

η' rediscovery: approval plots

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Introduction

- Rediscovery of η' in different decay channels
 - ▶ $\eta' \rightarrow \eta \pi^+ \pi^-$
 - ★ $\eta \rightarrow \gamma \gamma$
 - ★ $\eta \rightarrow \pi^+ \pi^- \pi^0$
 - ▶ $\eta' \rightarrow \rho \gamma$
- Documented on [BELLE2-NOTE-PH-2018-038](#)
- RC: [Bryan](#), Torben, Sasha.

Technicalities

- release-04-01-xx
- HLT_HADRON, only good runs
- Exp 3 - Phase 2 - Proc9 $L = 0.49 \text{ fb}^{-1}$
- Exp 7+8 - Phase 3 - Proc10 $L = 5.18 \text{ fb}^{-1}$
- MC13b (Run dependent MC): $L = 10 \text{ fb}^{-1}$

Today

- What has changed wrt to BGM presentation
- Plot for approval

- use only 4S data for better MC comparison (was 4S+continuum)
- Use MC13b for MC (was only MC12d)
- Added τ pairs for MC
- fix mistake in $\eta \rightarrow \pi^+ \pi^- \pi^0$ reconstruction: was not using mass constraint for π^0 .
 - ▶ this was the reason for bad resolution in $\eta \rightarrow \pi^+ \pi^- \pi^0$ shown at B2GM: 6.5 MeV \rightarrow 2.4 MeV
- fix for $\eta' \rightarrow \eta \pi^+ \pi^-$, $\eta \rightarrow \pi^+ \pi^- \pi^0$ mass constraint for η
- better fit model for $\eta \rightarrow \pi^+ \pi^- \pi^0$ and $\eta' \rightarrow \eta \pi^+ \pi^-$, $\eta \rightarrow \gamma\gamma$: 2 Gaussian, w/ common mean.
- many cosmetic improvement in plot quality

- I'd like to have the following plot approved for data
 - ▶ $\eta \rightarrow \gamma\gamma$
 - ▶ $\eta \rightarrow \pi^+\pi^-\pi^0$
 - ▶ $\eta' \rightarrow \eta\pi^+\pi^-$
 - ★ $\eta \rightarrow \gamma\gamma$
 - ★ $\eta \rightarrow \pi^+\pi^-\pi^0$
 - ▶ $\eta' \rightarrow \rho\gamma$
- For **exp 7+8, proc10** and for exp3, proc9
 - ▶ **Discussion with RC about exp3 plots**
 - ▶ the yield found in exp3 is not fully compatible with that found in exp7+8
 - ▶ For rediscovery purpose, exp7+8 is probably enough, so we can skip exp3 plots, and avoid work to understand yield disagreement.
 - ▶ I will present the plot today for discussion.
- no plot for MC
 - ▶ I do have superimposed plot data on MC (on note), but the agreement is not very good
 - ▶ yield is ok, background level is sometime not

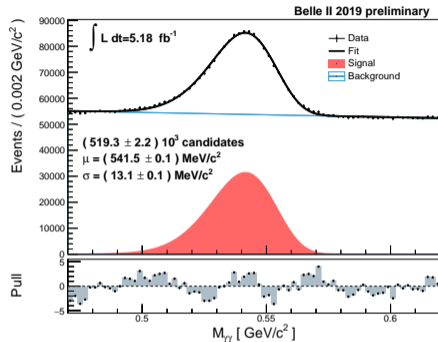
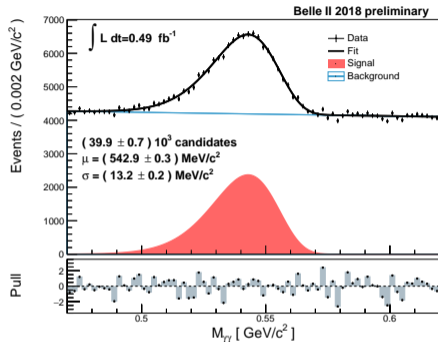


Figure: Invariant mass distribution for $\gamma\gamma$ candidates for 2018 data, phase 2 (left), and 2019 data, phase 3, (right), corresponding to 0.49 and 5.18 fb^{-1} , respectively. A clear peak corresponding to the decay $\eta \rightarrow \gamma\gamma$ is visible. A fit with a Crystal Ball function for signal plus a linear function for background is superimposed. The selection requires $E_\gamma > 400 \text{ GeV}$. The decay chain is fitted using TreeFitter algorithm. The uncertainties on fit parameters are statistical only. Further details can be found in internal note BELLE2-NOTE-PH-2018-038.

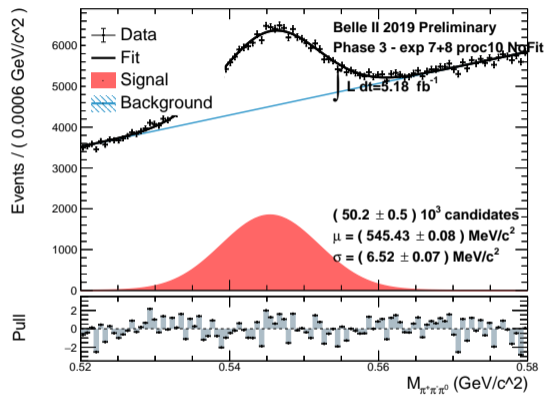
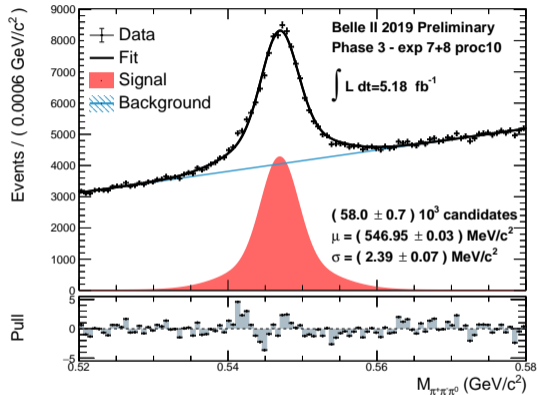


Figure: Invariant mass distribution of π⁺π⁻π⁰ candidates, with $p_{\pi} > 300$ MeV with vertex fit including π⁰ mass constraint (left) and without (right).

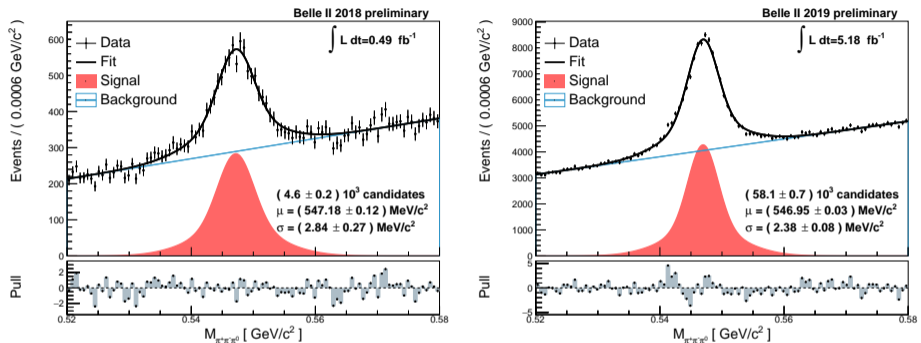


Figure: Invariant mass distribution for $\pi^+ \pi^- \pi^0$ candidates for 2018 data, phase 2 (left), and 2019 data, phase 3 (right), corresponding to 0.49 and 5.18 fb^{-1} , respectively. A clear peak corresponding to the decay $\eta \rightarrow \pi^+ \pi^- \pi^0$ is visible. A fit with a double Gaussian function, with common mean, for signal plus a linear function for background is superimposed. The selection requires: $E_\gamma > 200 \text{ MeV}$, $110 < M_{\gamma\gamma} < 150 \text{ MeV}$, and $p_\pi > 300 \text{ MeV}$ for all three pions. The decay chain is fitted using TreeFitter algorithm, constraining the mass of the two γ to that of π^0 . The uncertainties on fit parameters are statistical only. Further details can be found in internal note BELLE2-NOTE-PH-2018-038.

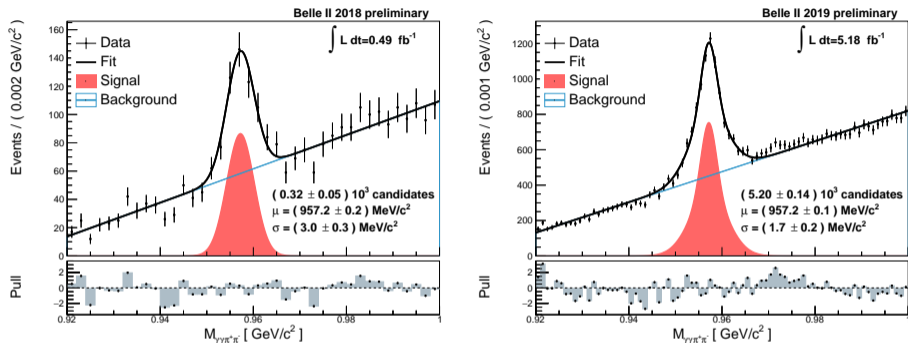


Figure: Invariant mass distribution for $\eta(\rightarrow \gamma\gamma)\pi^-\pi^+$ candidates for 2018 data, phase 2 (left), and 2019 data, phase 3, (right), corresponding to 0.49 and 5.18 fb^{-1} , respectively. A clear peak corresponding to the decay $\eta' \rightarrow \eta\pi^+\pi^-$ with $\eta \rightarrow \gamma\gamma$ is visible. A fit is superimposed, with a double Gaussian function with a common mean for signal plus a linear function for background. The selection requires: $E_\gamma > 400 \text{ MeV}$, $0.48 < M_{\gamma\gamma} < 0.58 \text{ GeV}$, $p_\pi > 400 \text{ MeV}$, and $p_\eta > 400 \text{ MeV}$. The decay chain is fitted using TreeFitter algorithm, constraining the mass of the two γ to that of η . The uncertainties on fit parameters are statistical only. Further details can be found in internal note BELLE2-NOTE-PH-2018-038.

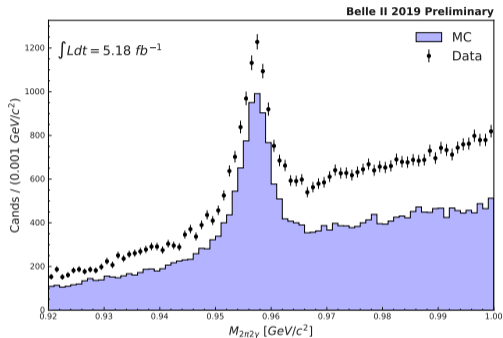


Figure: Invariant mass distribution for $\eta(\rightarrow \gamma\gamma)\pi^-\pi^+$ candidates for 2019 data, phase 3, corresponding to 5.18 fb^{-1} , with Montecarlo distribution superimposed, normalized to integrated luminosity. Further details can be found in internal note BELLE2-NOTE-PH-2018-038.

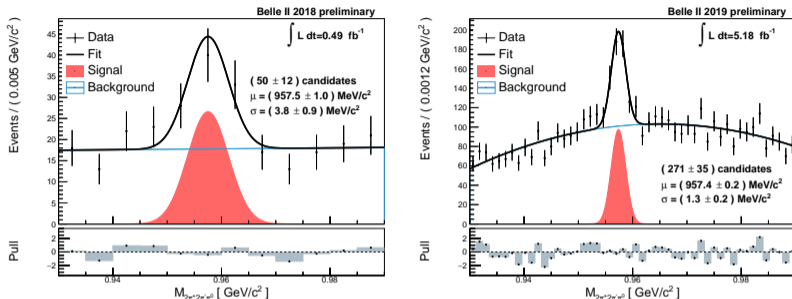


Figure: Invariant mass distribution for $\eta(\rightarrow \pi^+ \pi^- \pi^0) \pi^+ \pi^-$ candidates for 2018 data, phase 2 (left), and 2019 data, phase 3 (right), corresponding to 0.49 and 5.18 fb^{-1} , respectively. A clear peak corresponding to the decay $\eta' \rightarrow \eta \pi^+ \pi^-$ with $\eta \rightarrow \pi^+ \pi^- \pi^0$ is visible. A fit with a Gaussian function for signal plus a second degree polynomial function for background is superimposed. For Phase 2 data, a simpler linear function was used. The selection requires: $E_\gamma > 200 \text{ MeV}$, $110 < M_{\gamma\gamma} < 150 \text{ MeV}$, $p_{\pi^0} > 400 \text{ MeV}$, $0.51 < M_{\gamma\gamma} < 0.58 \text{ GeV}$, $p_\pi > 400 \text{ MeV}$, and $p_\eta > 400 \text{ MeV}$. The decay chain is fitted using TreeFitter algorithm, constraining the mass of the two γ to that of η . The uncertainties on fit parameters are statistical only. Further details can be found in internal note BELLE2-NOTE-PH-2018-038.

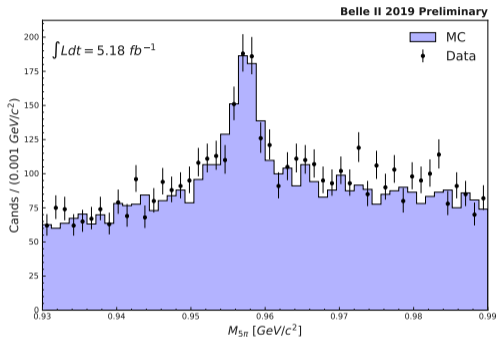


Figure: Invariant mass distribution for $\eta(\rightarrow \pi^+\pi^-\pi^0)\pi^-\pi^+$ candidates for 2019 data, phase 3, corresponding to 5.18 fb^{-1} , with Montecarlo distribution superimposed, normalized to integrated luminosity. Further details can be found in internal note BELLE2-NOTE-PH-2018-038.

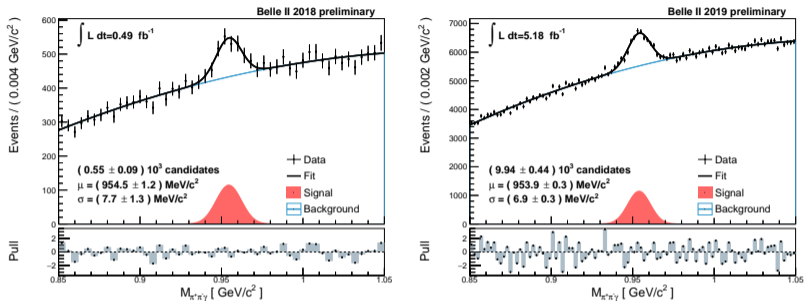


Figure: Invariant mass distribution for $\rho(\rightarrow \pi^+\pi^-)\gamma$ candidates for 2018 data, phase 2 (left), and 2019 data, phase 3 (right), corresponding to 0.49 and 5.18 fb^{-1} , respectively. A clear peak corresponding to the decay $\eta' \rightarrow \rho\gamma$ with $\rho \rightarrow \pi^+\pi^-$ is visible. A fit with a Gaussian function for signal plus a second degree polynomial function for background is superimposed. The selection requires: $E_\gamma > 600 \text{ MeV}$, $p_{\pi^0} > 600 \text{ MeV}$,

$0.57 < M_{\pi^+\pi^-} < 0.95 \text{ GeV}$. Furthermore a π^0 veto is applied, to reject candidates where invariant mass of the signal γ with any other γ in the event form an invariant mass $120 < M_{\gamma\gamma} < 145 \text{ MeV}$. The decay chain is fitted using TreeFitter algorithm, with no constraint on the mass of the ρ . The uncertainties on fit parameters are statistical only. Further details can be found in internal note BELLE2-NOTE-PH-2018-038.

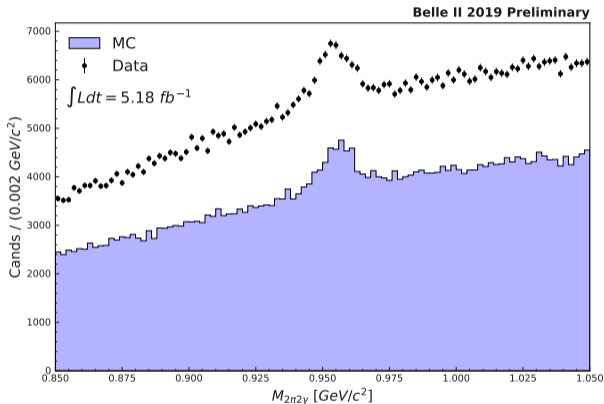


Figure: Invariant mass distribution for $\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$ candidates for 2019 data, phase 3, corresponding to 5.18 fb^{-1} , with Montecarlo distribution superimposed, normalized to integrated luminosity.

Channel	Dataset	Yield [candidates/ fb ⁻¹]	μ [MeV/c ²]	σ [MeV/c ²]
$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$	phasell	$(0.65 \pm 0.09)10^3$	957.24 ± 0.17	2.96 ± 0.25
	phaselll	$(1.01 \pm 0.03)10^3$	957.18 ± 0.07	1.68 ± 0.14
	MC	$(1.00 \pm 0.02)10^3$	957.20 ± 0.05	2.02 ± 0.12
$\eta' \rightarrow \eta(\rightarrow \pi^+\pi^-\pi^0)\pi^+\pi^-$	phasell	101 ± 24	957.53 ± 0.96	3.77 ± 0.87
	phaselll	65 ± 7	957.38 ± 0.16	1.40 ± 0.19
	MC	73 ± 6	957.23 ± 0.15	1.95 ± 0.20
$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$	phasell	$(1.12 \pm 0.19)10^3$	954.50 ± 1.16	7.73 ± 1.29
	phaselll	$(1.92 \pm 0.09)10^3$	953.96 ± 0.27	6.92 ± 0.32
	MC	$(1.39 \pm 0.05)10^3$	955.60 ± 0.20	6.37 ± 0.24

Table: Features of η' in three different decay channels in phase 2 ($\int \mathcal{L} dt = 0.49 \text{ fb}^{-1}$) and phase 3 ($\int \mathcal{L} dt = 5.18 \text{ fb}^{-1}$) compared with those found in phase 3 run dependent MC ($\int \mathcal{L} dt = 10 \text{ fb}^{-1}$). The uncertainties are statistical only.

Additional or backup slides

gamma

- in the CDC acceptance
 $0.296706 < \theta_\gamma < 2.61799$ rad
- $\text{clusterErrorTiming} < 1 \cdot 10^6$ ns
- for data processed with proc10
 $|\text{clusterTiming}| < 400$ ns
- $E_\gamma > 50$ MeV in barrel and forward region
- $E_\gamma > 75$ MeV in backward region
- $N_{\text{hits}} > 1.5$
- $E_9/E_{21} > 0.9$

pion

- in the CDC acceptance
- $\chi^2 > 0.0001$
- $dr < 0.5$ cm and $|dz| < 2$ cm
- No PID cut

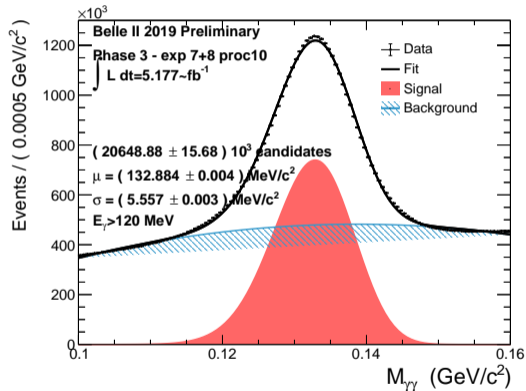
Selection:

- gamma from stdPhotons
 - ▶ $0.296706 < \theta_\gamma < 2.61799$
 - ▶ $clusterTimingError < 1e6$ and $[E_1/E_9 > 0.4 \text{ or } E > 0.075 \text{ GeV}]$
 - ▶ $E_{reg=1/2} > 0.05 \text{ GeV}$ $E_{reg=3} > 0.075 \text{ GeV}$
- Cluster: $N_{hits} > 1.5$, $E_9/E_{21} > 0.9$
- $E_\gamma > 120 \text{ MeV}$

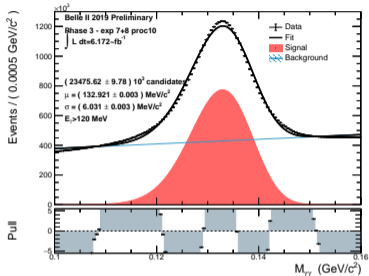
Binned-ML Fit with CrystalBall + Chebychev[2]

Pulls are bad, other model tested, this has least bias for peak and sigma

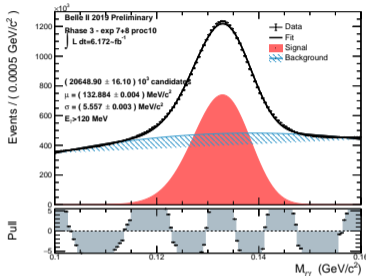
Invariant Mass plot for Data Proc10



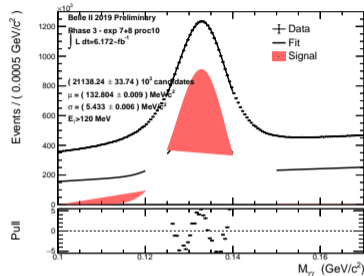
CrystalBall + Chebychev[1]



CrystalBall + Chebychev[2]



CB + Ch[1]: ranged fit



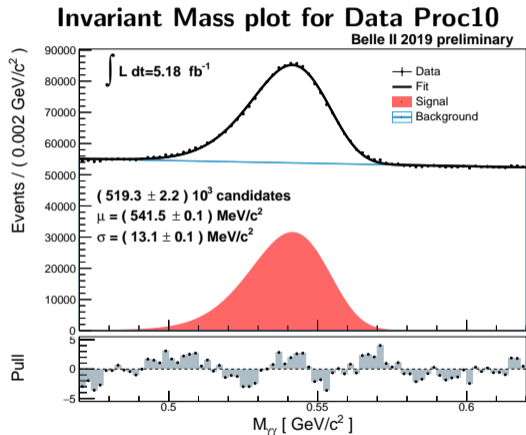
signal fit in FWHM, background from SB (problem in visualization)

- CB+Ch[1] (left) is worst model
- μ and σ varies among the three models
- $\mu \pm 0.1 \text{ MeV}/c^2$ and $\sigma \pm 0.13 \text{ MeV}/c^2$ for CB+ch[2] and CB+Ch[1]
- systematic uncertainties due to fit model

Selection:

- gamma from stdPhotons
 - ▶ $0.296706 < \theta_\gamma < 2.61799$
 - ▶ $clusterTimingError < 1e6$ and $[E_1/E_9 > 0.4 \text{ or } E > 0.075 \text{ GeV}]$
 - ▶ $E_{reg=1/2} > 0.05 \text{ GeV}$
 - ▶ $E_{reg=3} > 0.075 \text{ GeV}$
- Cluster: $N_{hits} > 1.5, E_9/E_{21} > 0.9$
- $E_\gamma > 400 \text{ MeV}$

Binned-ML Fit with CrystalBall + Chebychev[1]

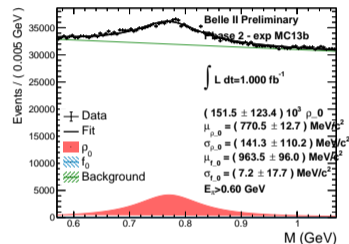
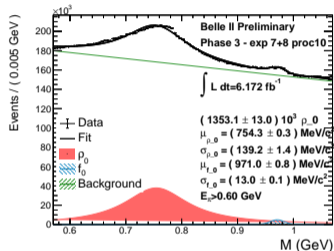
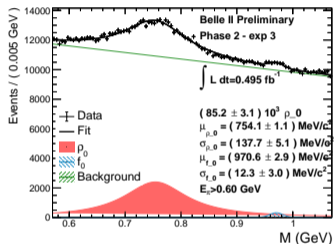


$$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$$

- $\eta \rightarrow \gamma\gamma$
 - ▶ `gamma:tight` from `stdPhotons`
 - ▶ $E_\gamma > 400$ MeV
- π^\pm
 - ▶ $d_r(\pi) < 0.5$ cm, $|d_z(\pi)| < 2$ cm
 - ▶ $P(\chi^2) > 0.0001$
 - ▶ $p_\pi > 400$ MeV
- η
 - ▶ $0.48 < M_{\gamma\gamma} < 0.58$ GeV
 - ▶ $p_\eta > 400$ MeV
- η' : $0.9 < M_{\gamma\gamma\pi^\pm} < 1.1$ GeV
- TreeFitter η mass constraint

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

- $\pi^0 \rightarrow \gamma\gamma$
 - ▶ `gamma:gamma:tight` from `stdPhotons`
 - ▶ $E_\gamma > 200$ GeV
 - ▶ $110 < M_{\pi^0} < 150$ MeV
 - ▶ $p_{\pi^0} > 400$ MeV
- π^\pm
 - ▶ $d_r(\pi) < 0.5$ cm, $|d_z(\pi)| < 2$ cm
 - ▶ $p_\pi > 400$ MeV
- η : $510 < M_\eta < 580$ MeV
- η' : $0.9 < M_{\eta'} < 1.1$ GeV
- TreeFitter π^0, η mass constraint



ρ (and f_0) for phase 2, experiment 3, Proc9 (left), phase 3, experiment 7+8, proc10 (center), Run dependent Montecarlo Mc13b, experiment 7+8, proc10 (right)

- $\rho \rightarrow \pi^+\pi^-$
 - ▶ $p_\pi > 0.6 \text{ GeV}$
 - ▶ $0.57 < M_\rho < 0.95 \text{ GeV}$
- γ gamma: tight from stdPhotons
 - ▶ $E_\gamma > 0.6 \text{ GeV}$
- π^0 veto
- TreeFitter No mass constraint on ρ .
- build π^0 candidate with the γ from η' and one from RoE
- reject η' candidates if $120 < M_{\gamma\gamma} < 145 \text{ MeV}/c^2$.
- no corresponding η veto needed

