)	μ (MeV)	σ (MeV)
II	3	proc9	3.285 ± 0.007	132.447 ± 0.012	5.300 ± 0.009
	7+8		3.375 ± 0.003	132.118 ± 0.005	5.732 ± 0.004
III	8	prompt	3.735 ± 0.003	132.153 ± 0.005	5.752 ± 0.004
	7+8	all	3.497 ± 0.002	132.135 ± 0.004	5.742 ± 0.003
MC	7+8	proc9	3.367 ± 0.001	133.692 ± 0.002	5.270 ± 0.002
	8	prompt	3.213 ± 0.001	133.779 ± 0.003	5.365 ± 0.002

- Yield ok Data/MC
- Peak +1 MeV in MC (~1%)
- Width -0.4 MeV in MC

$\eta \to \gamma\gamma$







- Same cut as for $\pi^0 \to \gamma\gamma$
  - **E_γ>400 MeV**
- Peak: +5 MeV in MC phase3
- Width : **13 vs 14 vs 12.5 MeV** (phase2, 3, MC12d)
  - At Belle (10.5 /fb)
  - $\eta \to \gamma\gamma$ width was **12 MeV/c^2**

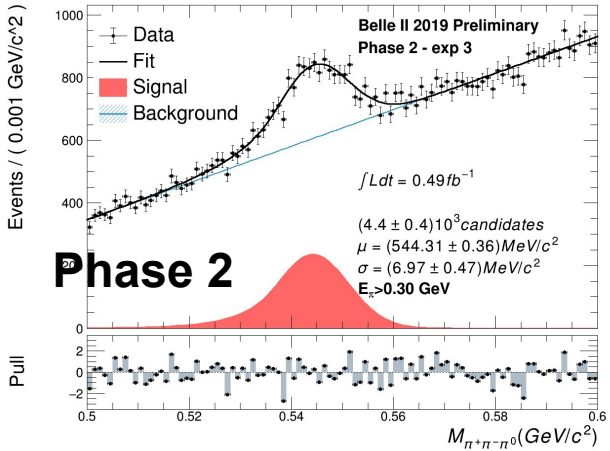
$\eta \to \gamma\gamma$ fit features

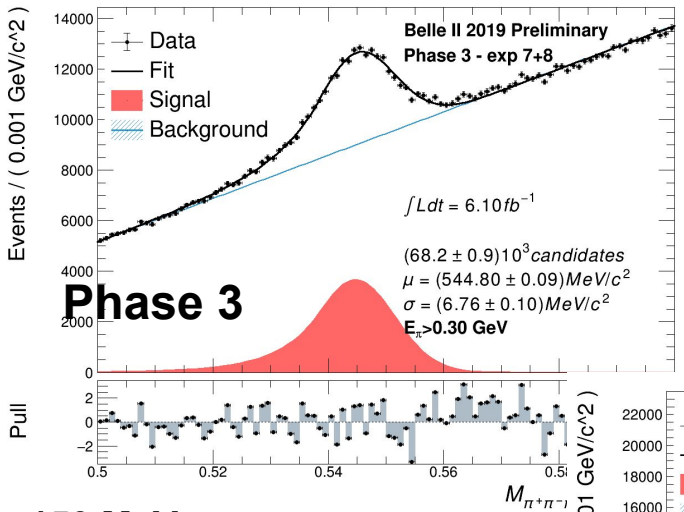
- Yield in MC significantly less than in data
- Peak position +5 MeV in MC
  - ~1% as for π^0
- Width -1 MeV in Mc

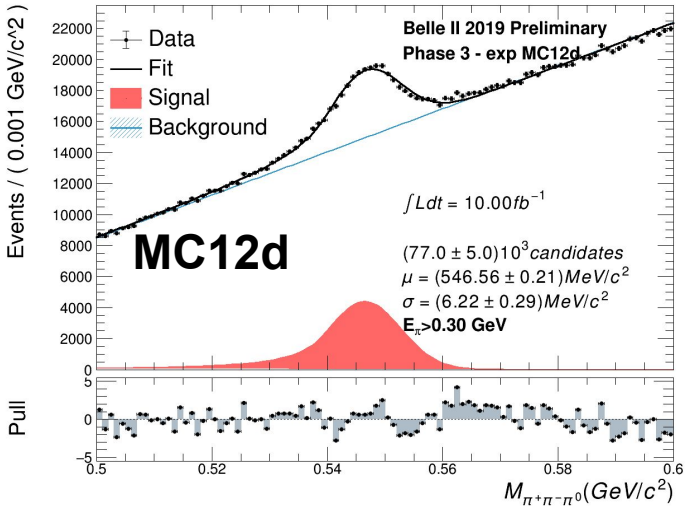
TABLE 2: Features of $\eta \to \gamma\gamma$ peak fit in different datasets

Phase	Exp	proc	yield (1E3/ fb^{-1})	μ (MeV)	σ (MeV)
II	3	proc9	79.1 ± 1.9	542.9 ± 0.3	13.1 ± 0.2
	7+8		80.4 ± 0.8	540.6 ± 0.1	13.3 ± 0.1
III	8	prompt	87.4 ± 0.9	540.4 ± 0.1	13.4 ± 0.1
	7+8	all	82.6 ± 0.6	540.5 ± 0.1	13.4 ± 0.1
MC	7+8	proc9	53.1 ± 0.4	545.1 ± 0.1	12.1 ± 0.1
	8	prompt	53.5 ± 0.4	545.1 ± 0.1	12.1 ± 0.1

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







- $\pi^0 \to \gamma\gamma$
  - **E_γ>200 MeV, 110<m_{π^0}<150 MeV,**
- $\pi^{+/-}$: P(□^{2})>10^{-4}, dr<0.5 cm, |dz|<2 cm
- **p(π^{0+-})>300 MeV**
- TreeFitter, π^0 mass constraint
- Peak: +2 MeV in MC phase3
- Width : **7 vs 7 vs 6.4 MeV** (phase2, 3, MC12d)
  - Not used at Belle (10.5 /fb)

$\eta \to \pi^+\pi^-\pi^0$ features

$\eta \to \pi^+\pi^-\pi^0$ vs p_π cut Data

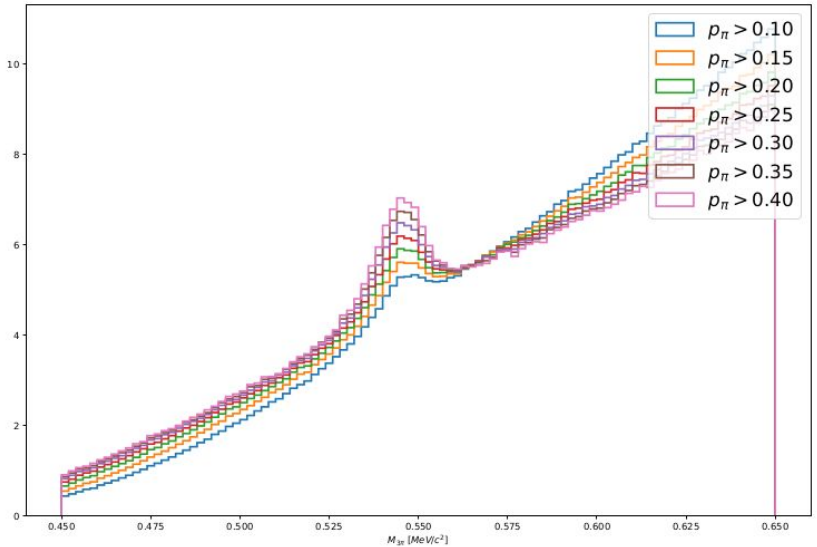
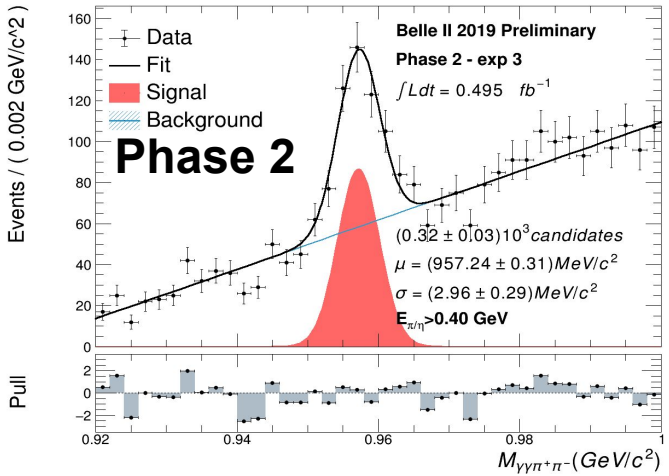


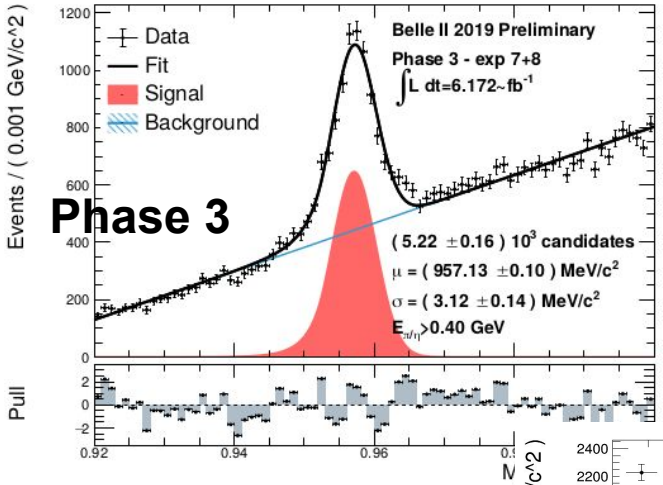
TABLE 3: Features of $\eta \to \pi^+\pi^-\pi^0$ peak fit in different datasets

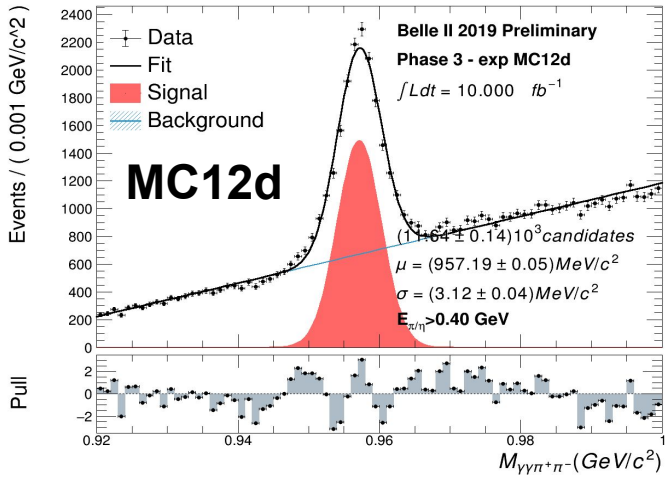
Phase	Exp	proc	yield (1E3/fb^{-1})	μ (MeV)	σ (MeV)
II	3	9	8.87 ± 0.91	544.31 ± 0.36	6.97 ± 0.47
	7+8		11.84 ± 0.24	544.84 ± 0.11	6.57 ± 0.13
III	8	prompt	9.69 ± 0.20	544.66 ± 0.14	7.29 ± 0.16
	7+8	all	11.05 ± 0.15	544.80 ± 0.09	6.76 ± 0.10
MC	7+8	proc9	7.70 ± 0.50	546.56 ± 0.21	6.22 ± 0.29
	8	prompt	7.23 ± 2.23	546.76 ± 0.23	5.85 ± 0.43

- Yield lower in MC (not stable in Data)
- Peak +2 MeV in MC
- Sigma -1 MeV in MC
  - Different in Prompt Data and MC wrt proc9
  - In Prompt MC -2 MeV

$\eta' \to \eta(\to \gamma\gamma)\,\pi^+\pi^-$







- γ and $\pi^{+/-}$ as before
  - $480 < M_\eta < 580$ MeV, $E_\gamma > 400$ MeV
- **$p(\pi/\eta) > 400$ MeV**
- TreeFitter with η mass constraint
- Peak: same in data and MC
- Width : **3.0 vs 3.1 vs 3.1** (phase2, 3, MC12d)
  - at Belle (10.5 /fb), width was **2.7 MeV**

$\eta' \to \eta(\to \gamma\gamma)\,\pi^+\pi^-$

Peak vs $p_{\eta\pi\pi}$ cut Data

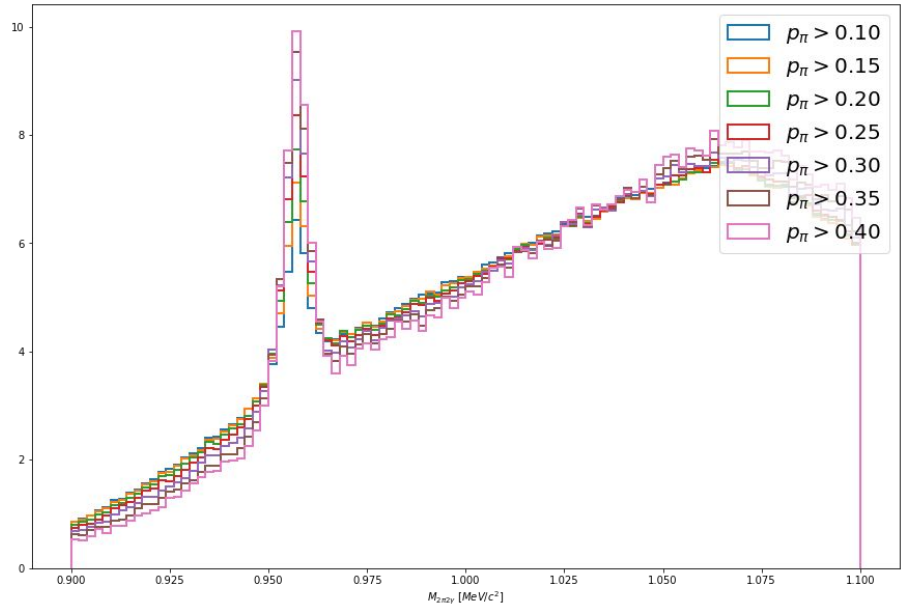
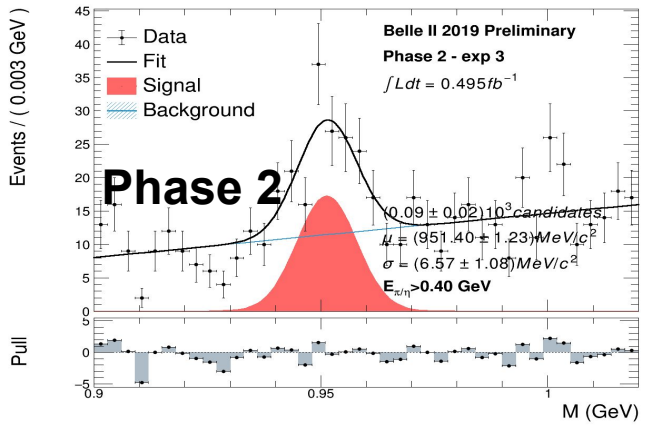


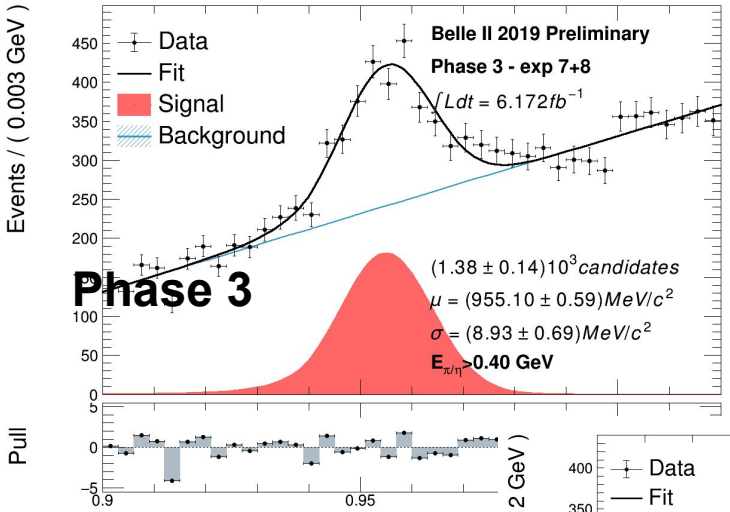
TABLE 4: Features of $\eta' \to \eta(\to \gamma\gamma)\pi^+\pi^-$ peak fit in different datasets

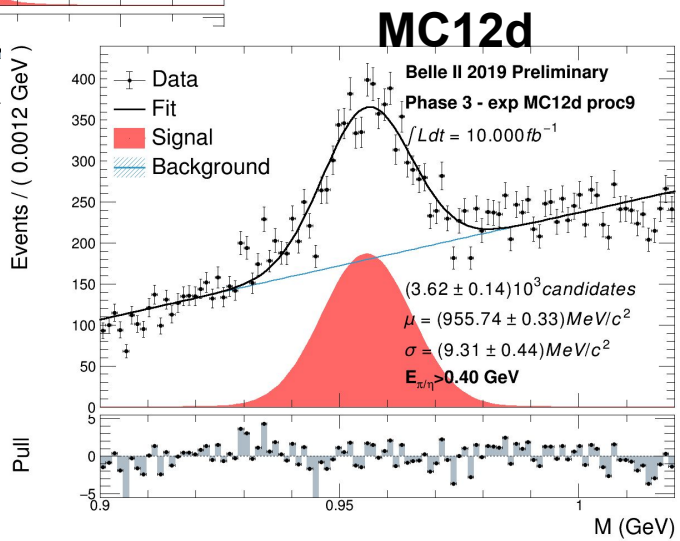
Phase	Exp	proc	yield (1E3/ fb^{-1})	μ (MeV)	σ (MeV)
II	3	proc9	0.65 ± 0.06	957.24 ± 0.31	2.96 ± 0.29
	7+8		0.90 ± 0.03	957.06 ± 0.12	3.22 ± 0.14
III	8	prompt	0.78 ± 0.03	957.26 ± 0.13	2.89 ± 0.18
	7+8	all	0.85 ± 0.03	957.13 ± 0.10	3.12 ± 0.14
MC	7+8	proc9	1.16 ± 0.01	957.19 ± 0.05	3.12 ± 0.04
	8	prompt	1.13 ± 0.02	957.26 ± 0.05	2.95 ± 0.06

- Yield larger in MC than in data
  - Some fluctuation in Data
- Peak position very good agreement
- Sigma very good agreement
  - Better in Prompt than in proc9

$\eta' \to \eta(\to \pi^+\pi^-\pi^0)\,\pi^+\pi^-$







- γ and $\pi^{+/-}$ as before
  - 510<M_η<580 MeV, E_π>400 MeV
- **p(π/η)>400 MeV**
- TreeFitter with η and π^0 mass constraint
- Peak: same in data and MC (lower in phase 2)
- Width : **6.6 vs 8.9 vs 9.3** (phase2, 3, MC12d)
  - Not used at Belle (10.5 /fb)
- Yield (/fb) ($3\pi/2\gamma$)~0.23/0.85 ~ 0.27 - BR($3\pi/2\gamma$)=0.6
  - **$\varepsilon(3\pi/2\gamma)$~0.5**

$\eta' \to \eta(\to \pi^+\pi^-\pi^0)\,\pi^+\pi^-$

Peak vs $p_{\eta\pi\pi}$ cut Data

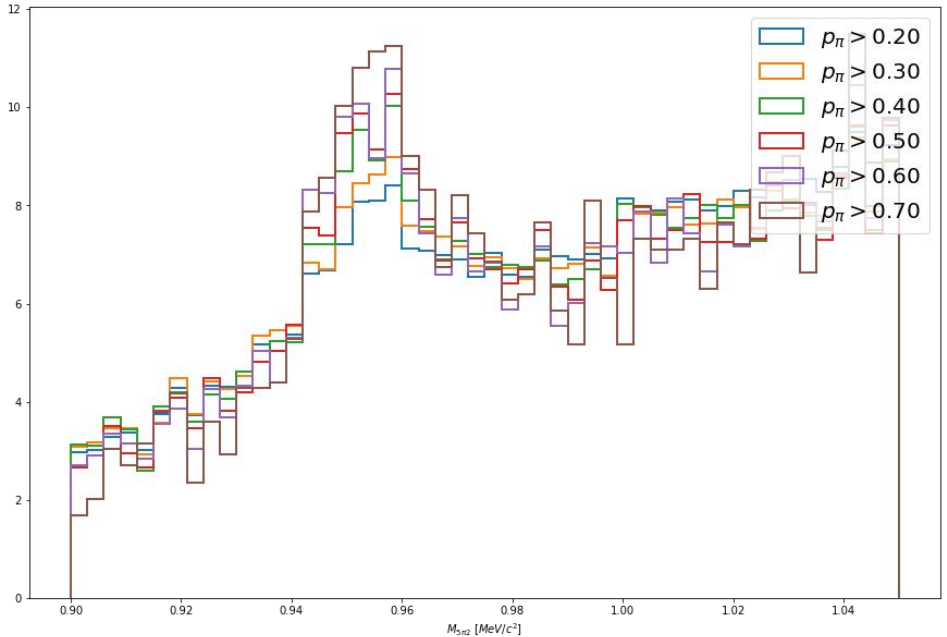


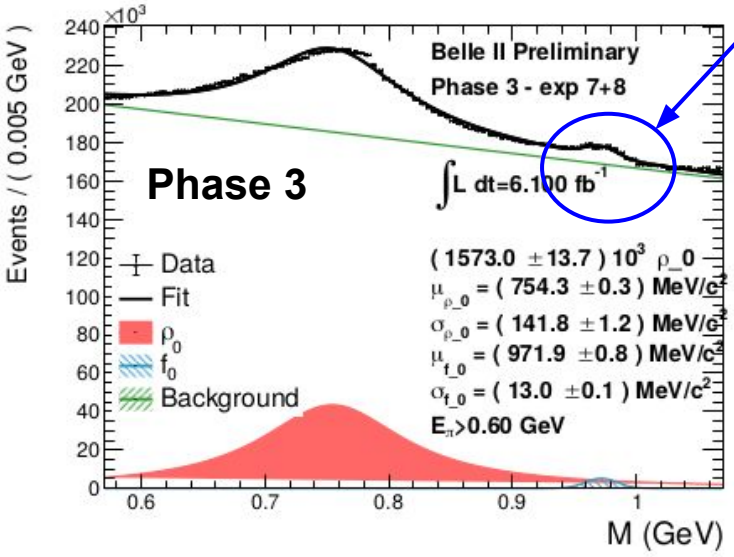
TABLE 5: Features of $\eta' \to \eta(\to \pi^+\pi^-\pi^0)\pi^+\pi^-$ peak fit in different datasets

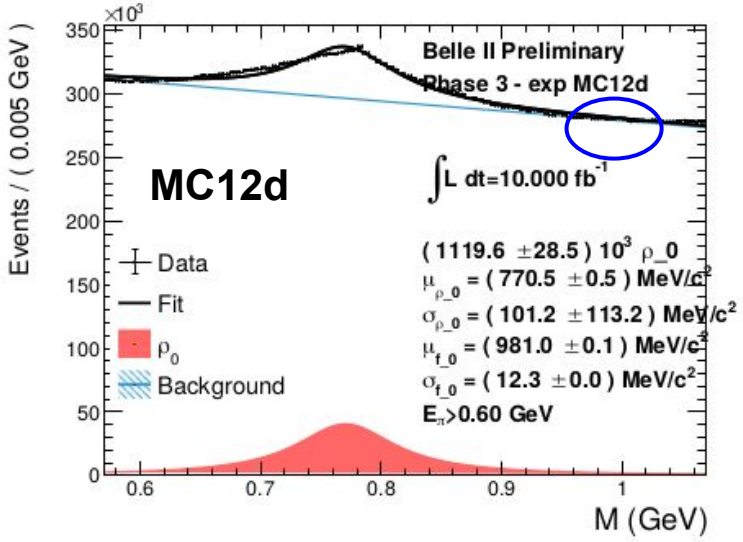
Phase	Exp	proc	yield ($1E3/\mathrm{fb}^{-1}$)	μ (MeV)	σ (MeV)
II	3	proc9	0.19 ± 0.03	951.40 ± 1.22	6.57 ± 1.08
	7+8		0.29 ± 0.04	954.60 ± 1.13	12.37 ± 1.57
III	8	prompt	0.21 ± 0.02	955.01 ± 0.66	7.06 ± 0.68
	7+8	all	0.22 ± 0.02	955.10 ± 0.59	8.93 ± 0.69
MC	7+8	proc9	0.36 ± 0.01	955.74 ± 0.33	9.31 ± 0.44
	8	prompt	0.33 ± 0.01	956.05 ± 0.39	10.13 ± 0.48

- Yield larger in MC
  - Larger in phase 3 wrt phase 2
- Peak good agreement
- Sigma not so stable in data
  - Smaller in prompt than in proc9
  - Larger in MC

$\eta' \to \rho(\to \pi^+\pi^-)\,\gamma$: $\rho(\to \pi^+\pi^-)$

- Larger BR but larger background
  - Hard to see with release 3
  - Much better with release 4
  - **Higher threshold: p(π/γ)>600 MeV**
- γ and $\pi^{+/-}$ as before
- ρ from $\pi^+\pi^-$: no mass constraint (large resonance)
  - Fit with BW (poor fit) plut Gauss for $f^0(980)$ in Data (not simulated in MC)





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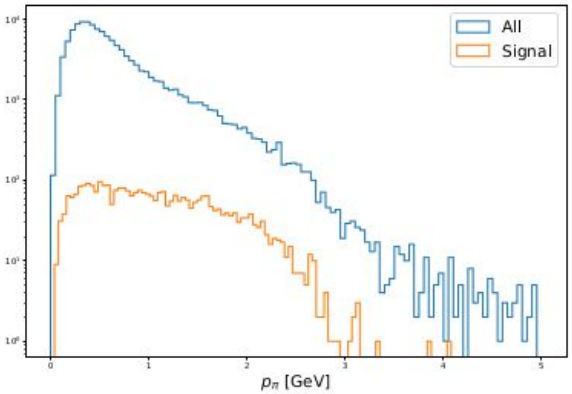
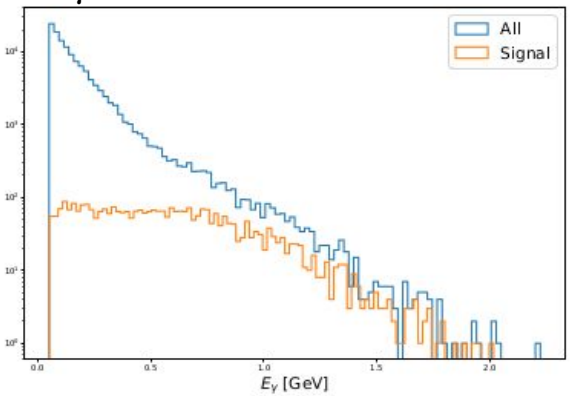
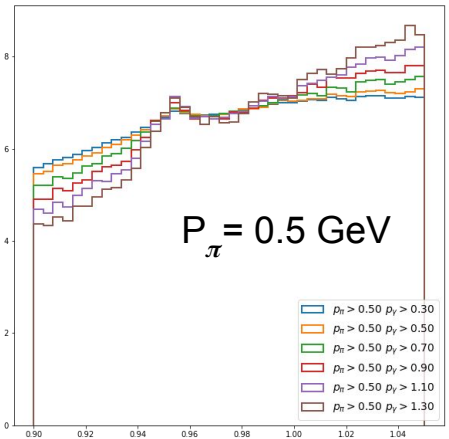
Cut on π and γ

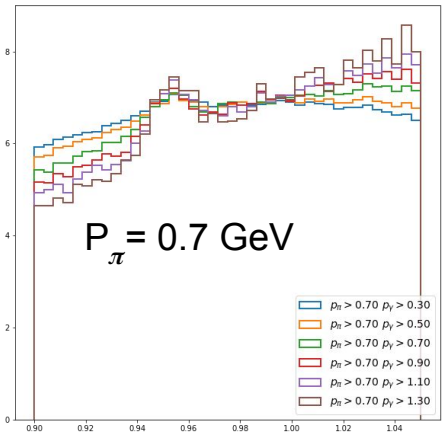
MC: Signal and background P_π and E_γ distribution

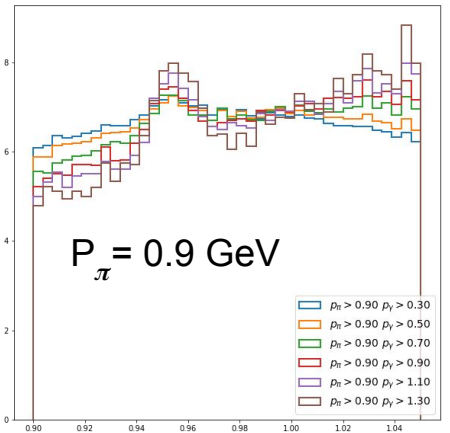




Peak on data varying
P_π = 0.5 - 0.9 GeV
E_γ = 0.3 - 1.3 GeV







$\eta' \to \rho(\to \pi^+\pi^-)\,\gamma$: π^0/η veto

- γ background from π^0/η
- Apply veto: build π^0/η candidate from signal γ plus ROE γ
  - Select that with $M_{\gamma\gamma}$ closer to π^0/η respectively
- Clear π^0 peak seen, not so for η
  - Apply veto if
- $M_{\gamma\gamma}$(sig,ROE) $\in$ [120,145] MeV
- No veto for η
- *Other potential discriminating variable*
  - cosθ*: angle between
    - γ in the η rest frame
    - and η momentum
      - Used in Belle

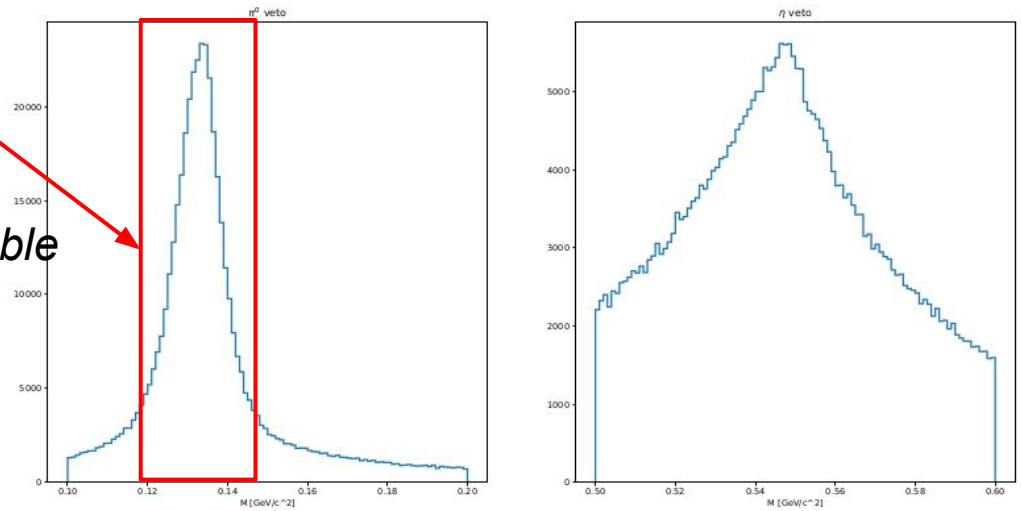
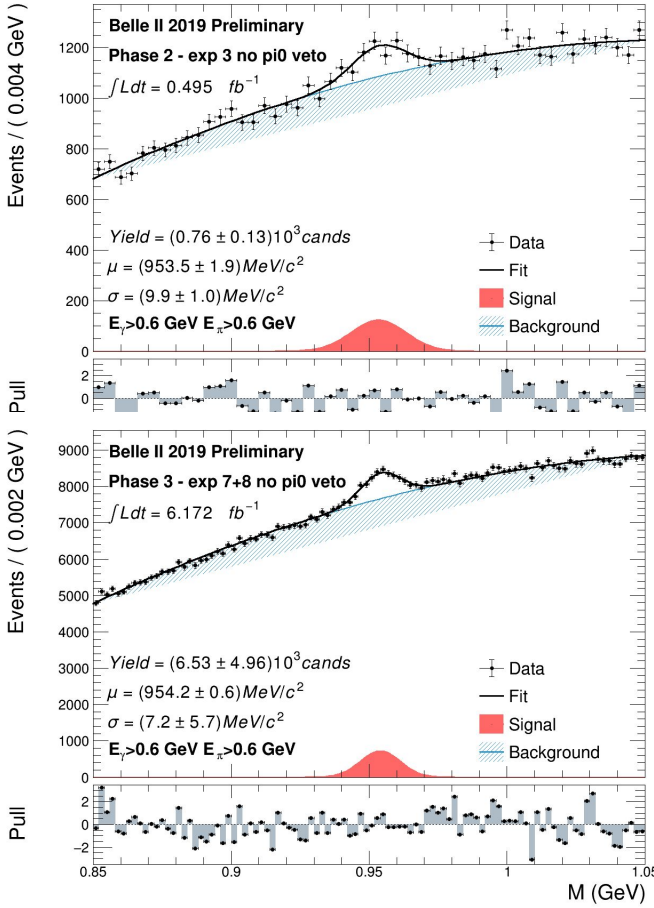


FIG. 15: Distribution of invariant mass of γ γ candidates for π^0/η veto.

Impact of π^0 veto on Data $\eta' \to \rho(\to \pi^+\pi^-)\,\gamma$

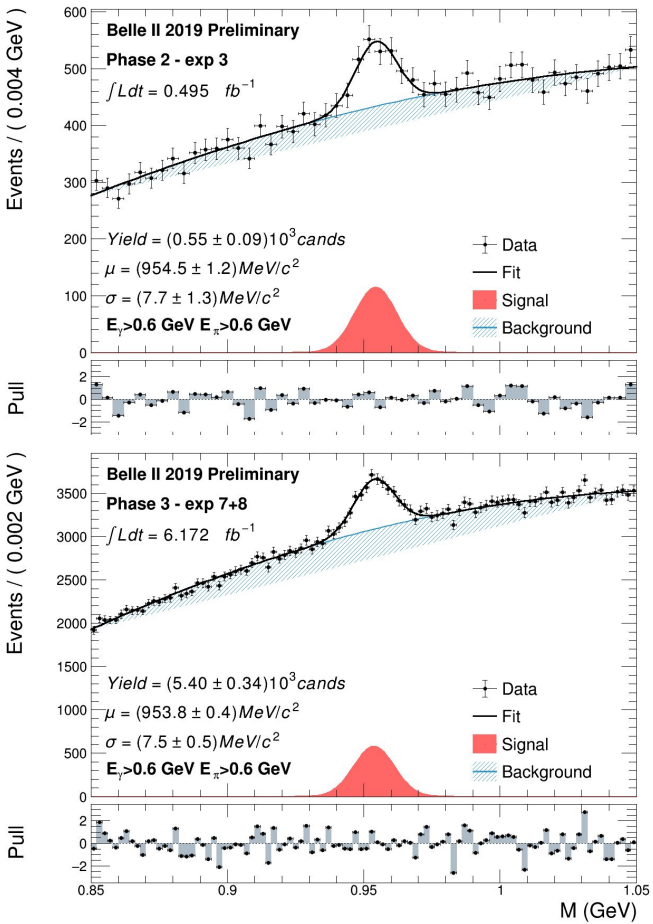
No π^0 veto



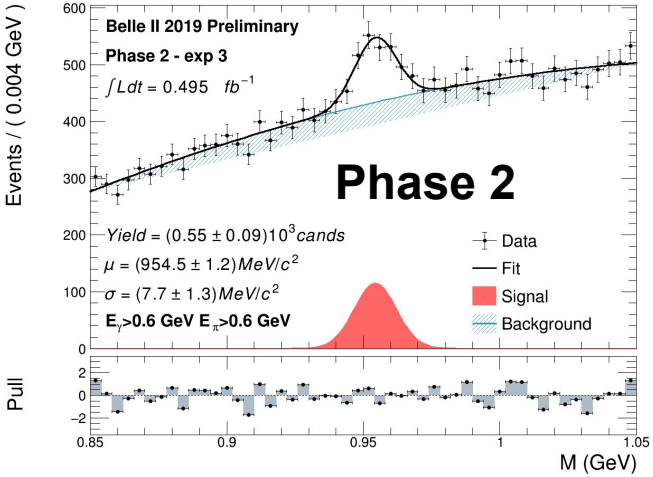
Phase 2

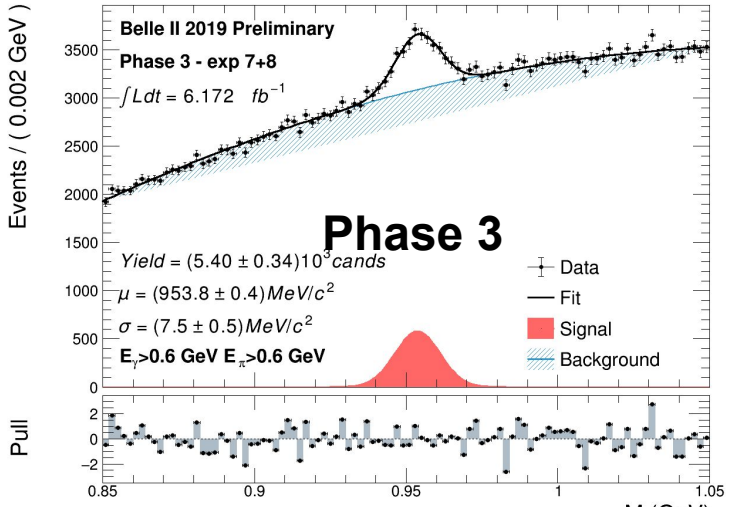
Phase 3

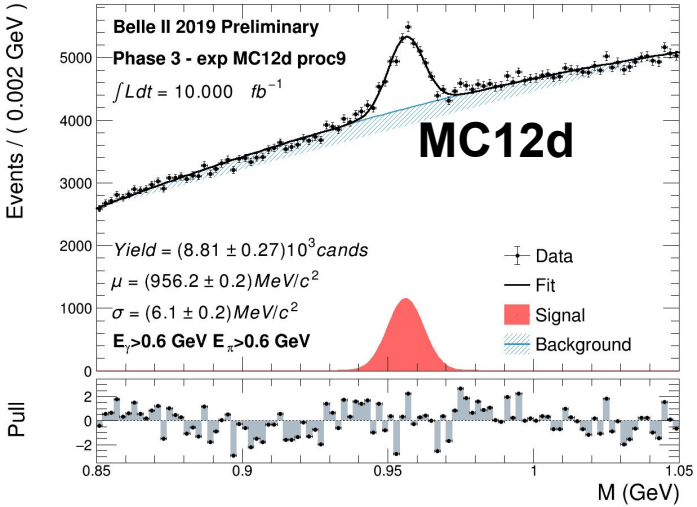
π^0 veto



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







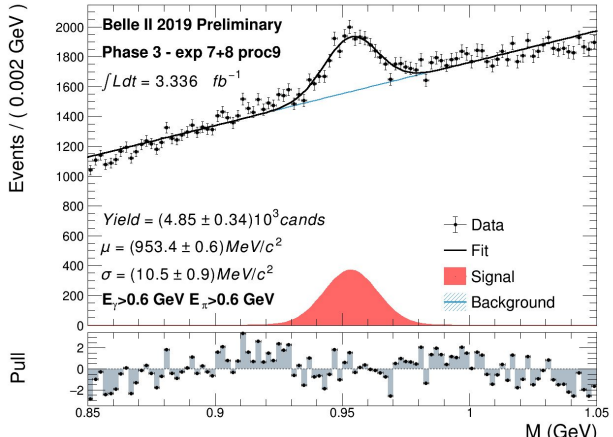
- γ and $\pi^{+/-}$ as before
  - **$p(\pi/\gamma)$>600 MeV**
  - **π^0 veto**: no γ in ROE with 120<$M_{\gamma\gamma}$<145 MeV
- TreeFitter: without ρ mass constraint (large res)
- Peak: +3 MeV in MC
- Width : **7.7 vs 7.5 vs 6.6** (phase2, 3, MC12d)
  - At Belle (10.5 /fb) **8.8 MeV**
- Yield (/fb) $(\rho\gamma/2\gamma 2\pi)$~0.85/0.85 ~ 1 - BR$(\rho\gamma/2\gamma 2\pi)$=2.3
  - **$\varepsilon(3\pi/2\gamma)$~0.4**

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

TABLE 7: Features of $\eta' \to \rho(\to \pi^+\pi^-)\gamma$ peak fit in different datasets

Phase	Exp	proc	yield (1E3/ fb^{-1})	μ (MeV)	σ (MeV)
II	3	proc9	1.12 ± 0.19	954.50 ± 1.16	7.73 ± 1.29
	7+8		1.45 ± 0.10	953.43 ± 0.56	10.51 ± 0.94
III	8	prompt	0.78 ± 0.09	954.22 ± 0.65	7.16 ± 0.88
	7+8	all	0.88 ± 0.05	953.83 ± 0.41	7.46 ± 0.47
MC	7+8	proc9	0.88 ± 0.03	956.23 ± 0.22	6.12 ± 0.18
	8	prompt	0.84 ± 0.04	956.34 ± 0.27	6.60 ± 0.32

- Yield not so stable in data: larger in phase 2 and proc9 wrt prompt
  - Reasonable agreement with MC
- Peak position +2 MeV in MC
- Width -1 MeV in MC
  - Larger in proc9: maybe fit problem



Summary

- η' seen in phase 3 (and phase 2) dataset in all final states
  - Overall good agreement with Run Dependent MC MC12d
- Resolution in good agreement also with Belle 10.5/fb publication
- Relative η' wrt to $\eta' \to \eta(\to \gamma\gamma)\, \pi^+\pi^-$
  - $\eta' \to \eta(\to \pi^+\pi^-\pi^0)\, \pi^+\pi^-$

    $\varepsilon(3\pi/2\gamma) \sim 0.5$

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

    $\varepsilon(3\pi/2\gamma) \sim 0.4$

Documentation almost ready
BELLE2-NOTE-PH-2018-038

Signal / width (MeV)	Ph 2	Ph 3	MC12d	Belle (10.5/fb)
$\eta \to \gamma\gamma$	13.1	13.4	12.1	12
$\eta \to \pi^+\pi^-\pi^0$	7.0	6.8	6.2	-
$\eta' \to \eta(\to \gamma\gamma)\, \pi^+\pi^-$	3.0	3.12	3.12	2.7
$\eta' \to \eta(\to \pi^+\pi^-\pi^0)\, \pi^+\pi^-$	6.6	8.9	9.3	-
$\eta' \to \rho(\to \pi^+\pi^-)\, \gamma$	7.7	7.5	6.1	8.8

Backup


AS REQUESTED, I FIT MY PRESENTATION ON ONE POWERPOINT SLIDE.
I HAD TO USE ALL OF THE WHITE SPACE, BUT I THINK IT WAS WORTH IT TO FIT EVERYTHING ON ONE PAGE.
IT'S ACTUALLY ONLY ONE BULLET POINT, BUT IT'S A LONG ONE.
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scottadams@aol.com
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Final states considered (Belle)

- $\eta' \to \eta\pi^+\pi^-$: BR=42.6%
  - $\eta \to \gamma\gamma$: BR=38.41%
  - $\eta \to \pi^+\pi^-\pi^0$:BR=22.94%
- $\eta' \to \rho(\to\pi^+\pi^-)\gamma$: BR=28.9%
  - Including non resonant $\pi^+\pi^-\gamma$
- $K^0_S \to \pi^+\pi^-$: BR=69.2 %

In Belle, most of signal comes from

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

$\eta \to \pi^+\pi^-\pi^0$ was not used here, only $\eta \to \gamma\gamma$

Mode	N_S	Σ	$\epsilon(\%)$	$\epsilon B_S(\%)$	$BF(10^{-6})$
$\eta'_{\eta\pi\pi}K^+$	$28.9^{+6.5}_{-5.7}$	9.4	21.7	3.78	69^{+15}_{-14}
$\eta'_{\rho\gamma}K^+$	$42.5^{+9.1}_{-8.3}$	7.5	14.2	4.18	92^{+20}_{-18}
$\eta'_{\eta\pi\pi}\pi^+$	$0.0^{+1.2}_{-0.0}$	0.0	23.7	4.11	–
$\eta'_{\rho\gamma}\pi^+$	$0.0^{+5.6}_{-0.0}$	0.0	15.4	4.55	–
$\eta'_{\eta\pi\pi}K^0$	$6.4^{+3.4}_{-2.7}$	3.5	20.8	1.25	46^{+25}_{-20}
$\eta'_{\rho\gamma}K^0$	$10.1^{+4.4}_{-3.6}$	4.0	11.5	1.16	79^{+34}_{-28}

Plan

- Rediscover η and η' in all final states, and compare with MC expectation
- Study selection and efficiency for B0->eta'K0 in MC
  - $\eta' \to \eta(\to \gamma\gamma)\, \pi^+\pi^-$,
  - $\eta' \to \eta(\to \pi^+\pi^-\pi^0)\, \pi^+\pi^-$,
  - $\eta' \to \rho(\to \pi^+\pi^-)\, \gamma$
- Apply selection to generic Run dependent MC to check signal yield
  - Setup and 2D fit on M_{bc}-ΔE for signal extraction
- Study Data continuum and side bands for background assessment
- Repeat for B+
- Document everything
- Finalize selection for Data
  - Review process toward unblinding
- Systematics and unblinding

Plan (today)

- Rediscover η and η' in all final states, and compare with MC expectation
- Study selection and efficiency for B0->eta'K0 in MC
  - $\eta' \to \eta(\to \gamma\gamma)\, \pi^+\pi^-$,
  - $\eta' \to \eta(\to \pi^+\pi^-\pi^0)\, \pi^+\pi^-$,
  - $\eta' \to \rho(\to \pi^+\pi^-)\, \gamma$
- Apply selection to generic Run dependent MC to check signal yield
  - Setup and 2D fit on M_{bc}-ΔE for signal extraction (not today but ready)
- Study Data continuum and side bands for background assessment
- Repeat for B+
- Document everything
- Finalize selection for Data
  - Review process toward unblinding
- Systematics and unblinding

A lot of work still needed, hard for Moriond

eta->gamma gamma for low trhesholds

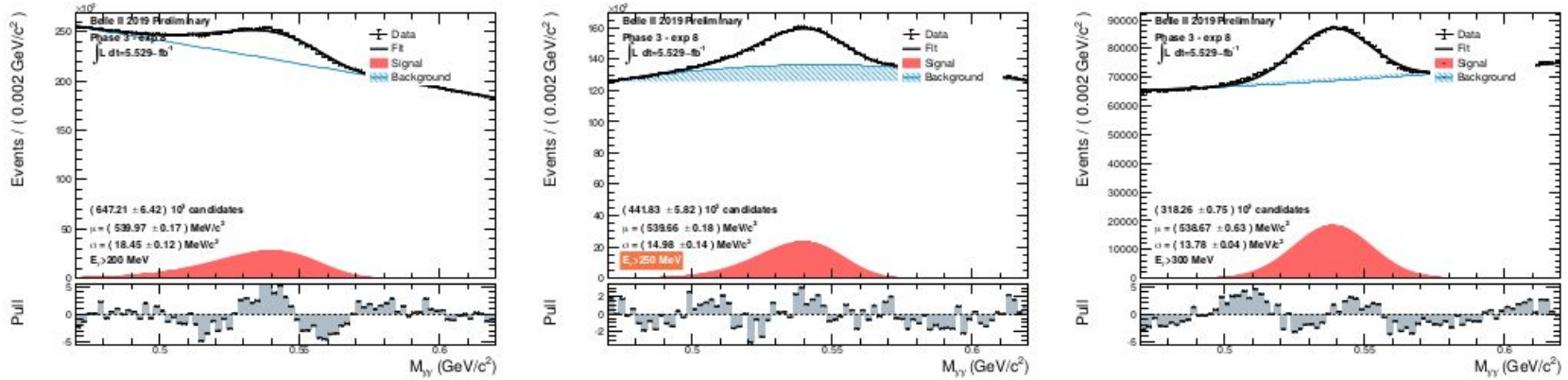

FIG. 5: $\eta \to \gamma\ \gamma$ fit results for low thresholds of 200, 250, and 300 MeV, showing the not optimal modelling of data of the fitting function (Novosibirsk + Chebychev(2)) for the lower one.