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University of Science and Technology of China

Study of Inclusive η Production

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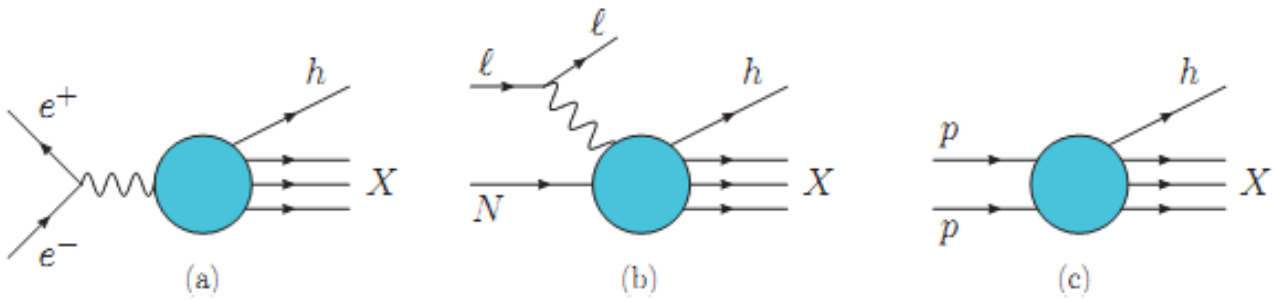
Outline

- Introduction
- Description of analysis
- Summary

Introduction

- **Fragmentation Function $D_i^h(z, Q^2)$:** probability that hadron *h* is found in the debris of a parton *i* carrying a fraction $z = 2E_h/\sqrt{s}$ of parton's momentum.



- **Universality: e^+e^-, DIS, pp, $p\bar{p}$**
- **Not calculable because of non-perturbative QCD dynamics**

Introduction

- **Splitting Functions $P_{ij}(z)$ calculable in pQCD**
  Probability of parton i going into parton j with momentum fraction z

- **Evolution with Q^2 calculable in pQCD: DGLAP**

$$P_{qq}(z) = \frac{4}{3}\frac{1+z^2}{1-z}$$

$$P_{qg}(z) = \frac{1}{2}(z^2+(1-z)^2)$$

$$P_{gq}(z) = \frac{4}{3}\frac{1+(1+z)^2}{z}$$

$$P_{gg}(z) = 6\left(\frac{z}{1-z}+\frac{1-z}{z}+z(1-z)\right)$$

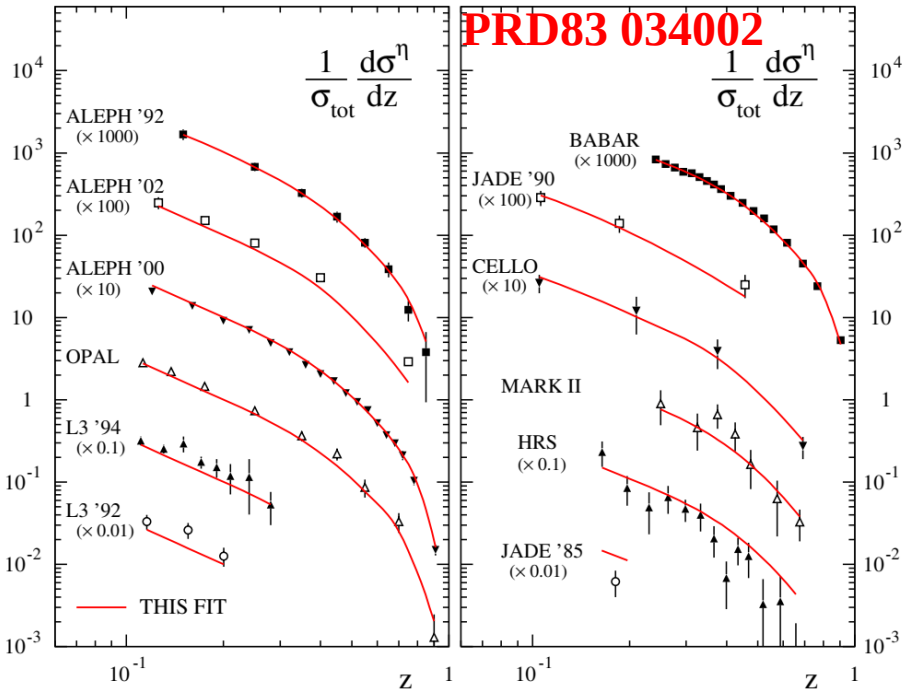
Study of Fragmentation Function: parametrization & experimental data

Study of Fragmentation Function at e^+e^- colliders

- Multiplicity: $\frac{1}{\sigma(e^+e^-\to\text{hadrons})}\frac{\mathrm{d}\sigma(e^+e^-\to h+X)}{\mathrm{d}p_h}$
- At leading order $\sim \sum_q e_q^2 D_q^h(z,Q^2)$

Introduction

World Data:



- η Frag. Func. @ NLO: **no data** at $\sqrt{s} < 10$ **GeV** e^+e^- collision
- **This work:**
  - Provide more constraints for Frag. Func. parameters fitting
  - Helps to study QCD in low energy region

Data Samples

- **BOSS Version: 6.6.4.p01, 6.6.5.p01**

- **Experimental data:**
  2012, 2015 R-scan data

- **Energy point selection:**
  ~200 MeV intervals, avoid low statistic points

	$\sqrt{s}$ (GeV)	Run No.	$\mathcal{L}_{\rm int}$ ($\rm pb^{-1}$)
2015	2.0000	41729-41909	10.074
	2.2000	40989-41121	13.699
	2.3960	40463-40769	66.869
	2.6444	40128-40298	33.722
	2.9000	39775-40069	105.253
2012	3.0500	28312-28346	14.893
	3.5000	33725-33733	3.633
	3.6710	33759-33764	4.628

- **Monte-Carlo simulation:**
  $e^+e^- \to q\bar{q}$ by **LUARLW**
  $e^+e^- \to q\bar{q}$ by **Hybrid**
  $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$, $e^+e^- \to \mu^+\mu^-$ by **Babayaga v3.5**
  $e^+e^- \to \tau^+\tau^-$ by **KKMC**
  $e^+e^- \to e^+e^- + X$(X: leptons and hadrons) by **DIAG36**, **EKHARA**, **GALUGA 2.0**

Hadronic Event Selection

Same as R-value analysis published in PRL 128, 062004 (2022)

Track Level

- **Veto Bhabha and Di-gamma events**
  - $N_{\text{shower}} \geq 2$
  - $E_1 \geq E_2 \geq 0.65E_{\text{beam}}$
  - $|\Delta\theta| = |\theta_1 + \theta_2 - 180°| < 10°$
- **Isolated photon**
  - Energy deposition should be larger than 0.1 GeV
  - Angle from the nearest charged track should be larger than 20°
  - $0 < T_{\text{EMC}} < 700$ ns
- **Good charged hadronic tracks**
  - $|V_r| < 0.5$ cm , $|V_z| < 5.0$ cm , $|\cos\theta| < 0.93$
  - $p_{\text{track}} < 0.94p_{\text{beam}}$, where $p_{\text{beam}} \approx E_{\text{beam}}$
  - $\chi_{\text{prob.}} = \left(\mathrm{d}E/\mathrm{d}x_{\text{measure}} - \mathrm{d}E/\mathrm{d}x_{\text{proton}}\right) / \sigma_{\text{proton}} > 10$
  - Remove charged tracks when $E/p > 0.8$ and $p > 0.65p_{\text{beam}}$
  - Veto γ-conversions when $M(e^+ e^-) < 0.1$ GeV and $\theta_{ee} < 15°$

Event Level

At least 2 good charged hadronic tracks

- **Number of good charged hadronic tracks = 2:**
  - $|\Delta\theta| = |\theta_1 + \theta_2 - 180°| > 10°$ or $|\Delta\phi| = ||\phi_1 - \phi_2| - 180°| > 15°$
  - At least 2 isolated photons
- **Number of good charged hadronic tracks = 3:**
  - The two highest momentum tracks are required not back-to-back: $|\Delta\theta| = |\theta_1 + \theta_2 - 180°| < 10°$ or $|\Delta\phi| = ||\phi_1 - \phi_2| - 180°| < 15°$
  - (number of track with $E/p > 0.8) \leq 1$
  - (number of track with PID ratio > 0.25) ≤ 1, where the PID ratio is defined as $r_{\text{PID}} = \frac{\text{Prob.}(e)}{\text{Prob.}(p)+\text{Prob.}(\text{K})+\text{Prob.}(\pi)+\text{Prob.}(e)}$
- **Number of good charged hadronic tracks ≥ 4:**
  No additional requirements

η Selection

Good photon selection:

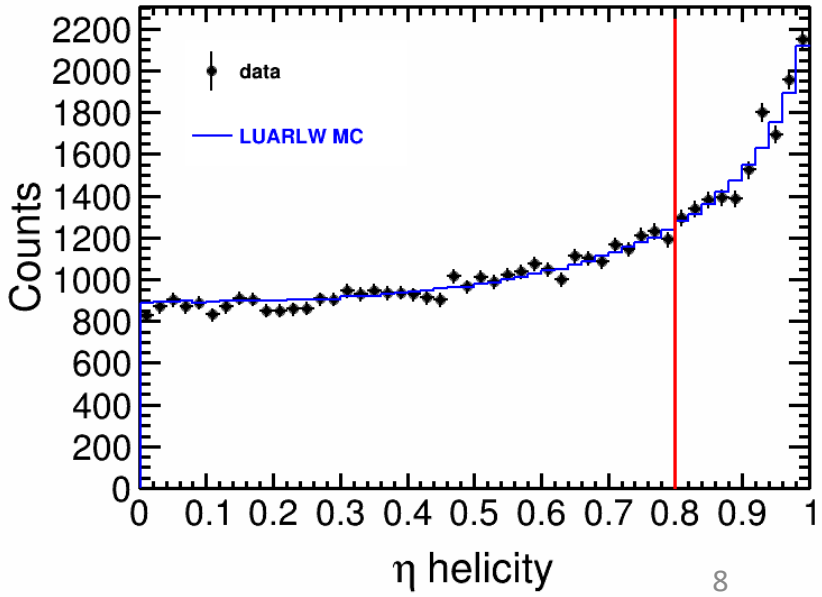
- Angle between any charged track $\theta_{\mathrm{trk}} > 10°$
- Deposited energy in EMC: $E_{\mathrm{endcap}} > 50\mathrm{MeV}$ and $E_{\mathrm{barrel}} > 25\mathrm{MeV}$
- EMC timing requirement: $0 \leq T \leq 700$ ns

Remove photons from π^0 : $\left|m_{\gamma\gamma} - m_{\pi^0}^{\mathrm{PDG}}\right| < 5\sigma_{\pi^0}$ $(\sigma_{\pi^0} = 4\ \mathrm{MeV})$

Reconstruct η from $\eta \rightarrow \gamma\gamma$

η helicity defined as $\cos\theta_h = \frac{|E_{\gamma_1} - E_{\gamma_2}|}{p_{\gamma\gamma}}$

$\cos\theta_h < 0.80$



η Control Sample

- $J/\psi \to K^+K^-\pi^+\pi^-\eta$, $\eta \to \gamma\gamma$

BOSS Version: 7.0.5

Data Set:

2019 J/ψ data & official inclusive MC (4100M)

5M signal MC events

Event Selection:

4 good charged tracks, net charge=0

≥ 2 good photons

PID: Prob(K)>Prob(π) && Prob(K)>Prob(p) for Kaons

Prob(π)>Prob(K) && Prob(π)>Prob(p) for pions

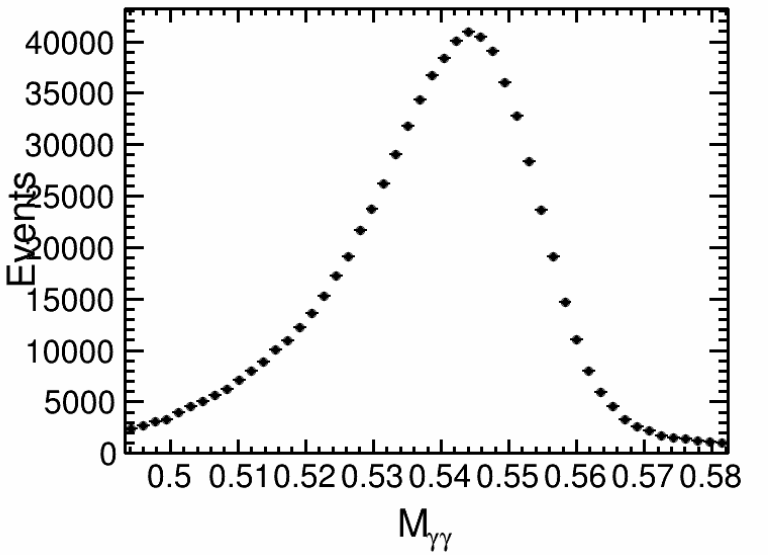
4C kinematic fit:

$\chi^2(K^+K^-\pi^+\pi^-\gamma\gamma) < \chi^2(K^+K^-\pi^+\pi^- + \mathrm{n}\gamma)$ $(\mathrm{n} = 1, 2, 4)$

$\chi^2(K^+K^-\pi^+\pi^-\gamma\gamma) < 50$

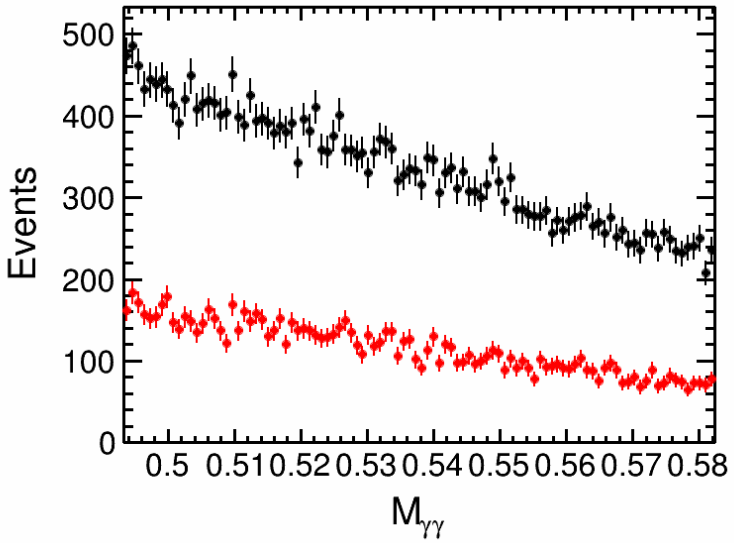
Check: η helicity cut

Mass distribution of η sample



η purity > 95% after selection

Mass distribution of backgrounds and fake η sample

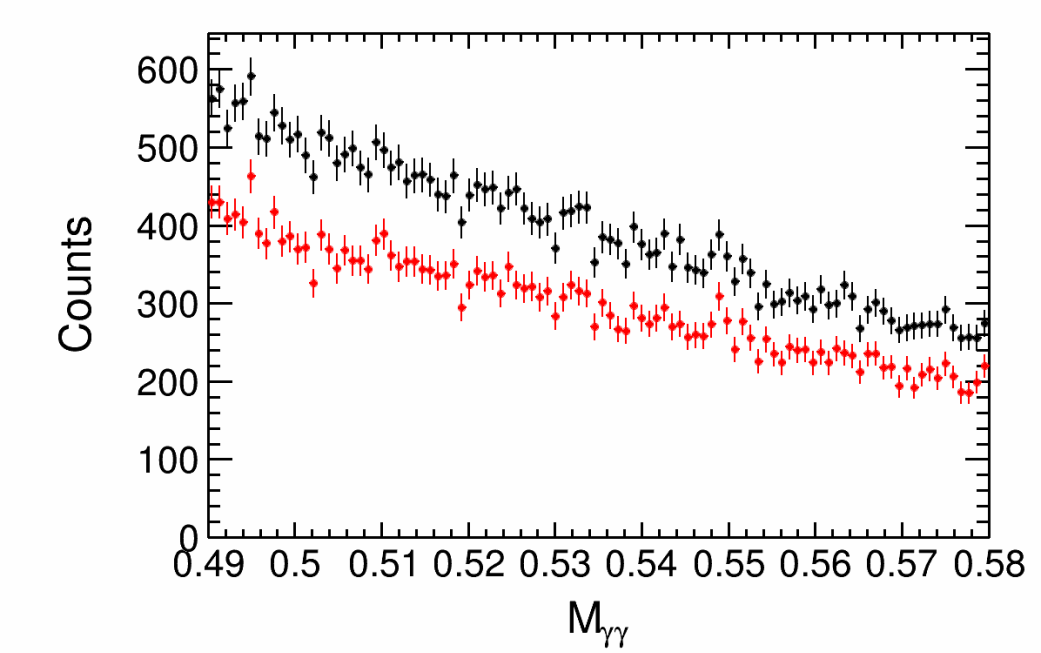


Dots in red: mis-combined photon pairs after helicity cut $\cos\theta_h < 0.8$

No peaking background after helicity cut

Check: π^0 photons veto

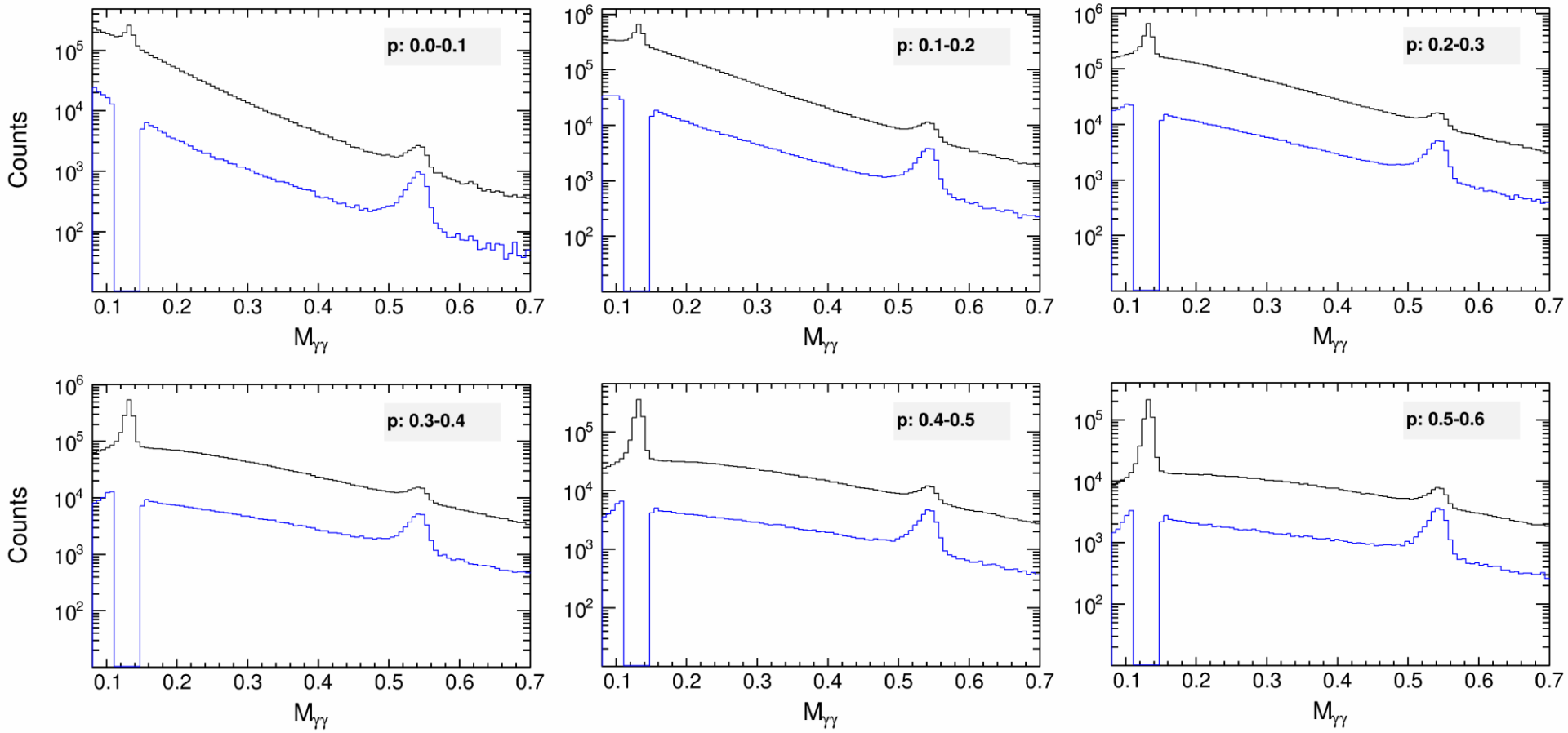
Mass distribution of backgrounds and fake η sample



Dots in red: mis-combined photon pairs after π^0 photons veto:
γ removed if $|m_{\gamma\gamma} - m_{\pi^0}| < 20$ MeV

No peaking background after π^0 photons veto

Check: π^0 photons veto



Black/Blue line: before/after π^0 photons veto

Backgrounds from π^0 photons reduced obviously

Data VS MC @ 2.9000 GeV

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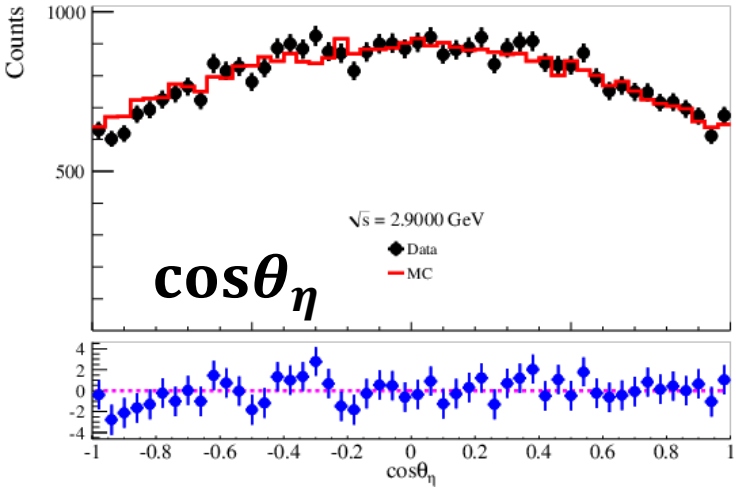
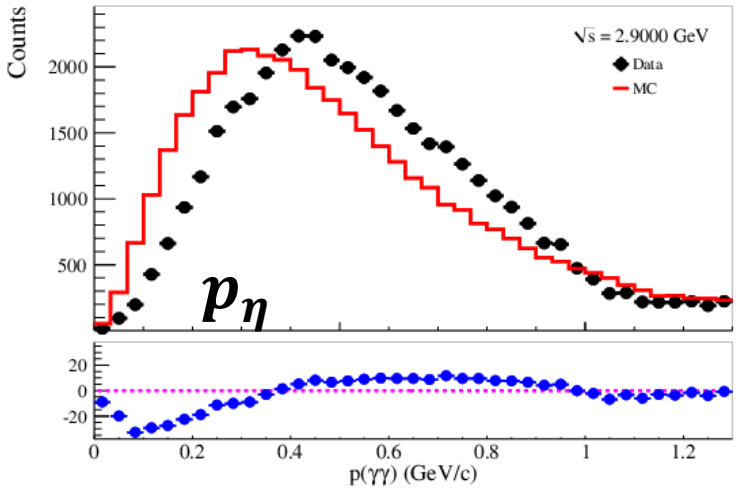
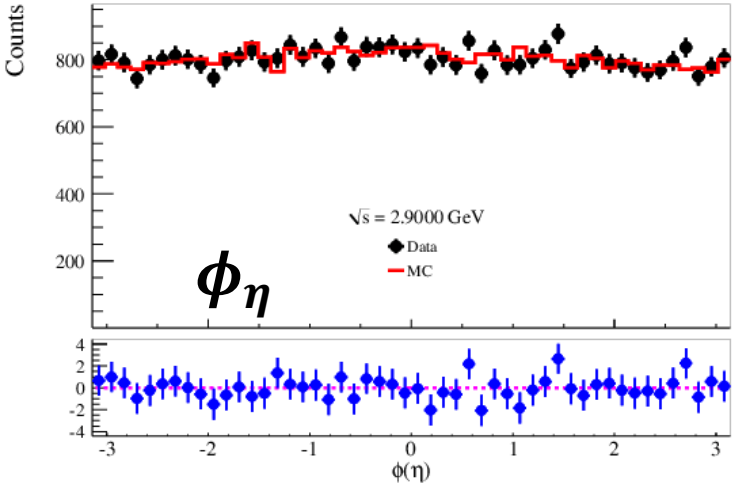
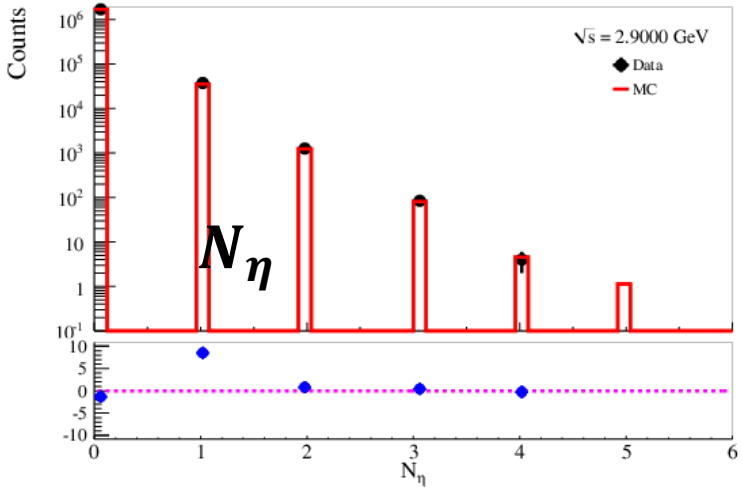




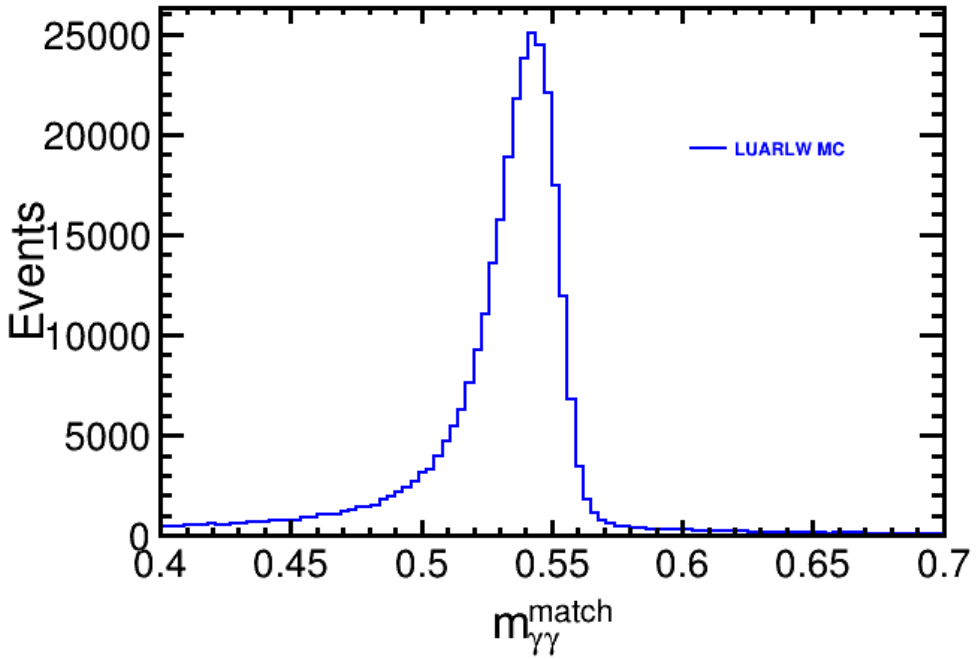




Fitting: η MC Shape

Match requirement:

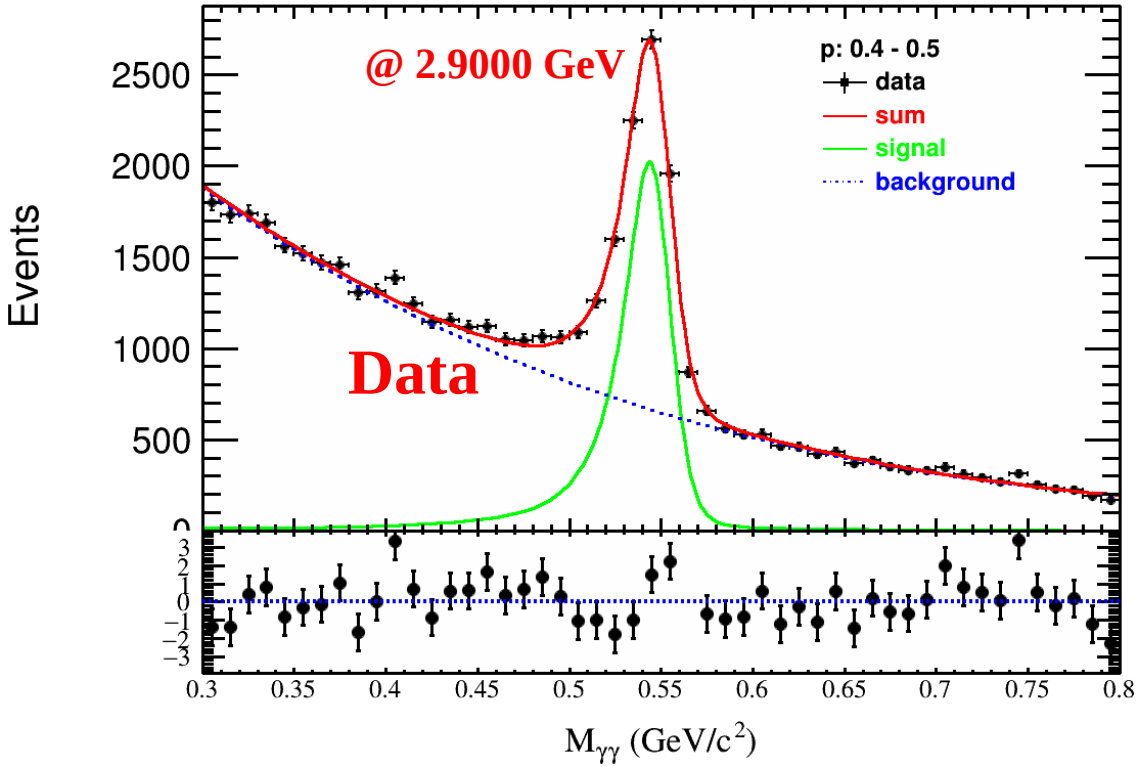
- For each truth-level η track in an event, select the reconstructed η with minimum θ_{match} ($\theta_{\mathrm{match}} = \mathrm{Angle}\left(\vec{p}_{\gamma\gamma}^{\,\mathrm{rec.}}, \vec{p}_{\eta}^{\,\mathrm{truth}}\right)$)
- Reject reconstructed η with minimum $\theta_{\mathrm{match}} > 25°$



Fitting to data

Un-binned Maximum Likelihood fits on $M_{\gamma\gamma}$

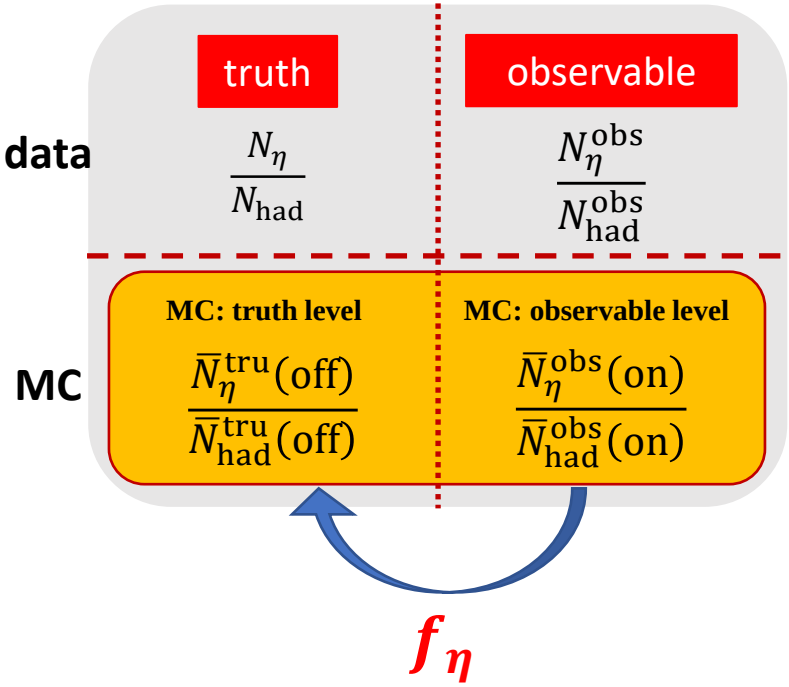
- Signal: Matched MC Shape ⊗ Gaussian
- Background: 3rd-order Chebychev Polynomials



Correction Factor

$$\frac{\textbf{Physical Value}}{\frac{\bar{N}_\eta^{\text{truth}}(\text{ISR off})}{\bar{N}_{\text{hadronic}}^{\text{truth}}(\text{ISR off})}} = \frac{\frac{N_\eta^{\text{observable}}}{N_{\text{hadronic}}^{\text{observable}}}}{\frac{\bar{N}_\eta^{\text{observable}}(\text{ISR on})}{\bar{N}_{\text{hadronic}}^{\text{observable}}(\text{ISR on})}}$$

$$f_\eta \equiv \frac{\frac{\bar{N}_\eta^{\text{tru}}(\text{off})}{\bar{N}_{\text{had}}^{\text{tru}}(\text{off})}}{\frac{\bar{N}_\eta^{\text{obs}}(\text{on})}{\bar{N}_{\text{had}}^{\text{obs}}(\text{on})}}, \qquad \textbf{Physical Value} = f_\eta \frac{N_\eta^{\text{obs}}}{N_{\text{had}}^{\text{obs}}}$$



$\bar{N}$: from Monte-Carlo

N : from experimental data

Correction factor f_η : ISR effect and detection efficiency

$$\frac{1}{\sigma_{\text{had}}}\frac{\mathrm{d}\sigma_\eta}{\mathrm{d}p_\eta} = \frac{N_\eta}{N_{\text{had}}}\frac{1}{\Delta p_\eta} = \frac{1}{Br(\eta \to \gamma\gamma)} f_\eta \frac{N_\eta^{\text{obs}}}{N_{\text{had}}^{\text{obs}}}\frac{1}{\Delta p_\eta}$$

Fitting to MC

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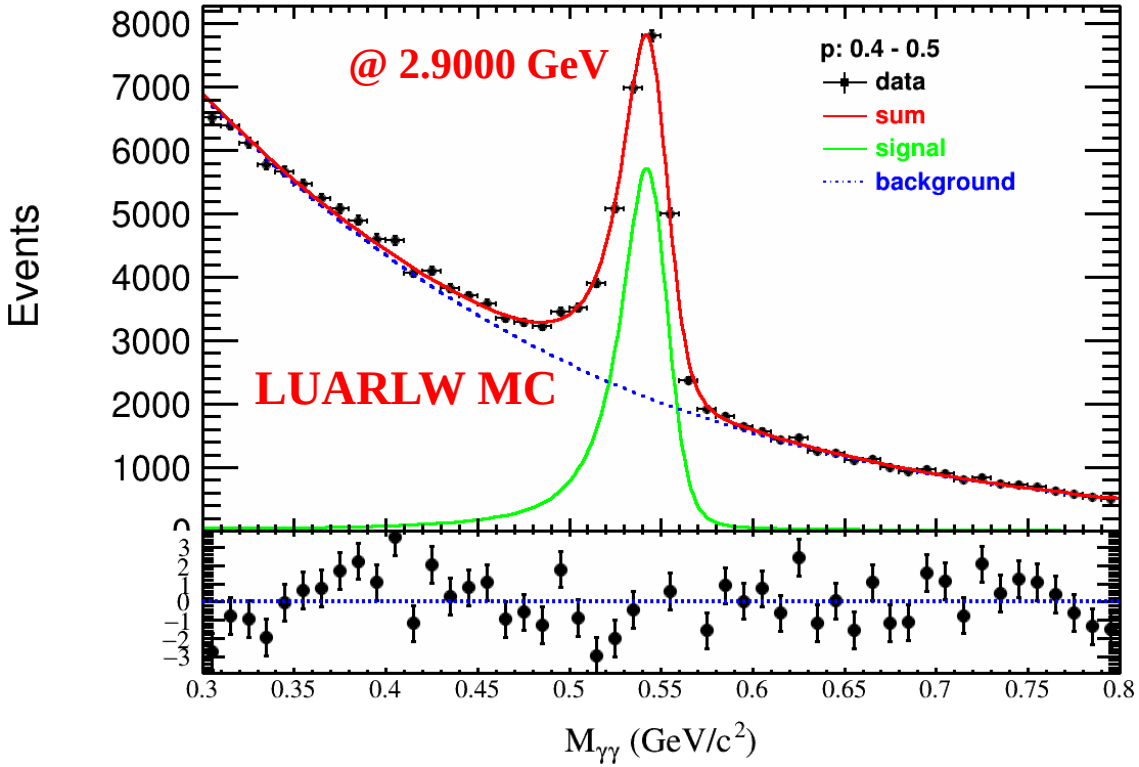
Un-binned Maximum Likelihood fits on $M_{\gamma\gamma}$

- Signal: Matched MC Shape
- Background: 3rd-order Chebychev Polynomials



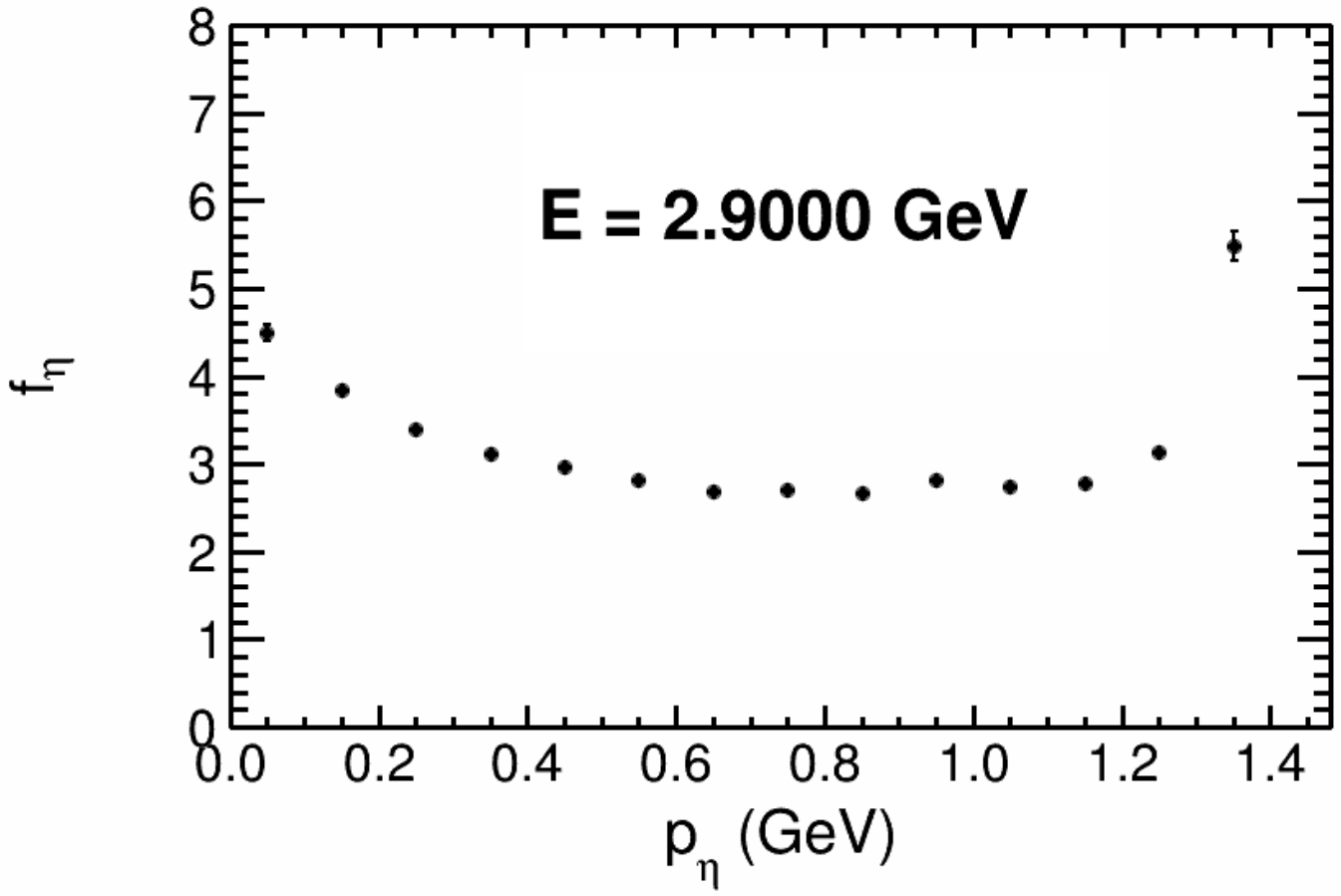
Correction Factors (2.3960 GeV)

$$f_\eta = \frac{\bar{N}_\eta^{\mathrm{tru}}(\mathrm{off})}{\bar{N}_{\mathrm{had}}^{\mathrm{tru}}(\mathrm{off})} \Big/ \frac{\bar{N}_\eta^{\mathrm{obs}}(\mathrm{on})}{\bar{N}_{\mathrm{had}}^{\mathrm{obs}}(\mathrm{on})}$$

p_η (GeV/c)	$\bar{N}_\eta^{\mathrm{obs}}(on)$	$\bar{N}_{\mathrm{had}}^{\mathrm{obs}}(on)$	$\bar{N}_\eta^{\mathrm{tru}}(off)$	$\bar{N}_{\mathrm{had}}^{\mathrm{tru}}(off)$	f_η
0.0-0.1	4319.0 ± 86.4	7216057	26906	10000000	4.495 ± 0.090
0.1-0.2	16985.6 ± 187.6	7216057	90446	10000000	3.842 ± 0.042
0.2-0.3	24564.8 ± 244.6	7216057	115848	10000000	3.403 ± 0.034
0.3-0.4	26028.9 ± 256.5	7216057	112162	10000000	3.109 ± 0.031
0.4-0.5	23320.4 ± 239.5	7216057	96112	10000000	2.974 ± 0.031
0.5-0.6	20038.9 ± 208.4	7216057	78248	10000000	2.818 ± 0.029
0.6-0.7	16513.2 ± 176.2	7216057	61687	10000000	2.696 ± 0.029
0.7-0.8	13042.0 ± 146.6	7216057	49015	10000000	2.712 ± 0.030
0.8-0.9	10322.3 ± 122.8	7216057	38236	10000000	2.673 ± 0.032
0.9-1.0	7770.7 ± 101.9	7216057	30253	10000000	2.809 ± 0.037
1.0-1.1	5848.4 ± 85.4	7216057	22280	10000000	2.749 ± 0.040
1.1-1.2	4140.9 ± 70.0	7216057	15994	10000000	2.787 ± 0.047
1.2-1.3	3438.3 ± 61.1	7216057	14895	10000000	3.126 ± 0.056
1.3-1.4	1068.3 ± 33.8	7216057	8118	10000000	5.484 ± 0.174

Correction Factors (2.3960 GeV)

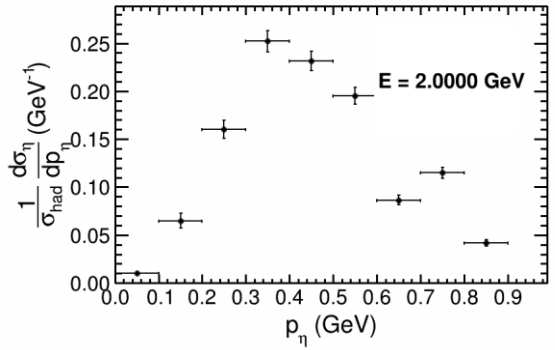
$$f_\eta = \frac{\bar{N}_\eta^{\mathrm{tru}}(\mathrm{off})}{\bar{N}_{\mathrm{had}}^{\mathrm{tru}}(\mathrm{off})} \Big/ \frac{\bar{N}_\eta^{\mathrm{obs}}(\mathrm{on})}{\bar{N}_{\mathrm{had}}^{\mathrm{obs}}(\mathrm{on})}$$

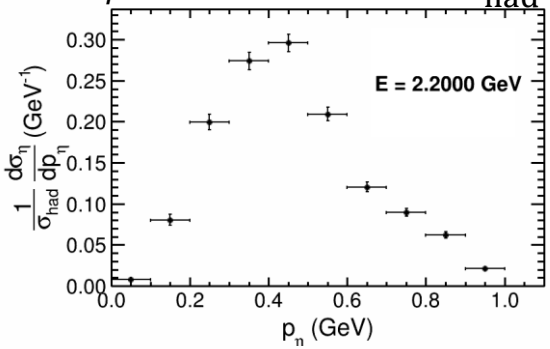


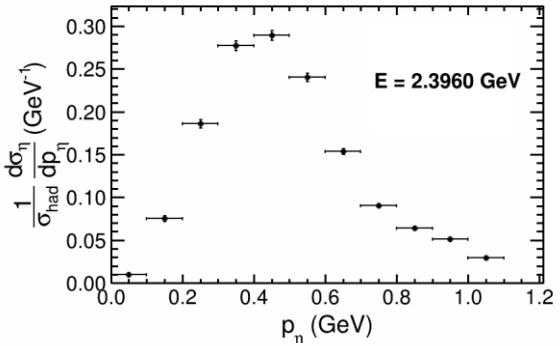
p_η	f_η
	± 0.090
	± 0.042
	± 0.034
	± 0.031
	± 0.031
	± 0.029
	± 0.029
	± 0.030
	± 0.032
	± 0.037
	± 0.040
	± 0.047
	± 0.056
	± 0.174

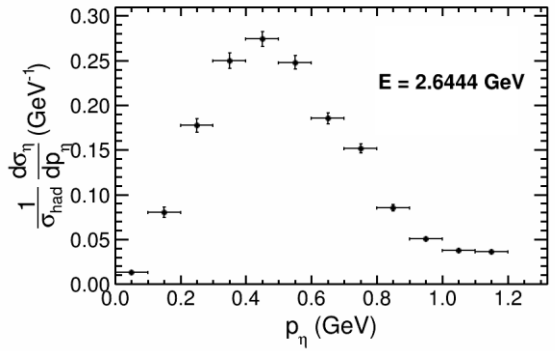
Results

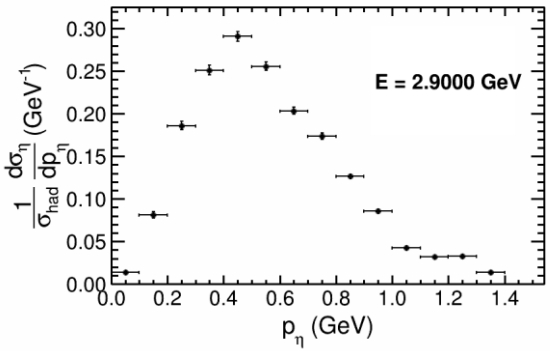
$$\frac{1}{\sigma_{\mathrm{had}}}\frac{\mathrm{d}\sigma_\eta}{\mathrm{d}p_\eta} = \frac{1}{Br(\eta \to \gamma\gamma)} f_\eta \frac{N_\eta^{\mathrm{obs}}}{N_{\mathrm{had}}^{\mathrm{obs}}} \frac{1}{\Delta p_\eta}$$

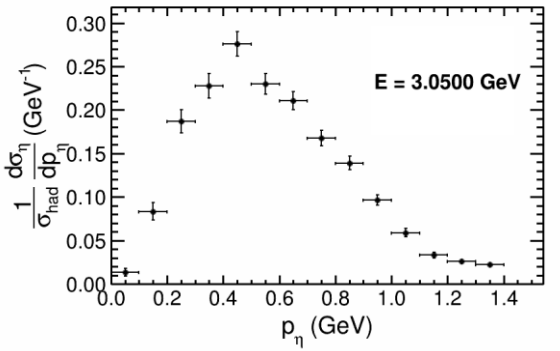


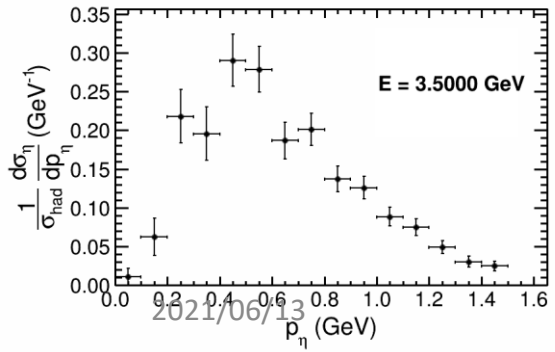


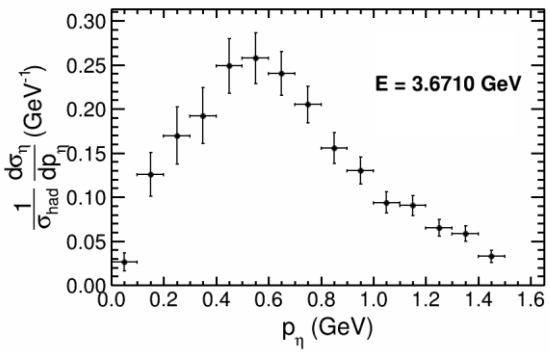












Statistic uncertainty only

Systematic Uncertainties

Systematic uncertainty: hadronic event selection

- Nominal selection criteria changed to alternative ones
- Differences of results are taken as systematic uncertainties

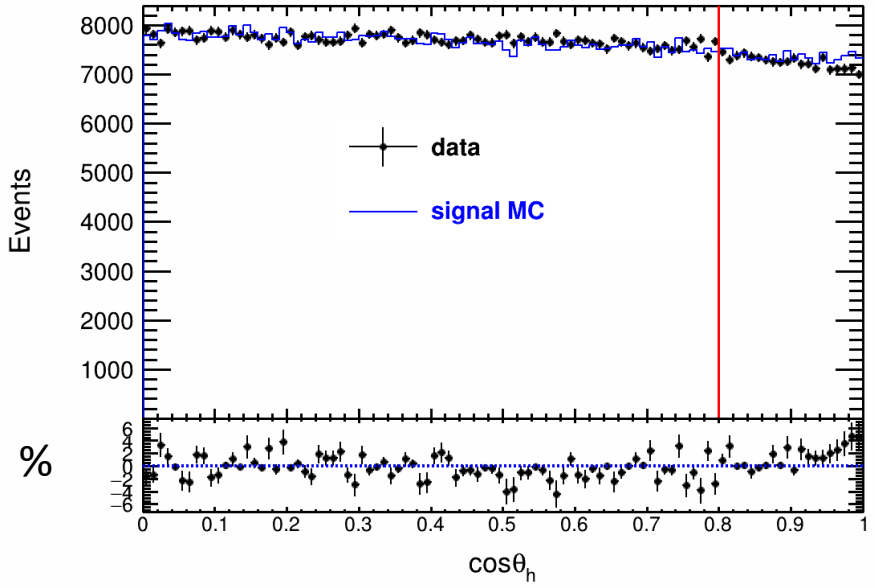
Category	Source	Nominal	Alternative	Abbreviation
Veto Bhabha and $\gamma\gamma$	$E_{\rm ratio}$	$0.65E_{\rm beam}$	$0.6\sim0.7E_{\rm beam}$	Eratio
	$\Delta\theta$	10°	$5^\circ\sim15^\circ$	dthveto
Selection of good tracks	V_r	0.5 cm	0.45 ~ 0.55 cm	Vr
	$\chi_{\rm Prob}$	10	15	Chip
	$p_{\rm track}$	$0.94p_{\rm beam}$	$0.92\sim0.96p_{\rm beam}$	ptrack
	E/p ratio	0.8	0.75 ~ 0.85	Epratio
	Bhabha momentum limit	$0.65p_{\rm beam}$	$0.6\sim0.7p_{\rm beam}$	BBplmt
	gamma conversion angle	15°	$10^\circ\sim20^\circ$	eeang
	gamma conversion mass	100 MeV	80 ~ 120 MeV	eeene
	isolated photon angle	20°	$15^\circ\sim25^\circ$	isoang
	isolated photon energy	100 MeV	75 ~ 125 MeV	isoene
	PID ratio value	0.25	0.1 ~ 0.4	pidratio
2 prongs events	$\Delta\theta$	10°	$5^\circ\sim15^\circ$	2prgdth
	$\Delta\phi$	15°	$10^\circ\sim20^\circ$	2prgdphi
3 prongs events	$\Delta\theta$	10°	$5^\circ\sim15^\circ$	3prgdth
	$\Delta\phi$	15°	$10^\circ\sim20^\circ$	3prgdphi

Same as R-value analysis published in PRL 128, 062004 (2022)

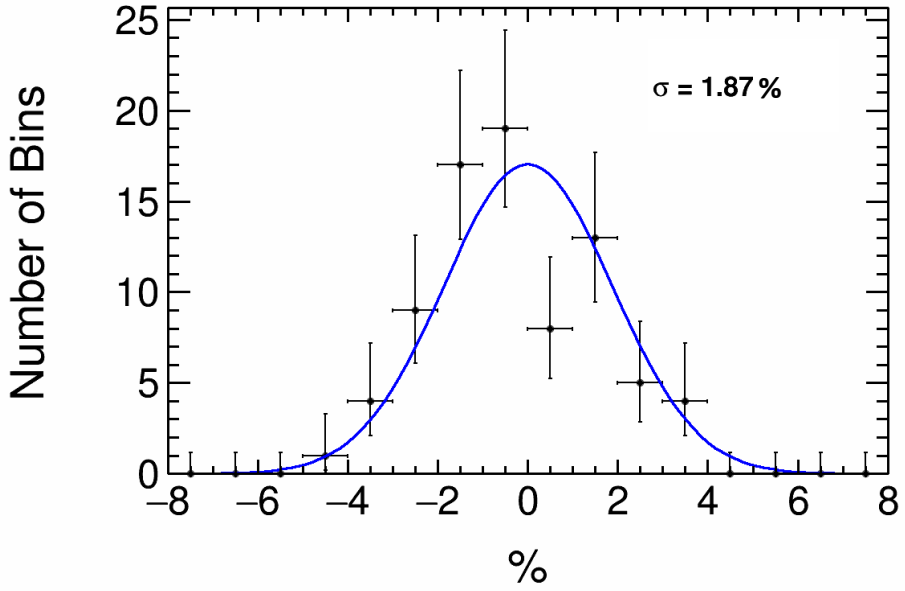
Systematic Uncertainties

Systematic uncertainty: η helicity

- η control sample: $J/\psi \to K^+K^-\pi^+\pi^-\eta$



Comparison of η helicity distributions between data and signal MC



The relative differences between data and MC are fitted with a Gaussian distribution

Systematic Uncertainties

- **η match angle:**

  Nominal requirement: $\theta\left(\vec{p}_{\eta}^{\,\mathrm{truth}}, \vec{p}_{\gamma\gamma}^{\,\mathrm{rec.}}\right) < 25°$

  Alternative requirements: $\theta\left(\vec{p}_{\eta}^{\,\mathrm{truth}}, \vec{p}_{\gamma\gamma}^{\,\mathrm{rec.}}\right) < 20°/30°$

- **η reconstruction:**

  2% for η since 1% for single photon reconstruction

- **Fitting:**

  Nominal signal model: **matched MC shape distribution**

  Alternative signal model: **Crystal Ball function**

  Nominal background model: **3$^{\mathrm{rd}}$-order** Chebychev polynomials

  Alternative background model: **2$^{\mathrm{nd}}$-order** Chebychev polynomials

- **Signal MC model:**

  Nominal signal MC model: **`LUARLW`**

  Alternative signal MC model for uncertainty study: **`HYBRID`**

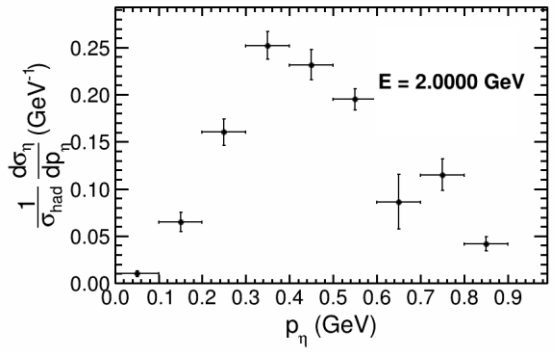
Systematic Uncertainties

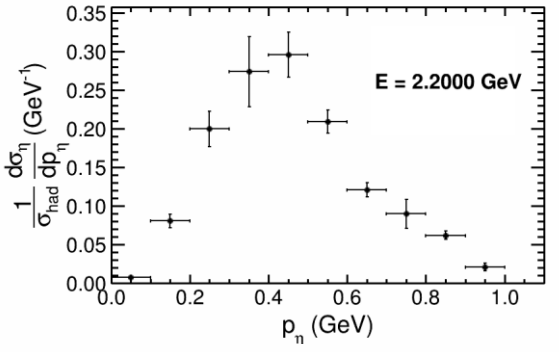
Systematic uncertainties in % at 2.9000 GeV

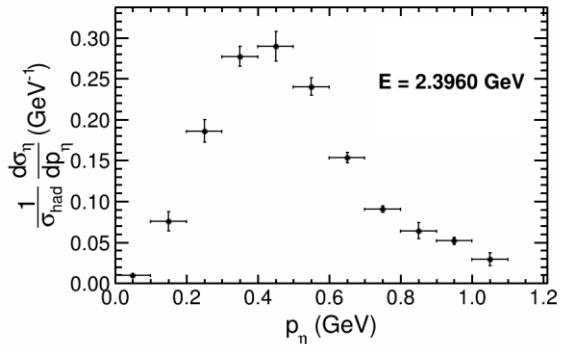
p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	1.92	1.87	0.91	2.36	-25.52	2.00	25.86
0.1-0.2	0.80	1.87	0.16	2.95	-16.69	2.00	17.18
0.2-0.3	0.57	1.87	0.11	1.18	-14.32	2.00	14.64
0.3-0.4	0.36	1.87	0.07	1.17	-10.22	2.00	10.65
0.4-0.5	0.76	1.87	0.01	1.37	-7.59	2.00	8.22
0.5-0.6	0.66	1.87	0.05	0.81	-4.59	2.00	5.44
0.6-0.7	0.63	1.87	0.03	0.47	1.01	2.00	3.02
0.7-0.8	0.88	1.87	0.06	1.22	1.55	2.00	3.49
0.8-0.9	0.86	1.87	0.01	0.28	8.01	2.00	8.51
0.9-1.0	0.54	1.87	0.01	0.68	5.56	2.00	6.26
1.0-1.1	0.98	1.87	0.01	0.54	12.99	2.00	13.32
1.1-1.2	1.02	1.87	0.02	0.79	6.64	2.00	7.30
1.2-1.3	1.12	1.87	0.03	0.56	27.82	2.00	27.98
1.3-1.4	2.01	1.87	0.07	0.22	-24.95	2.00	25.18

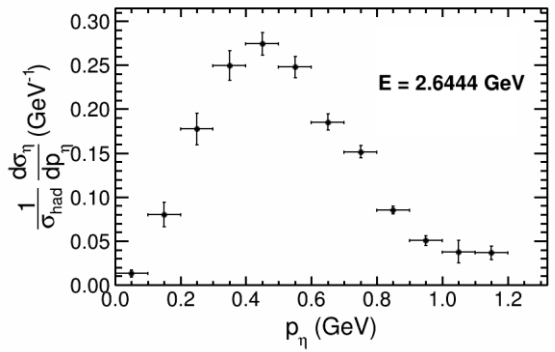
Final Results

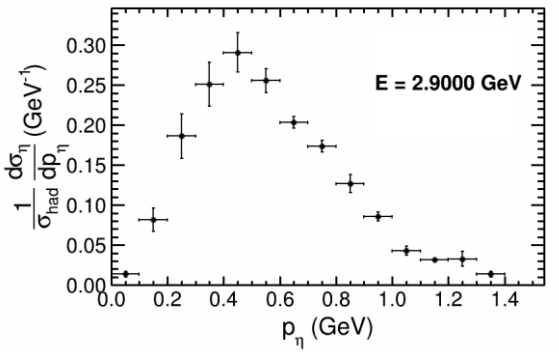
Systematic uncertainty included

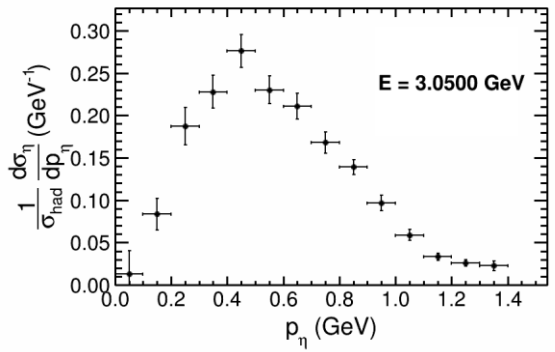


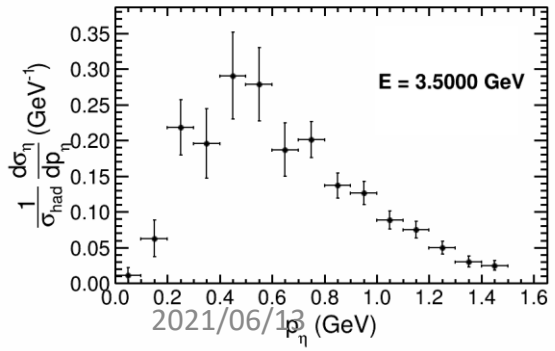


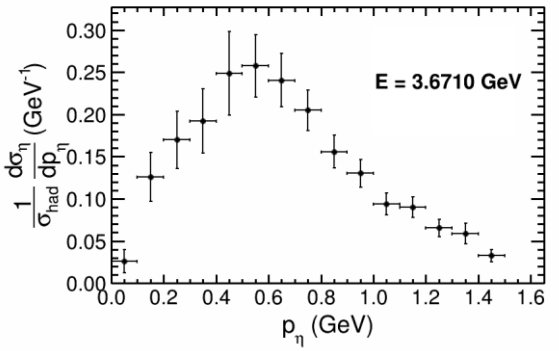












Summary

- **Inclusive production of η in e^+e^- annihilation at 8 energy points between 2.0000 and 3.6710 GeV was measured**
- **Study of all the systematic uncertainties including hadronic event selection, η helicity, match angle, fitting strategy and signal MC model has been finished**
- **Memo is ready**

Thanks for your attention!

Backups

Backup: Systematic Uncertainties

Systematic uncertainties in % at 2.0000 GeV

p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	14.29	1.87	0.23	3.68	-11.27	2.00	18.78
0.1-0.2	2.39	1.87	0.29	1.57	-9.85	2.00	10.62
0.2-0.3	2.16	1.87	0.10	2.28	-4.52	2.00	6.15
0.3-0.4	1.48	1.87	0.02	1.29	-1.21	2.00	3.58
0.4-0.5	0.88	1.87	0.03	0.86	4.17	2.00	5.14
0.5-0.6	1.08	1.87	0.04	1.42	0.58	2.00	3.32
0.6-0.7	1.18	1.87	0.09	2.96	32.72	2.00	32.99
0.7-0.8	0.61	1.87	0.09	0.61	13.36	2.00	13.67
0.8-0.9	2.09	1.87	0.09	2.38	14.95	2.00	15.52

Systematic uncertainties in % at 2.2000 GeV

p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	5.00	1.87	0.83	5.46	-3.47	2.00	8.66
0.1-0.2	2.46	1.87	0.52	3.11	-4.62	2.00	6.70
0.2-0.3	1.14	1.87	0.20	1.37	9.83	2.00	10.36
0.3-0.4	1.02	1.87	0.07	0.91	15.79	2.00	16.08
0.4-0.5	1.53	1.87	0.00	0.71	8.62	2.00	9.20
0.5-0.6	1.01	1.87	0.01	0.21	4.80	2.00	5.62
0.6-0.7	1.48	1.87	0.06	1.64	4.53	2.00	5.74
0.7-0.8	1.10	1.87	0.04	1.09	19.95	2.00	20.20
0.8-0.9	1.61	1.87	0.10	1.39	4.68	2.00	5.82
0.9-1.0	0.86	1.87	0.01	1.17	21.73	2.00	21.95

Systematic uncertainties in % at 2.3960 GeV

p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	3.86	1.87	0.43	6.79	-26.11	2.00	27.39
0.1-0.2	1.04	1.87	0.16	2.94	-14.12	2.00	14.72
0.2-0.3	0.51	1.87	0.08	0.92	-5.96	2.00	6.64
0.3-0.4	0.77	1.87	0.07	2.13	1.26	2.00	3.77
0.4-0.5	0.79	1.87	0.03	1.75	4.88	2.00	5.92
0.5-0.6	1.30	1.87	0.02	0.28	2.60	2.00	4.00
0.6-0.7	1.14	1.87	0.13	0.38	-1.01	2.00	3.16
0.7-0.8	1.08	1.87	0.03	0.95	1.59	2.00	3.48
0.8-0.9	1.14	1.87	0.02	0.52	14.20	2.00	14.52
0.9-1.0	0.79	1.87	0.03	0.54	7.83	2.00	8.35
1.0-1.1	0.62	1.87	0.00	0.22	26.03	2.00	26.18

Backup: Systematic Uncertainties

Systematic uncertainties in % at 2.6444 GeV

p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	3.22	1.87	0.33	6.52	-21.67	2.00	23.02
0.1-0.2	1.62	1.87	0.27	2.51	-15.38	2.00	15.91
0.2-0.3	0.93	1.87	0.04	0.45	-8.76	2.00	9.24
0.3-0.4	1.11	1.87	0.06	2.23	-4.54	2.00	5.86
0.4-0.5	0.76	1.87	0.01	1.11	-1.69	2.00	3.49
0.5-0.6	0.93	1.87	0.04	0.66	-2.27	2.00	3.73
0.6-0.7	1.21	1.87	0.02	0.90	1.87	2.00	3.64
0.7-0.8	0.67	1.87	0.03	0.80	1.21	2.00	3.17
0.8-0.9	0.91	1.87	0.04	0.64	-0.09	2.00	2.96
0.9-1.0	0.91	1.87	0.04	1.24	8.62	2.00	9.18
1.0-1.1	1.25	1.87	0.03	1.72	32.96	2.00	33.14
1.1-1.2	0.74	1.87	0.00	1.22	20.42	2.00	20.65

Backup: Systematic Uncertainties

Systematic uncertainties in % at 3.0500 GeV

p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	199.41	1.87	0.46	5.72	-20.92	2.00	200.61
0.1-0.2	1.61	1.87	0.07	2.86	-18.10	2.00	18.60
0.2-0.3	1.42	1.87	0.19	0.43	-8.83	2.00	9.37
0.3-0.4	1.13	1.87	0.11	0.94	-4.92	2.00	5.82
0.4-0.5	1.00	1.87	0.04	3.20	-2.03	2.00	4.78
0.5-0.6	0.68	1.87	0.05	0.74	-4.01	2.00	4.96
0.6-0.7	1.13	1.87	0.09	1.69	-3.93	2.00	5.21
0.7-0.8	1.35	1.87	0.03	0.57	-4.24	2.00	5.26
0.8-0.9	0.79	1.87	0.01	1.55	-0.55	2.00	3.29
0.9-1.0	1.02	1.87	0.01	2.09	6.50	2.00	7.42
1.0-1.1	1.83	1.87	0.04	1.28	6.23	2.00	7.17
1.1-1.2	1.79	1.87	0.03	0.94	4.06	2.00	5.29
1.2-1.3	1.81	1.87	0.00	0.93	9.78	2.00	10.36
1.3-1.4	2.16	1.87	0.01	0.46	21.00	2.00	21.29

Backup: Systematic Uncertainties

Systematic uncertainties in % at 3.5000 GeV

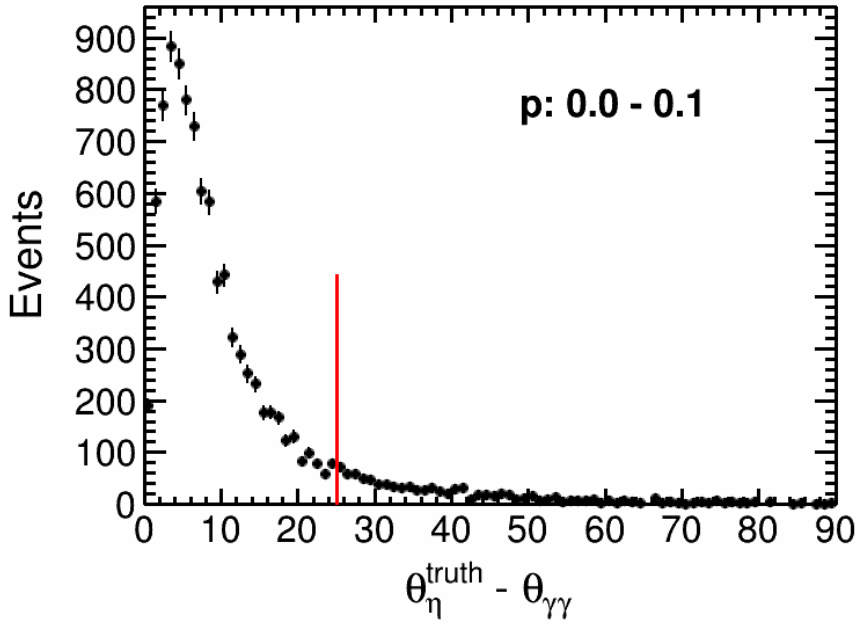
p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	2.44	1.87	0.23	3.50	-19.05	2.00	19.71
0.1-0.2	5.17	1.87	0.35	9.95	-4.29	2.00	12.32
0.2-0.3	2.13	1.87	0.15	3.91	4.73	2.00	7.05
0.3-0.4	3.63	1.87	0.21	9.93	12.88	2.00	16.89
0.4-0.5	1.70	1.87	0.24	1.83	16.89	2.00	17.29
0.5-0.6	1.77	1.87	0.13	1.41	14.54	2.00	14.97
0.6-0.7	1.83	1.87	0.14	1.47	15.06	2.00	15.48
0.7-0.8	1.49	1.87	0.01	0.32	6.66	2.00	7.36
0.8-0.9	2.04	1.87	0.09	0.70	2.56	2.00	4.33
0.9-1.0	2.33	1.87	0.06	2.19	3.16	2.00	5.26
1.0-1.1	2.28	1.87	0.01	0.52	-0.15	2.00	3.60
1.1-1.2	3.59	1.87	0.07	0.81	-0.78	2.00	4.65
1.2-1.3	3.71	1.87	0.04	0.84	3.75	2.00	6.00
1.3-1.4	2.08	1.87	0.01	4.41	1.85	2.00	5.89
1.4-1.5	5.71	1.87	0.02	0.56	5.79	2.00	8.60

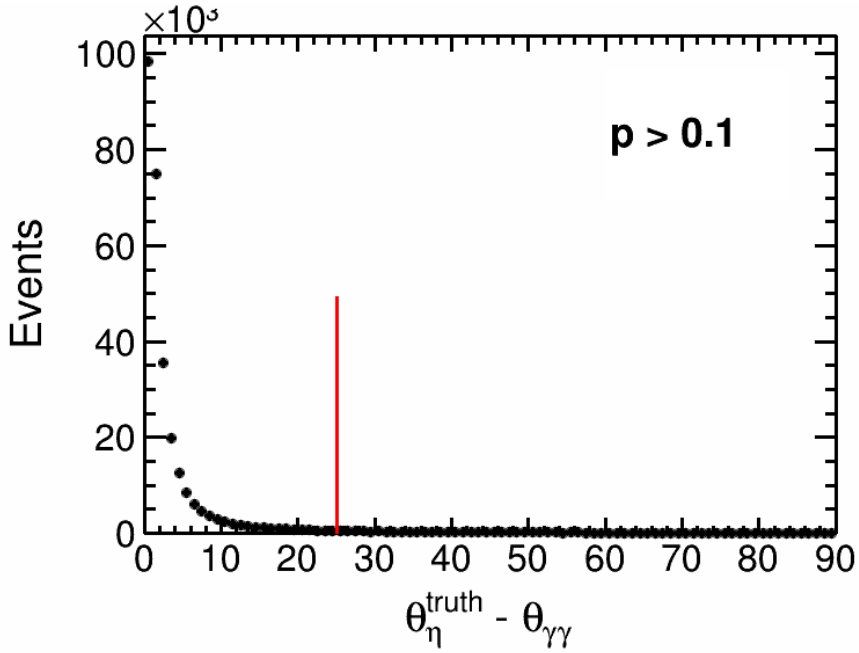
Backup: Systematic Uncertainties

Systematic uncertainties in % at 3.6710 GeV

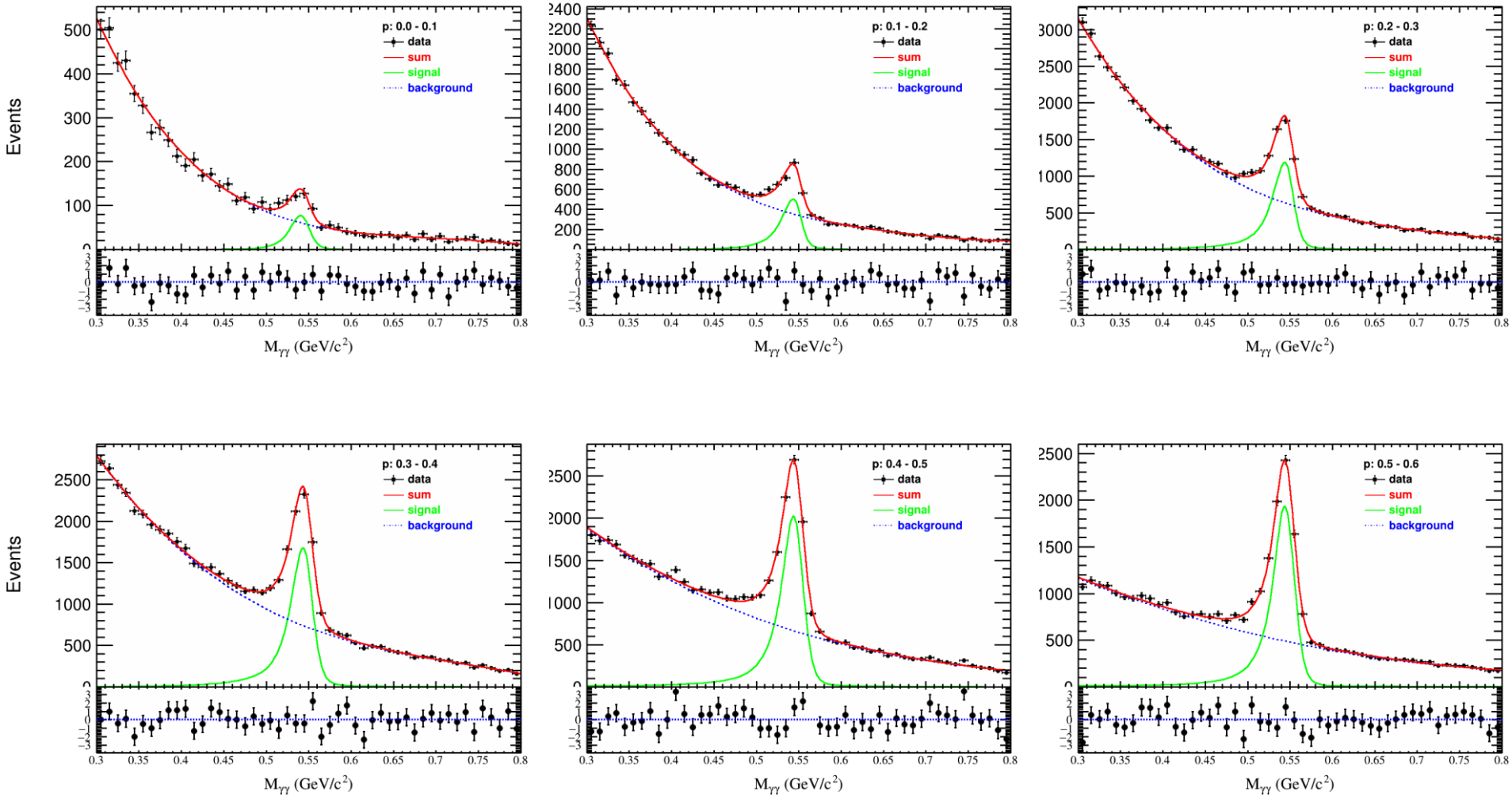
p_η (GeV/c)	Event Selection	η helicity	Match Angle	Fitting	MC Model	Photon Eff.	Total
0.0-0.1	1.07	1.87	1.47	27.91	-17.47	2.00	33.09
0.1-0.2	1.68	1.87	0.17	5.03	-9.09	2.00	10.88
0.2-0.3	2.52	1.87	0.35	1.89	2.84	2.00	5.06
0.3-0.4	1.83	1.87	0.17	2.12	10.16	2.00	10.89
0.4-0.5	2.12	1.87	0.31	5.27	14.11	2.00	15.46
0.5-0.6	1.91	1.87	0.04	1.09	8.51	2.00	9.20
0.6-0.7	1.39	1.87	0.03	1.55	7.25	2.00	8.03
0.7-0.8	1.62	1.87	0.11	3.29	3.83	2.00	5.97
0.8-0.9	1.97	1.87	0.03	4.33	0.29	2.00	5.50
0.9-1.0	1.73	1.87	0.03	1.21	-3.48	2.00	4.91
1.0-1.1	1.85	1.87	0.00	0.31	2.58	2.00	4.20
1.1-1.2	1.14	1.87	0.02	2.49	-2.45	2.00	4.58
1.2-1.3	2.04	1.87	0.01	1.12	3.21	2.00	4.82
1.3-1.4	3.20	1.87	0.00	3.25	13.68	2.00	14.68
1.4-1.5	3.34	1.87	0.04	5.01	3.18	2.00	7.34

Backup: Match Angle





Backup: Data Fitting (2.9000 GeV)



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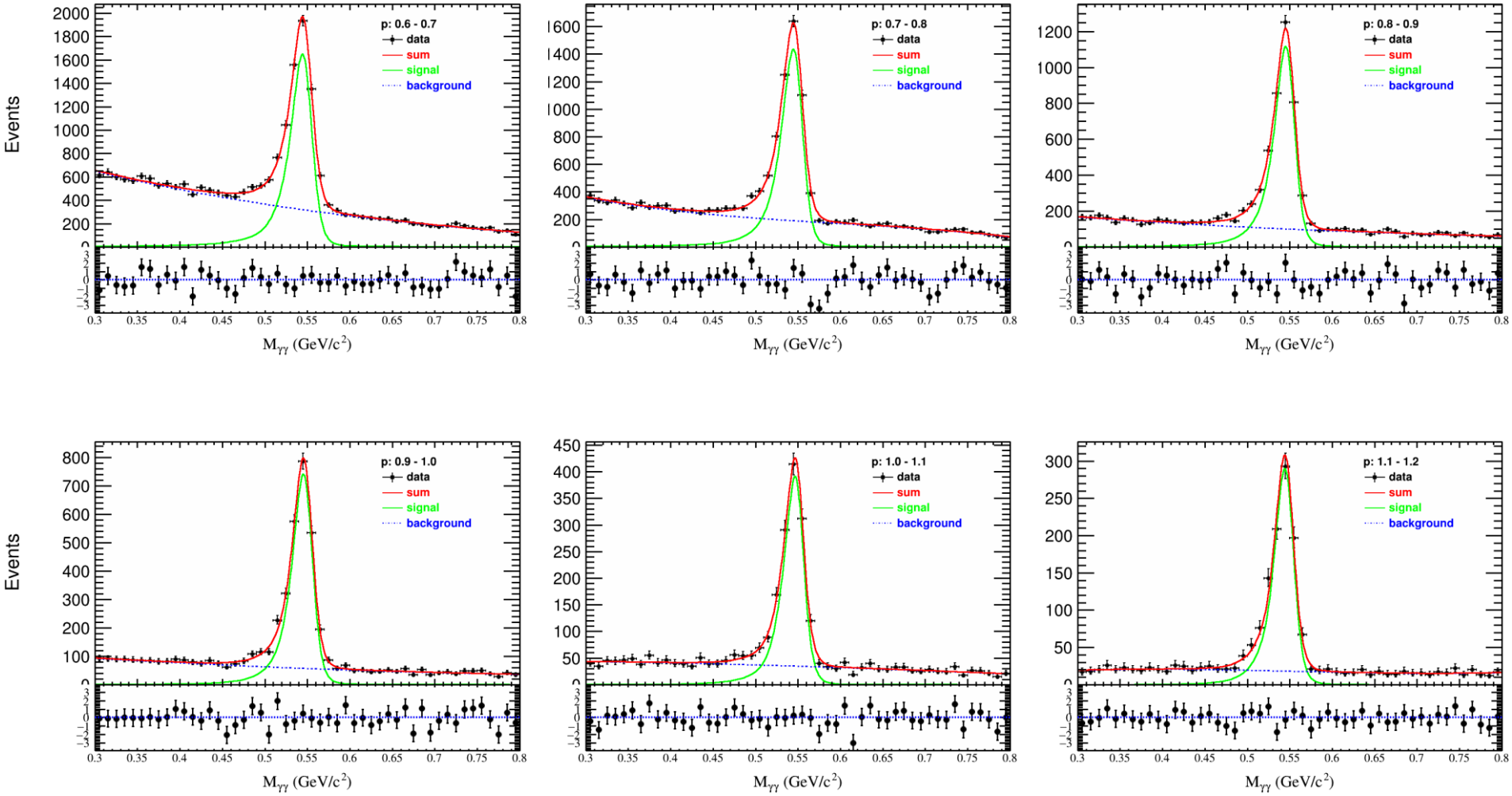
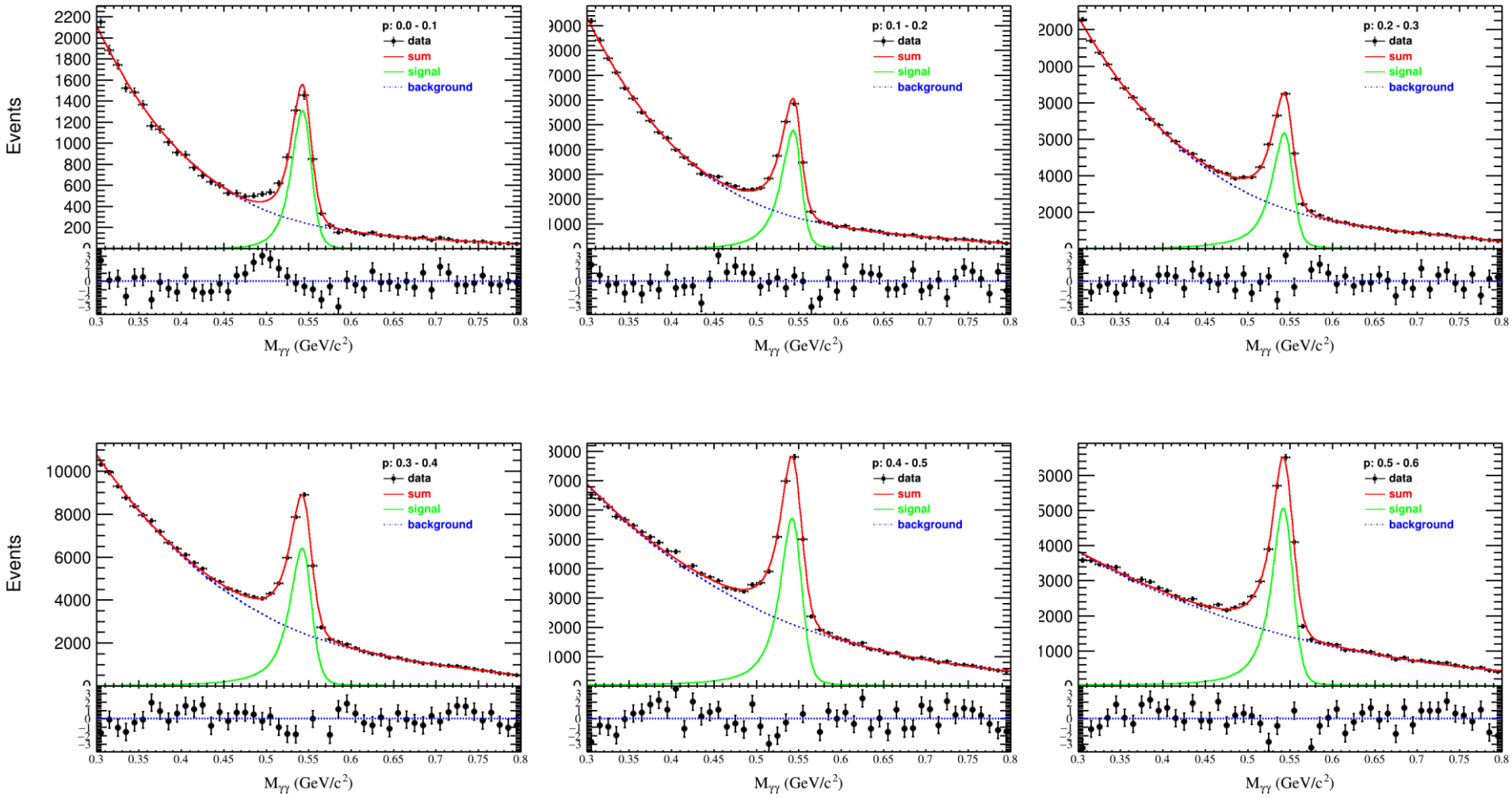
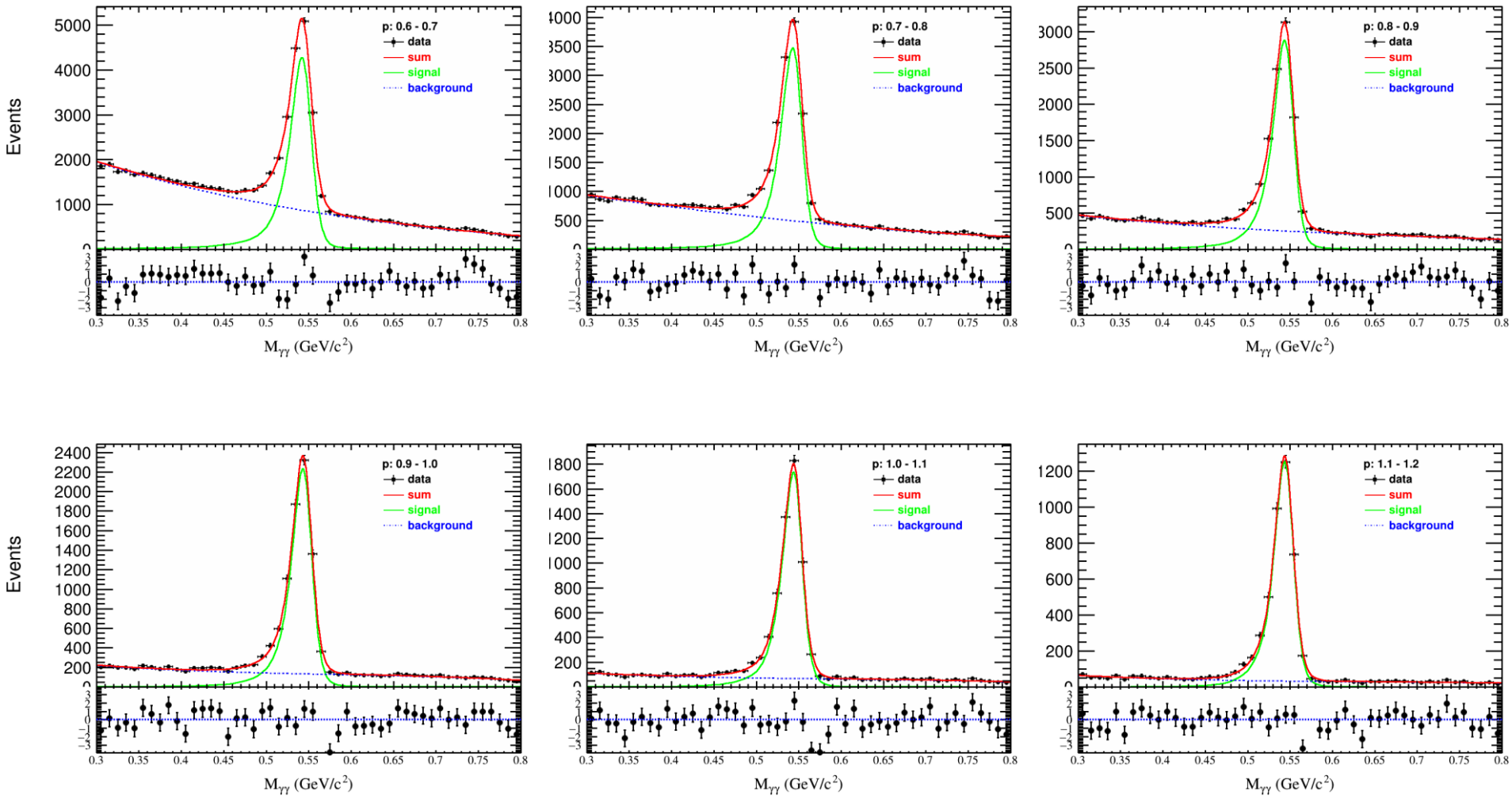


Backup: LUARLW MC Fitting (2.9000 GeV)



Backup: LUARLW MC Fitting (2.9000 GeV)



Data VS MC

2.9000 GeV

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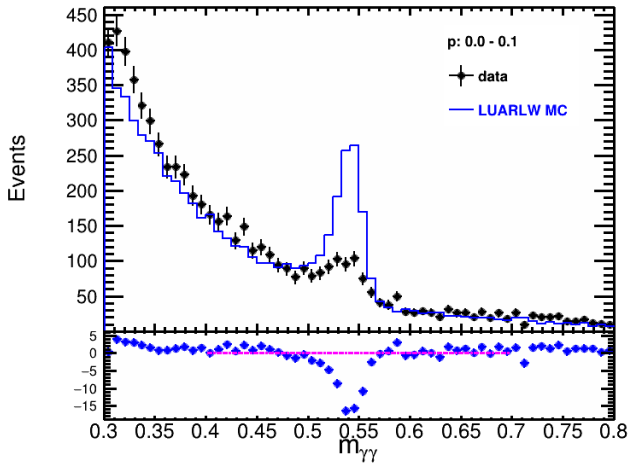

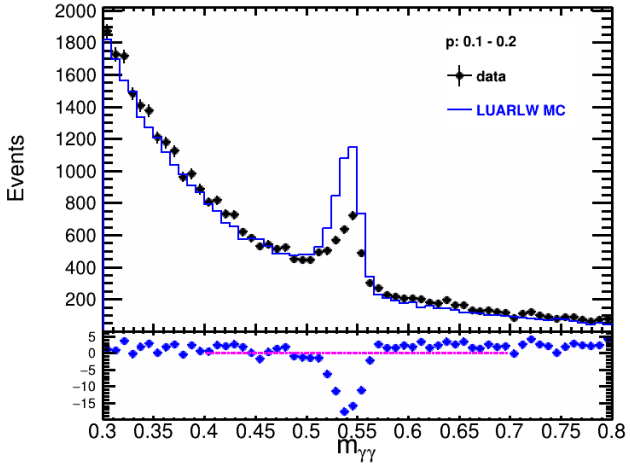

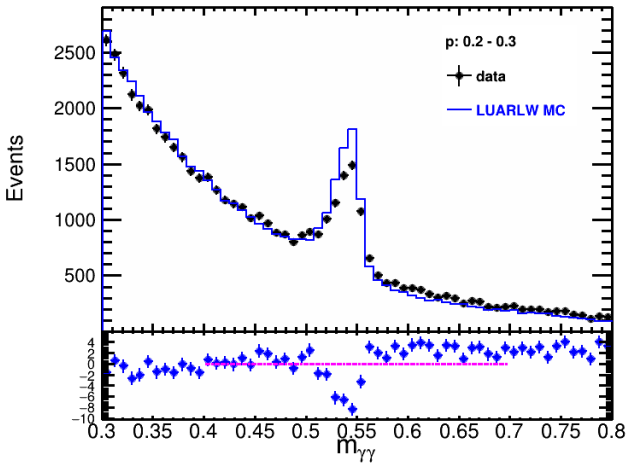

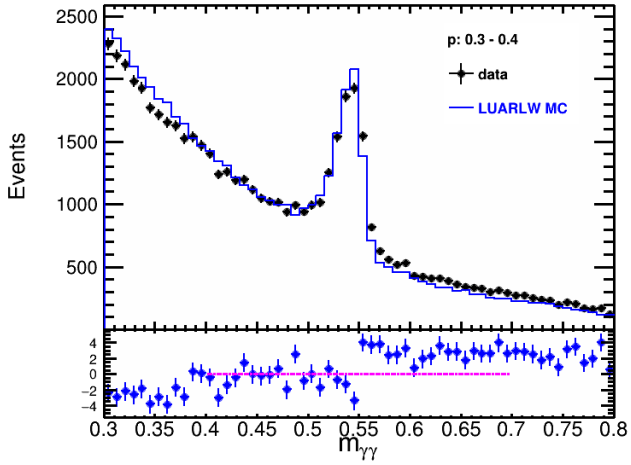

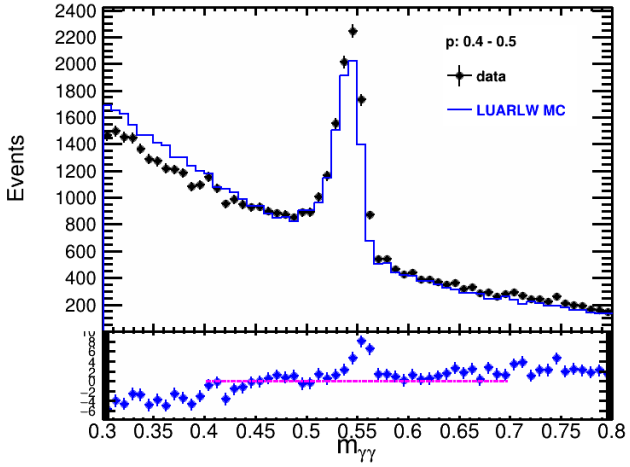

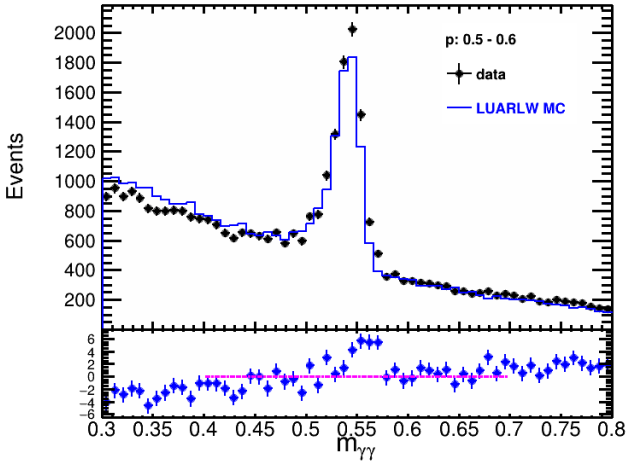

Data VS MC

2.9000 GeV

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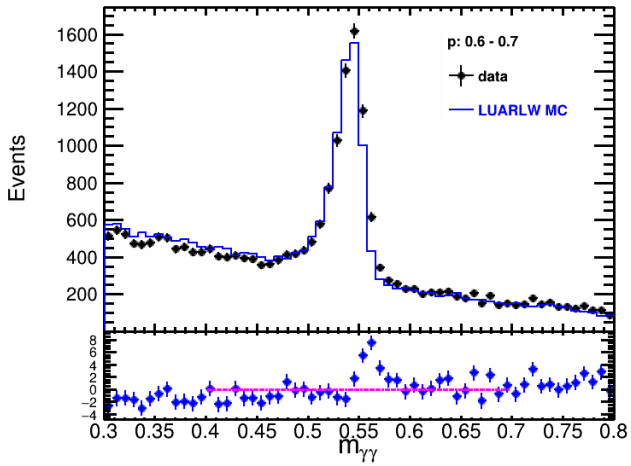
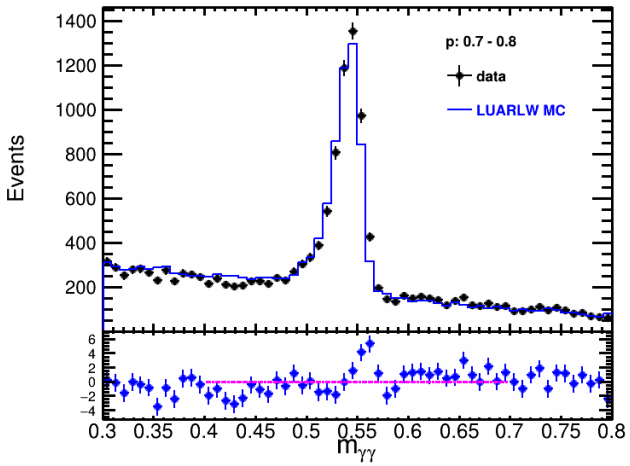
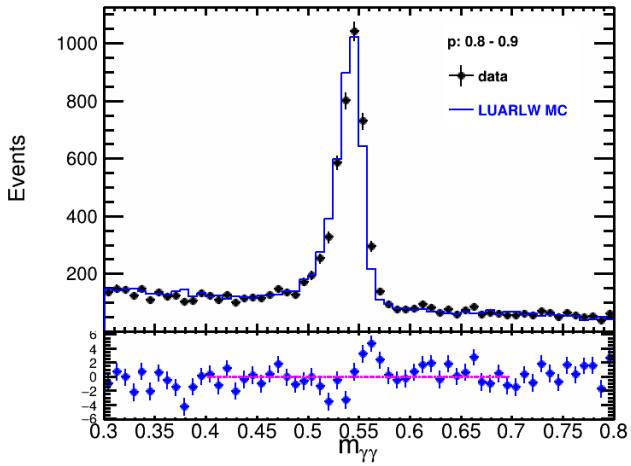
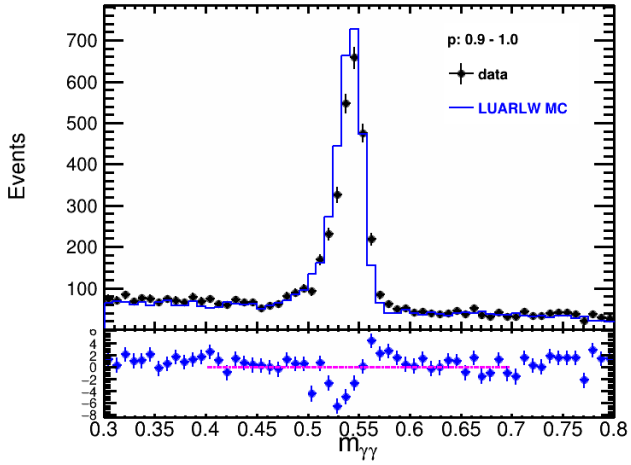
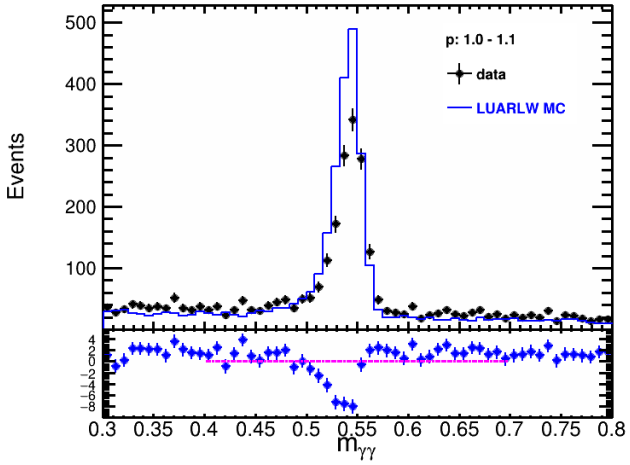
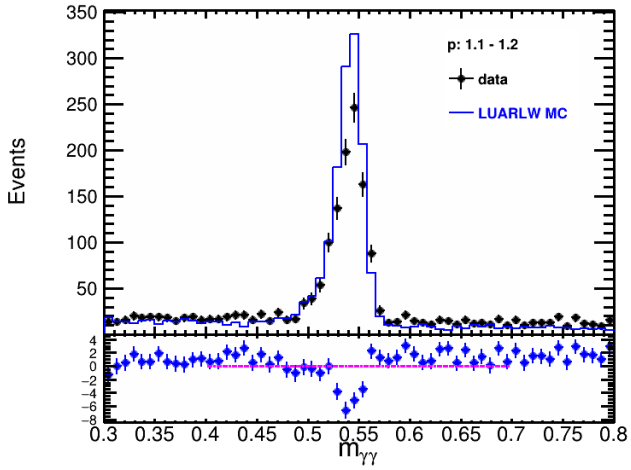




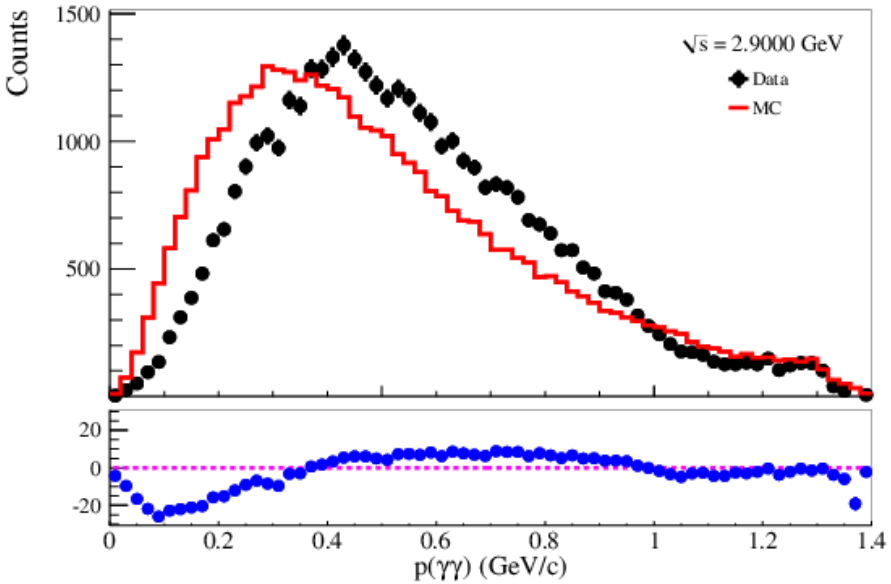








Backup: momentum weighted MC



0	0.289	0.341	0.295	0.308	0.304
1	0.400	0.442	0.479	0.514	0.607
2	0.625	0.699	0.767	0.819	0.789
3	0.761	0.913	0.918	1.019	1.051
4	1.104	1.175	1.204	1.208	1.169
5	1.144	1.270	1.280	1.264	1.337
6	1.250	1.378	1.343	1.308	1.288
7	1.449	1.425	1.439	1.316	1.440
8	1.358	1.281	1.391	1.287	1.311
9	1.230	1.237	1.222	1.069	0.992
10	0.900	0.805	0.718	0.808	0.829
11	0.723	0.721	0.813	0.794	0.833
12	0.970	0.731	0.835	0.963	0.888
13	0.960	0.604	0.424	−0.031	0.533

p_η (GeV/c)	unweighted	weighted	diff(%)
0.0-0.1	0.014 ± 0.002	0.014 ± 0.002	-0.02
0.1-0.2	0.081 ± 0.004	0.081 ± 0.004	-0.24
0.2-0.3	0.186 ± 0.005	0.186 ± 0.005	-0.24
0.3-0.4	0.251 ± 0.006	0.251 ± 0.006	-0.17
0.4-0.5	0.291 ± 0.006	0.291 ± 0.006	-0.02
0.5-0.6	0.256 ± 0.005	0.256 ± 0.005	0.06
0.6-0.7	0.204 ± 0.004	0.204 ± 0.004	0.03
0.7-0.8	0.173 ± 0.004	0.173 ± 0.004	0.06
0.8-0.9	0.127 ± 0.003	0.127 ± 0.003	0.02
0.9-1.0	0.086 ± 0.001	0.086 ± 0.001	-0.09
1.0-1.1	0.043 ± 0.002	0.043 ± 0.002	0.11
1.1-1.2	0.032 ± 0.001	0.032 ± 0.001	-0.02
1.2-1.3	0.032 ± 0.001	0.033 ± 0.001	0.91
1.3-1.4	0.013 ± 0.001	0.012 ± 0.001	-7.05

LUARLW MC weighted by momentum at 2.9000 GeV

No obvious difference found compared with unweighted results

Backup