Study of $\gamma^*\gamma^* \rightarrow p\bar{p}$

Kedi Hao (USTC)

MC Generation

➢ Yield Estimation of $\gamma\gamma \to p\bar{p}$ at 3.773GeV

$$N_{ee\to p\bar{p}} = \int \sigma_{\gamma\gamma\to p\bar{p}}(W_{\gamma\gamma}) * L_{int} * \frac{dL_{\gamma\gamma}(W_{\gamma\gamma}, E_{cms})}{dW_{\gamma\gamma}} dW_{\gamma\gamma}$$

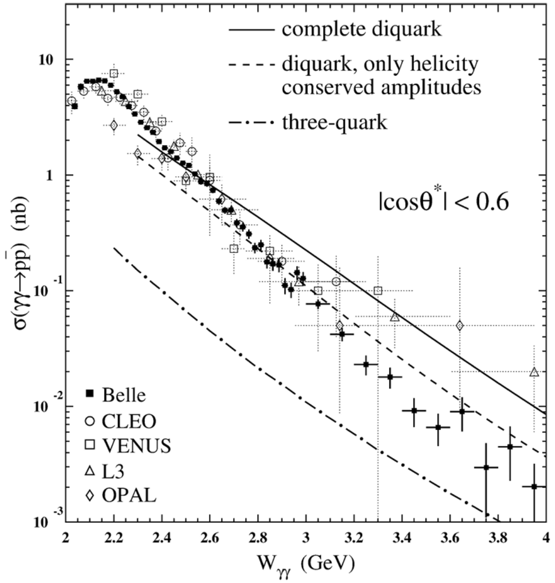


Fig. $\sigma_{\gamma\gamma\to p\bar{p}}(W_{\gamma\gamma})$ Belle Collaboration Physics Letters B 621 (2005) 41–55

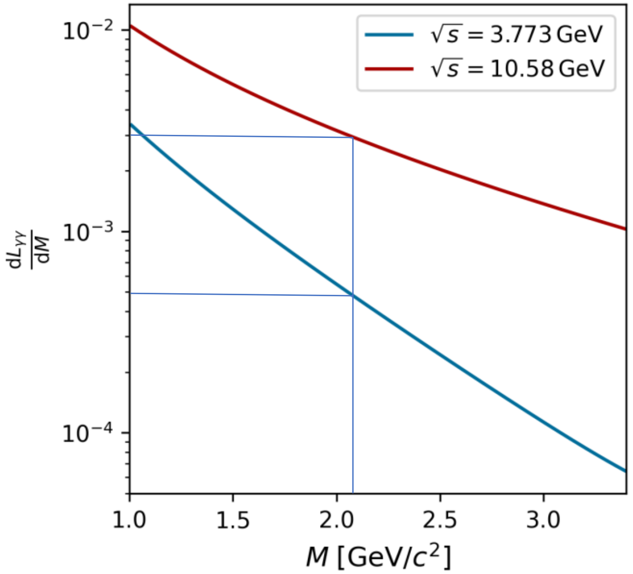
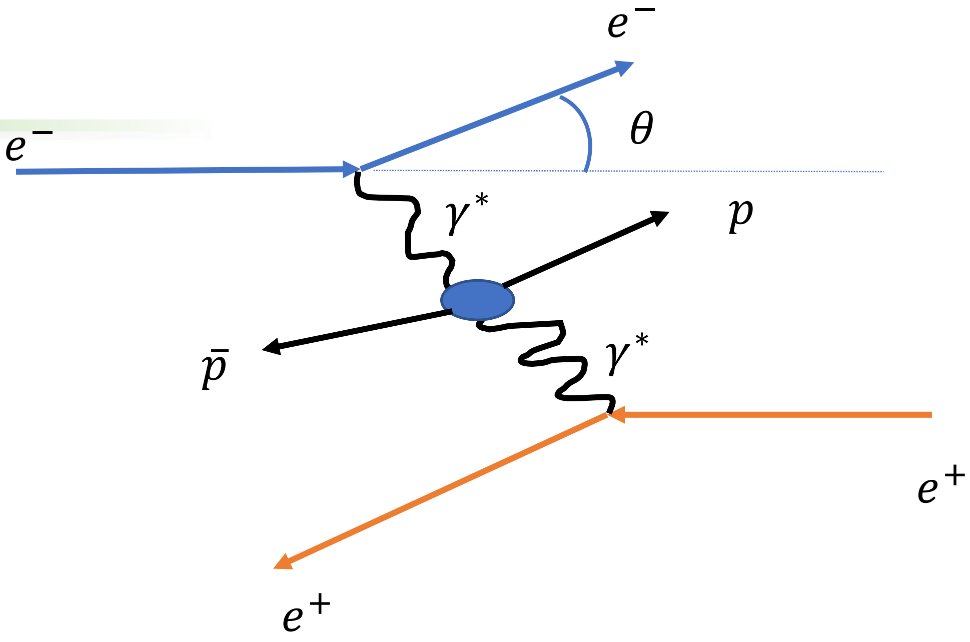


Fig. $\frac{dL_{\gamma\gamma}(W_{\gamma\gamma})}{dW_{\gamma\gamma}}$ calculation.



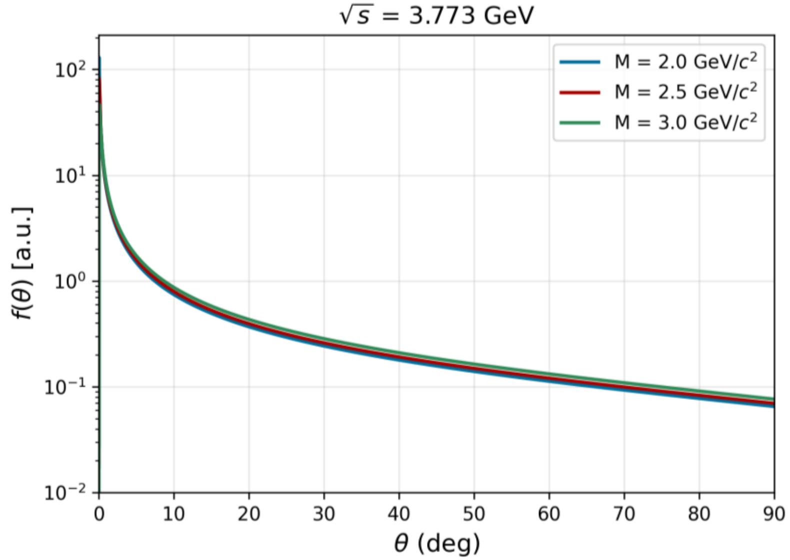


Fig. angular distribution of electron

$P(cos\theta > 0.92)$:
0.84 for 2.0GeV
0.82 for 2.5GeV
0.81 for 3.0GeV

Untag:0.69
Single:0.28
Double:0.03

MC Generation

- Yield Estimation of $\gamma\gamma \rightarrow p\bar{p}$ at 3.773GeV

  Angle distribution of $p/\bar{p}$ in $\gamma\gamma \rightarrow p\bar{p}$

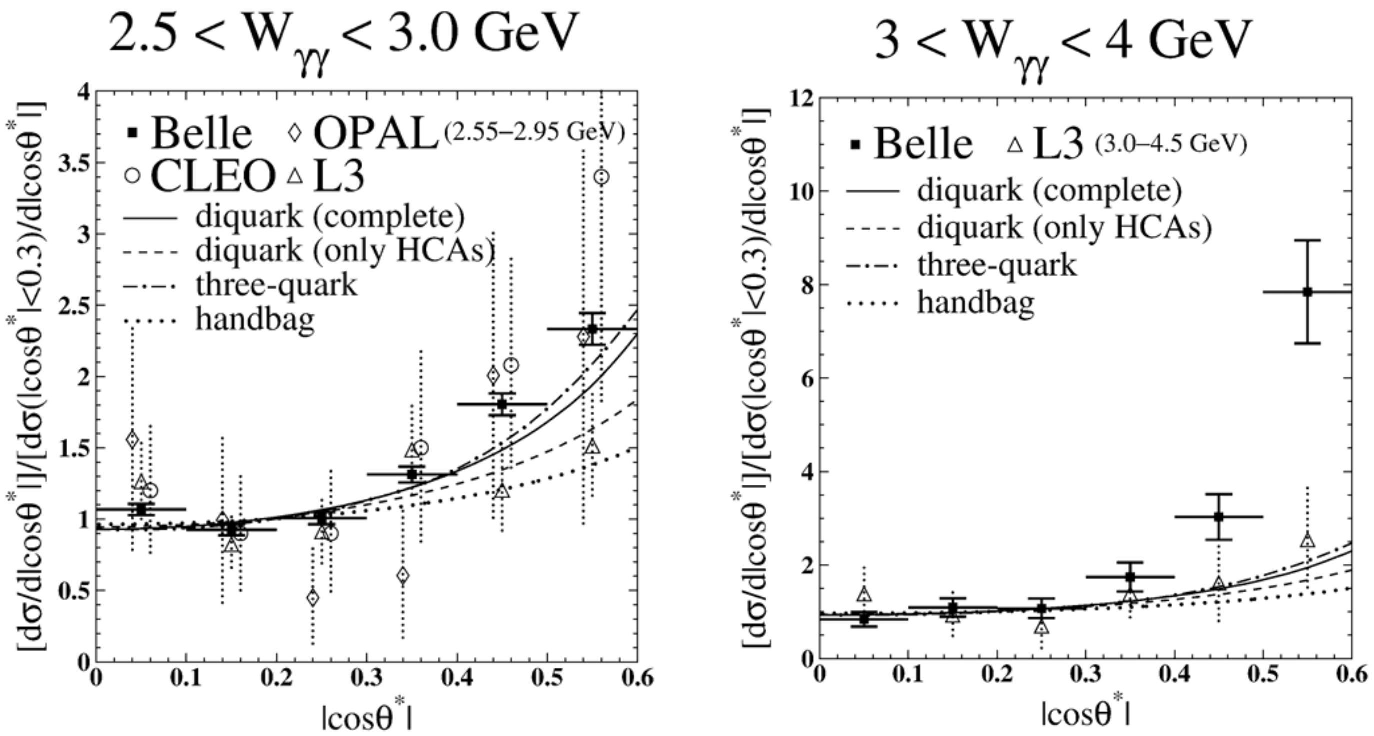


Fig. Differential cross section as a function of $|cos\theta^*|$.

MC Generation

➢ Yield Estimation of $\gamma\gamma \to p\bar{p}$ at 3.773GeV

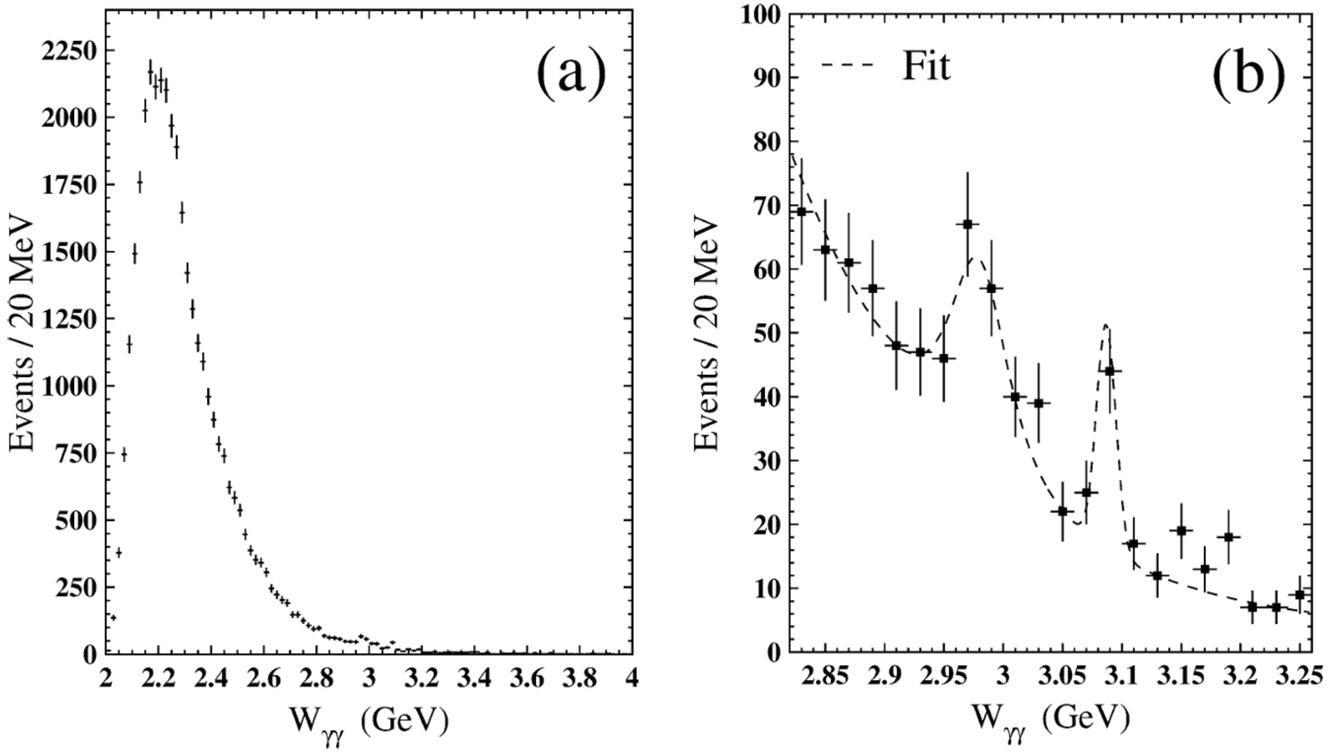


Fig. $W_{\gamma\gamma}$ distribution of events passing all the selection criteria.

Belle 89fb $^{-1}$ at 10.58GeV; $W_{\gamma\gamma} = 2 - 4GeV$, 36094 events

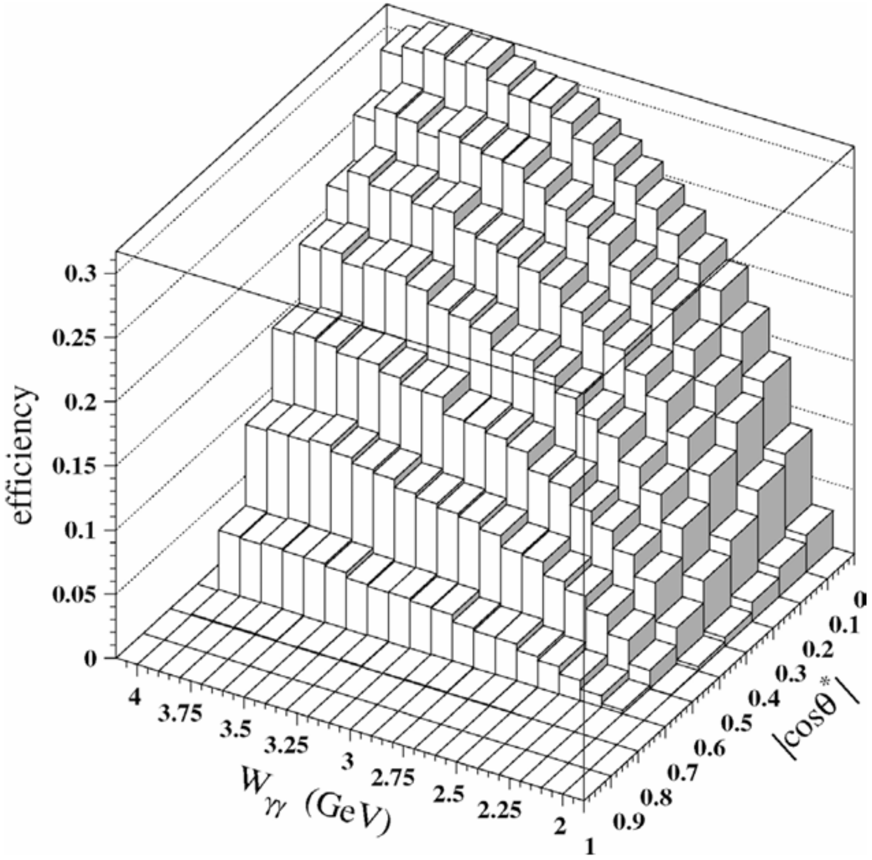


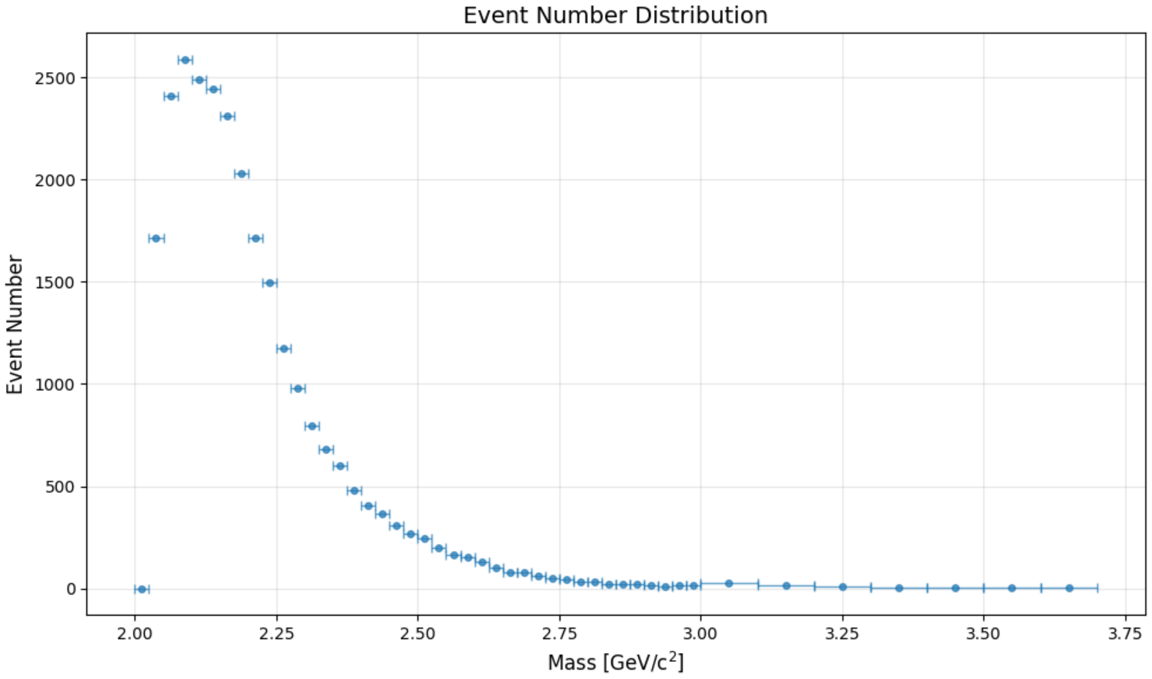
Fig. Overall detection efficiency of $\gamma\gamma \to p\bar{p}$ as a function of $W_{\gamma\gamma}$ and $|cos\theta^*|$

MC Generation

- Yield Estimation of $\gamma\gamma \rightarrow p\bar{p}$ at 3.773GeV

$$N_{ee\rightarrow p\bar{p}} = \int \sigma_{\gamma\gamma\rightarrow p\bar{p}}(W_{\gamma\gamma}) * L_{int} * \frac{dL_{\gamma\gamma}(W_{\gamma\gamma})}{dW_{\gamma\gamma}} dW_{\gamma\gamma}$$

Based on the assumption that $\gamma\gamma \rightarrow p\bar{p}$ follows a phase space distribution.



25MeV/Bin 100MeV/Bin

$$\frac{L_{Belle} * \frac{dL}{dW}(Belle) * \epsilon_{Belle}}{L_{BES} * \frac{dL}{dW}(BES) * \epsilon_{BES}} = 4.5*5*0.2=4.5$$

预期:

Untag 10000 events

Stag 1000 events

MC Generation

- Two Generators

1. cppGamGam & HadroTOPS
2. use same $\sigma_{\gamma\gamma\to p\bar{p}}(W_{\gamma\gamma})$
3. Derive momentum of final particles

- Simulation: TrackGen

Cppgamgam:

权重=亮度x相空间因子x形状因子x强子截面

HadroTOPS:

权重=亮度(TT)x相空间x截面(W, Q_1^2, Q_2^2, $cos\theta^*$)(TT)

+亮度(TL)x相空间x截面 (TL)

+亮度(LT)x相空间x截面 (LT)

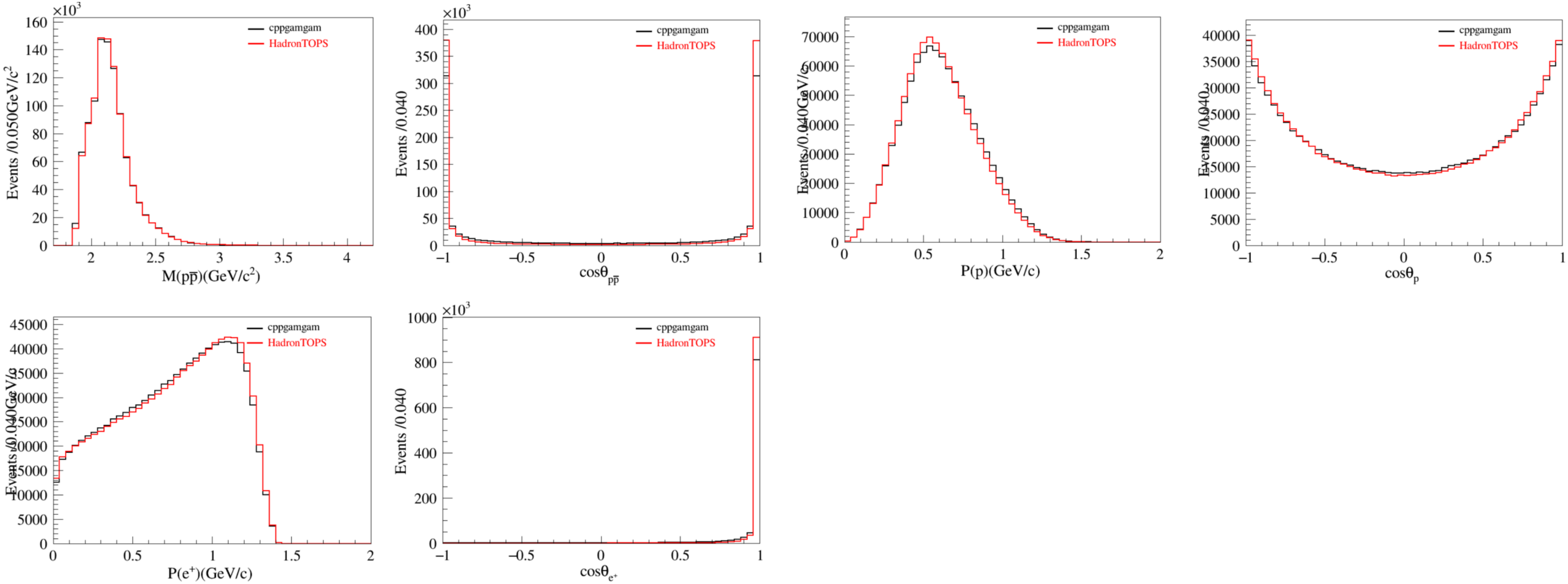
+亮度(LL)x相空间x截面 (LL)

+亮度(TT干涉)x相空间x截面 (TT干涉)

+亮度(TL干涉)x相空间x截面 (TL干涉)

Comparison of two Generators at truth level

Using the same input: Belle $\sigma_{\gamma\gamma\to p\bar{p}}(W_{\gamma\gamma})$ [PLB 621 (2005) 41], (Q², cos θ*) treated as phase space.



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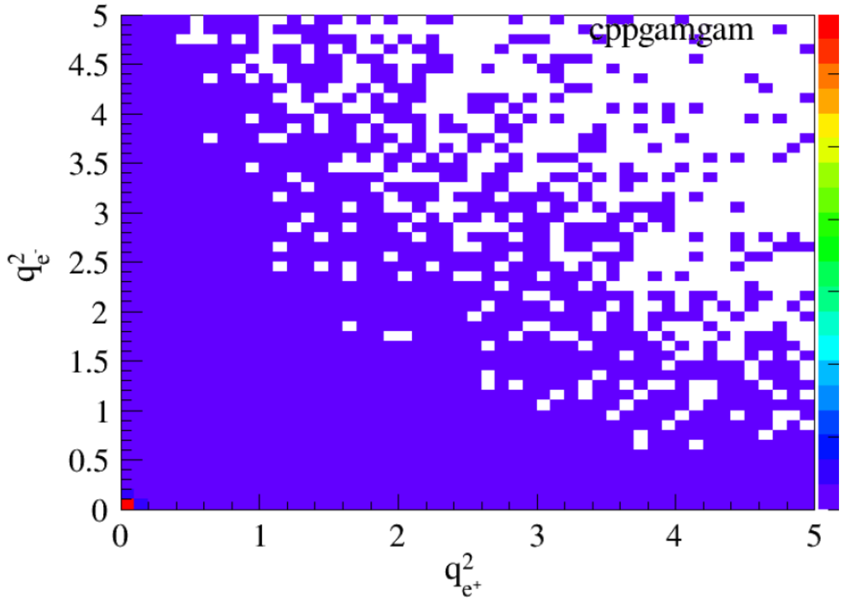
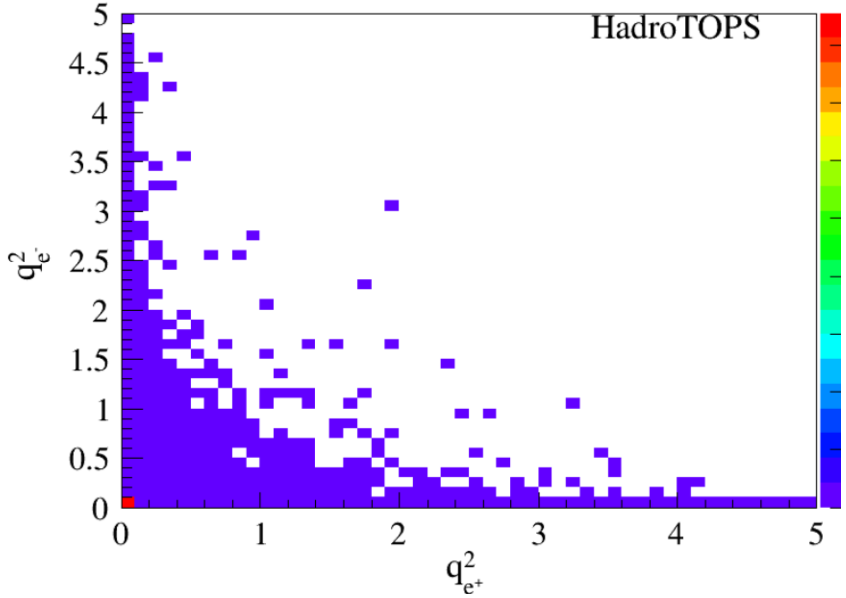
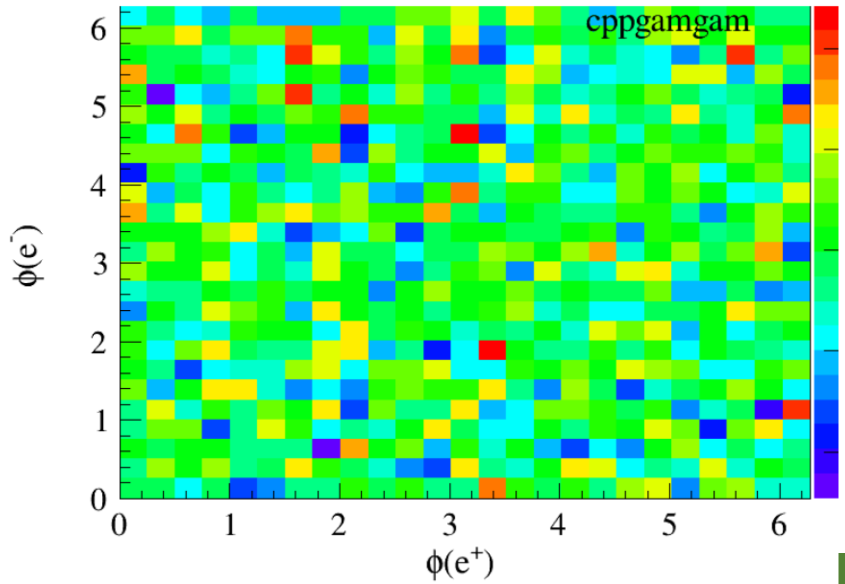
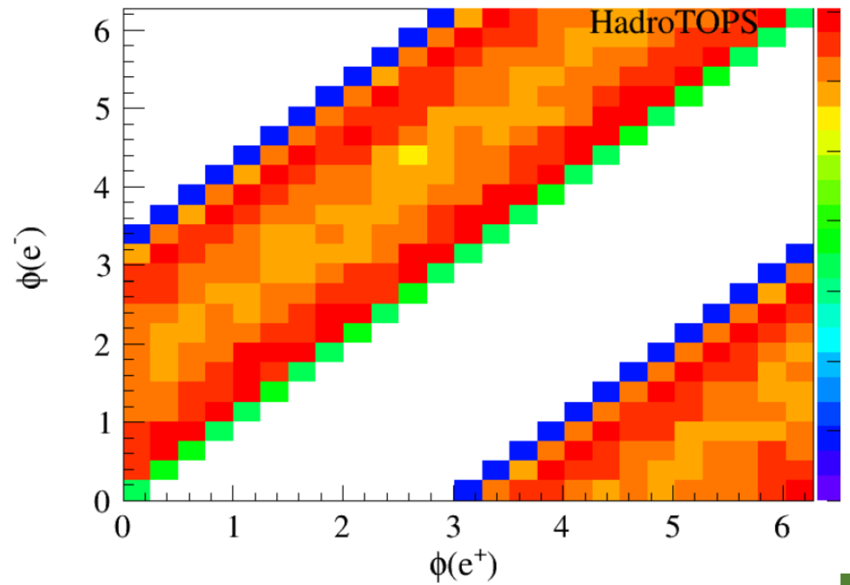




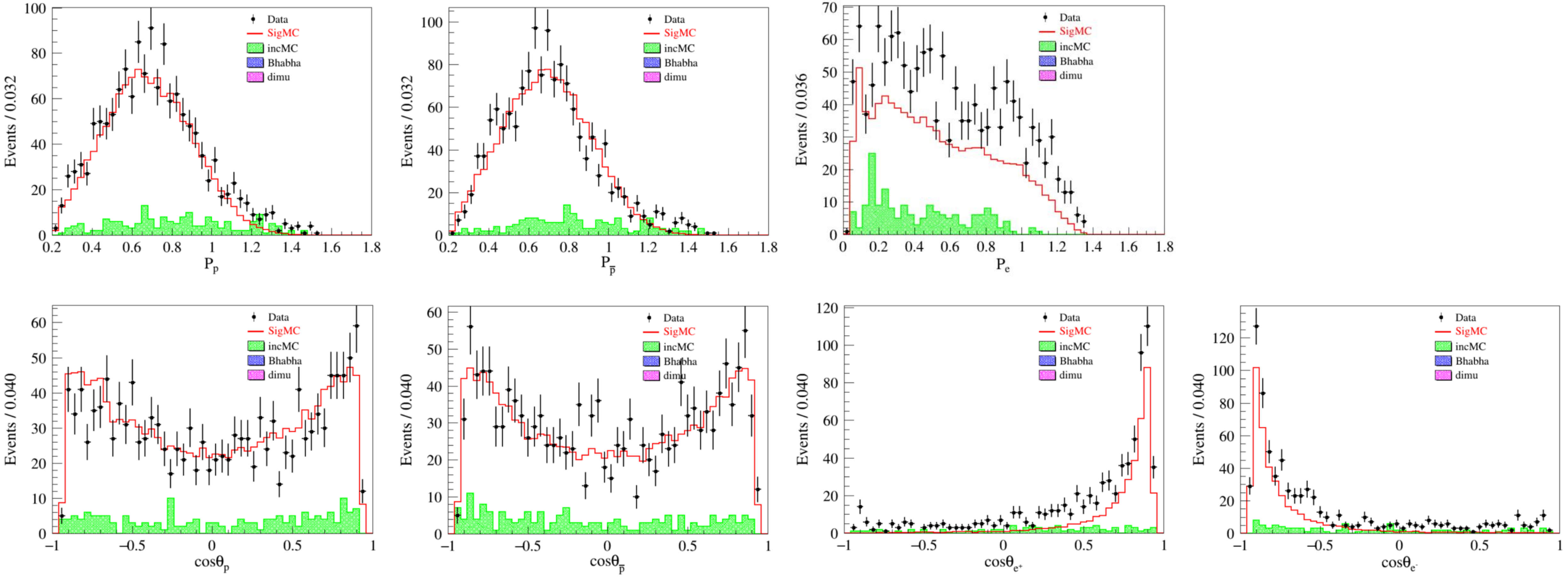




Comparison between data and cppgamgam MC.

IncMC and Bhabha dimu were scaled by luminosity, sigMC was scaled to 0.8*data_max/sigMC_max.

$$\cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p,\bar{p}) < 170;$$
$$10 < \theta(p/\bar{p},e) < 170;$$
$$-0.1 < Umiss < 0.1$$



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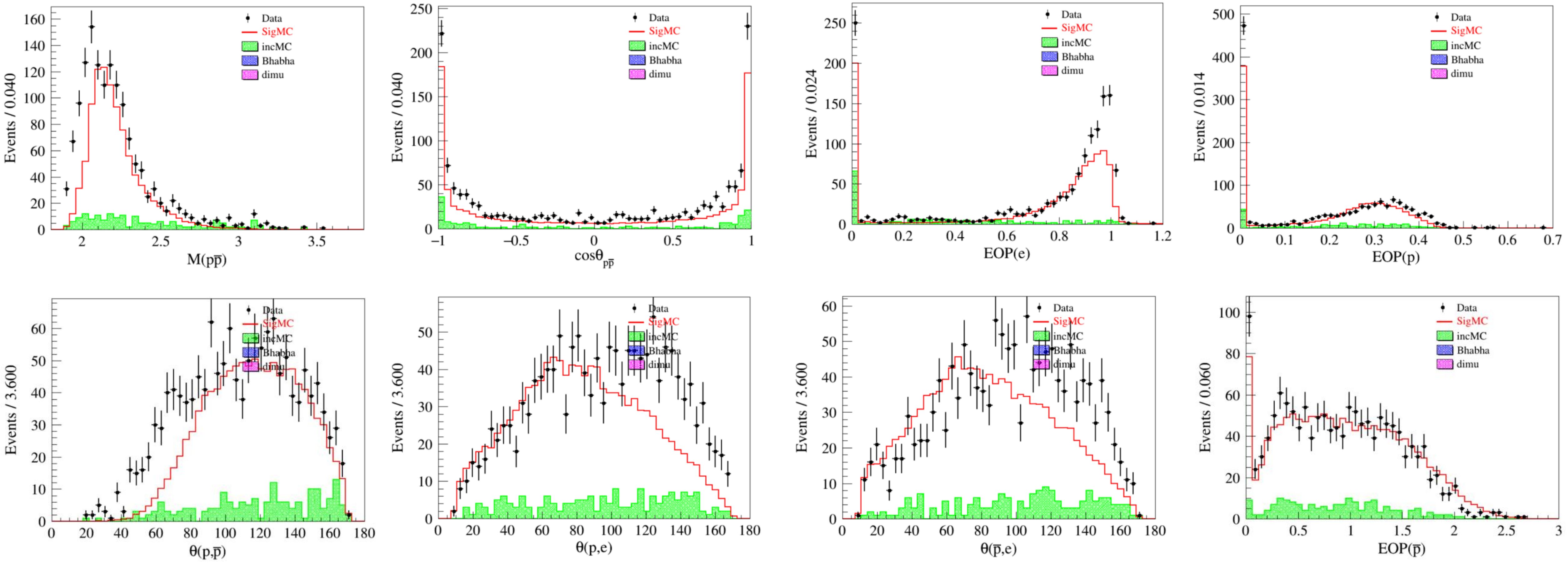

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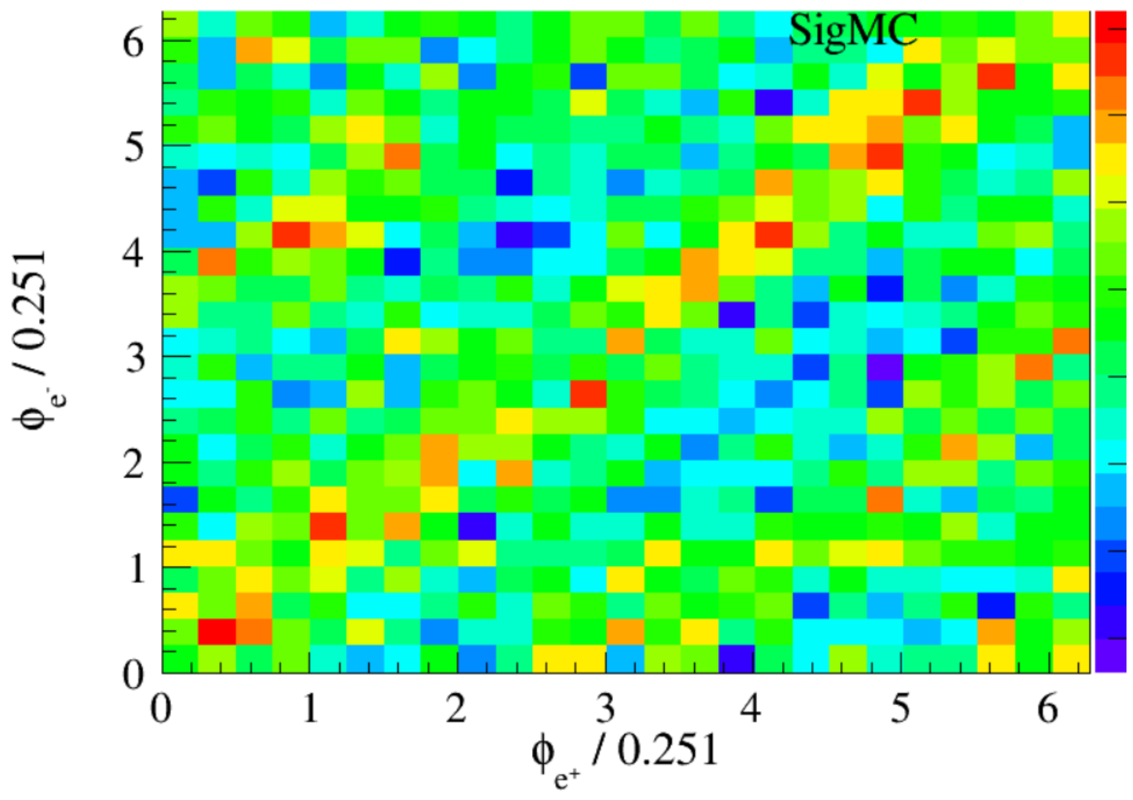

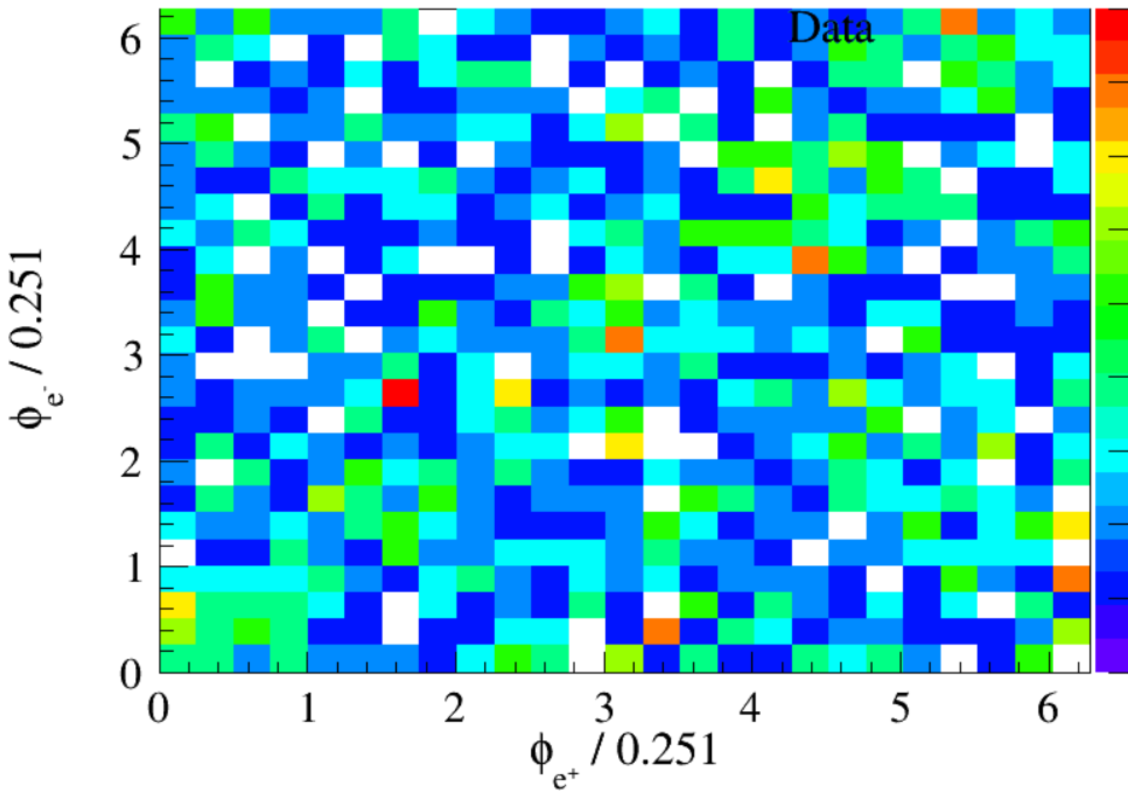

Faint structures can be observed. Since the distribution at the MC truth level (shown in page 6) is flat, this feature is likely caused by reconstruction effects.

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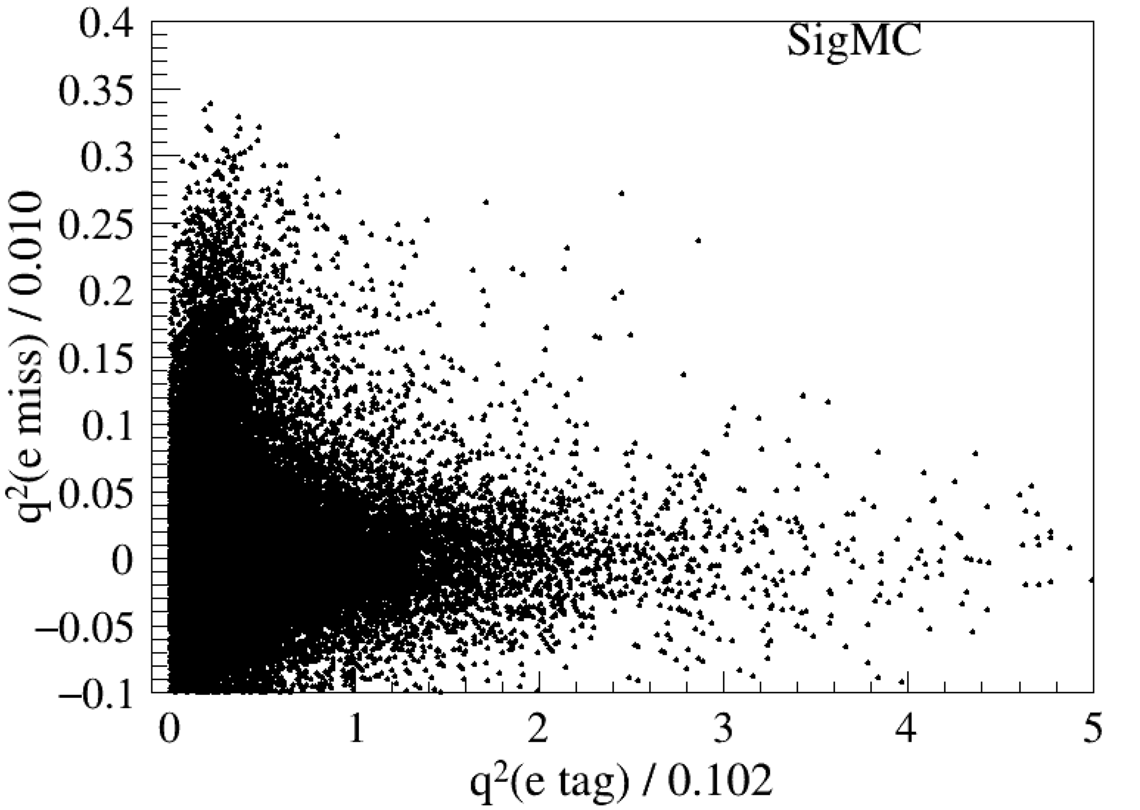
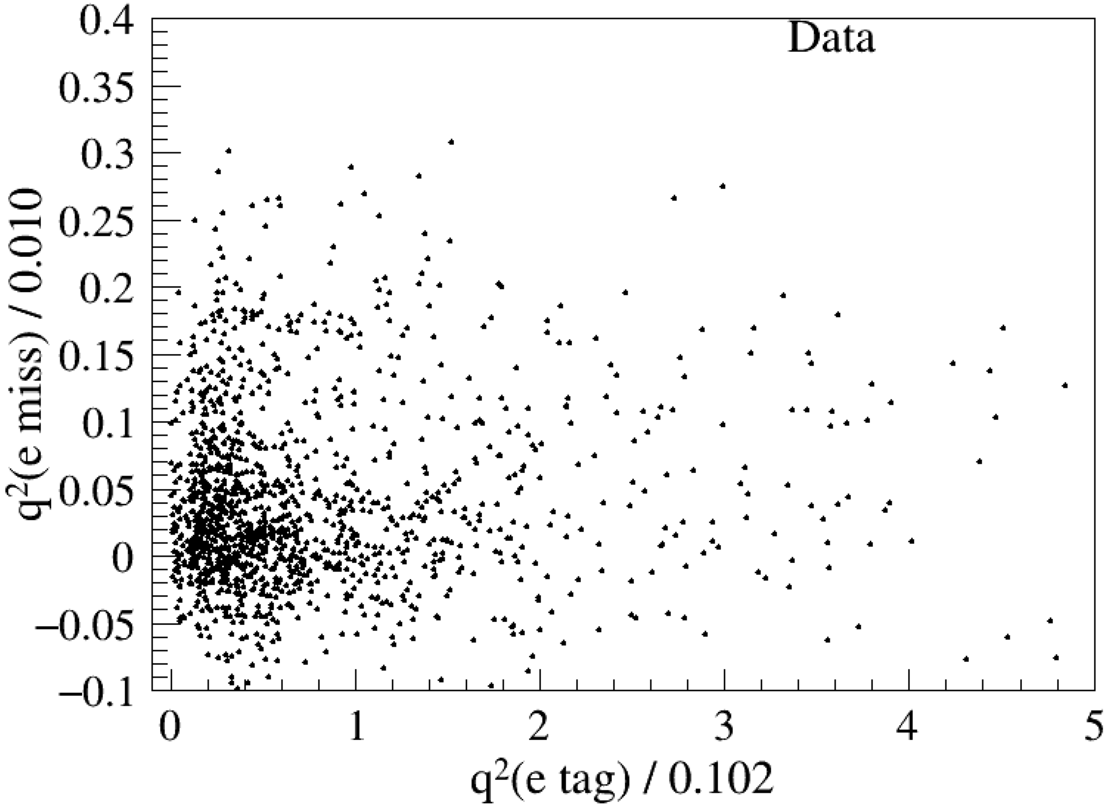




Faint structures can be observed. Since the distribution at the MC truth level (shown in page 6) is flat, this feature is likely caused by reconstruction effects.

Single tag

➢ Data and MC samples:

BOSS: 712

Data set: full data sat at 3.773GeV, 20.3fb $^{-1}$

IncMC sample: Hadron Hybrid; 0.25x Bhabha; 15x dimu; 1x $\gamma\gamma \to ee, \mu\mu, \pi\pi, KK, \eta, \eta'$

ExcMC sample: 1.5M $\gamma\gamma \to p\bar{p}$

➢ Event selection:

- Good charged track:

$$|V_{xy}| < 1cm, |V_z| < 10cm, |\cos\theta| < 0.93$$

$$N_{good} = 3, N_{charge} = \pm 1$$

- PID:

p: prob(p)>prob(e, μ, π, K),0.001

e: prob(e)>prob(μ, π, K, p),0.001

$$N_p = N_{\bar{p}} = N_e = 1$$

- Vertex Fit:

Vertex fit for $p\bar{p}e$, success;

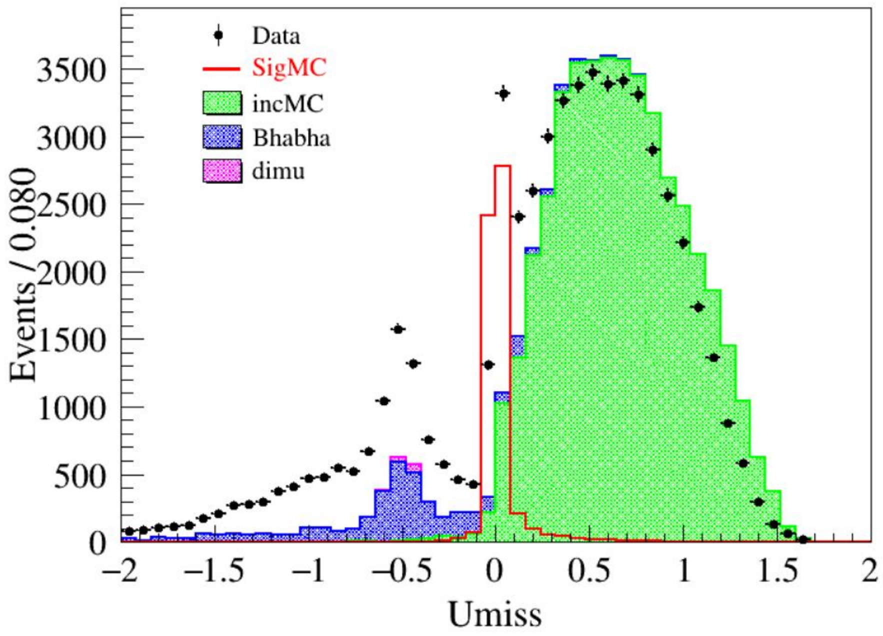
- Other:

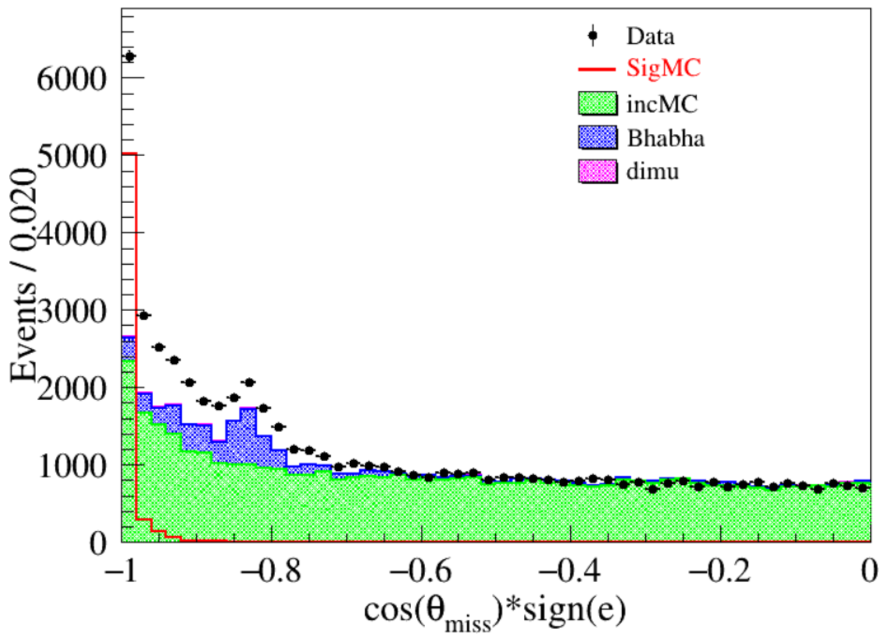
Cosθ_{miss} ×sign(e)<0;

Further Event selection

$cos\theta_{miss} * sign(e) < 0;$

Miss 系统的质量和角度:

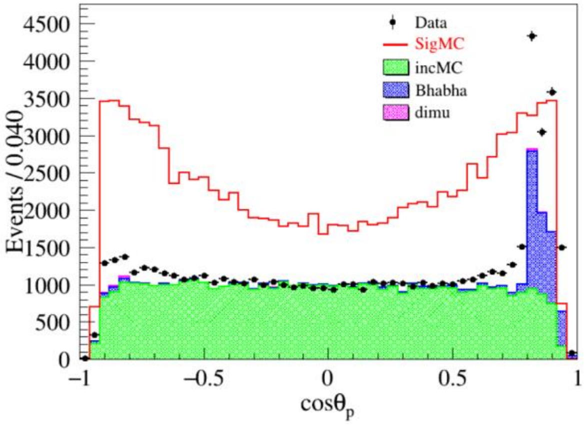


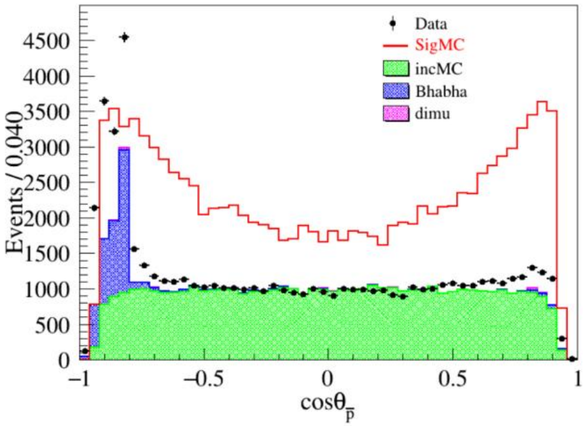


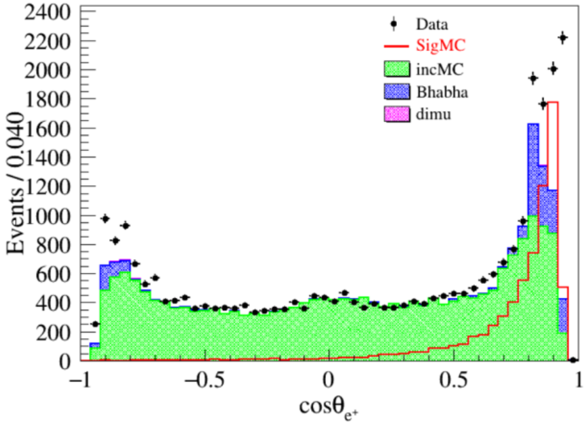
IncMC 主要成分：$p\bar{p} + n * \pi$

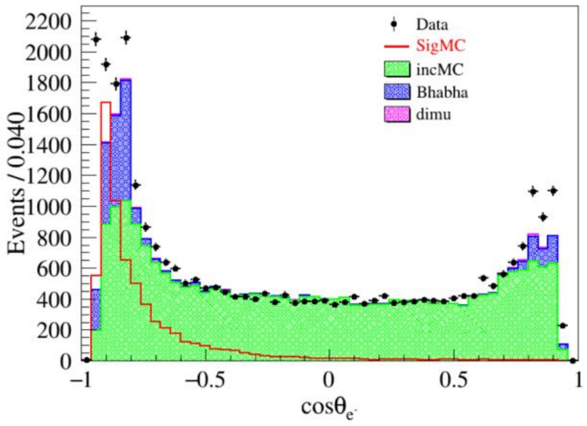
Further Event selection

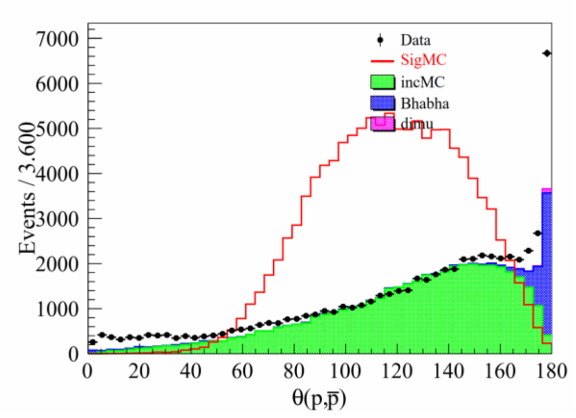
$cos\theta_{miss} * sign(e) < 0;$

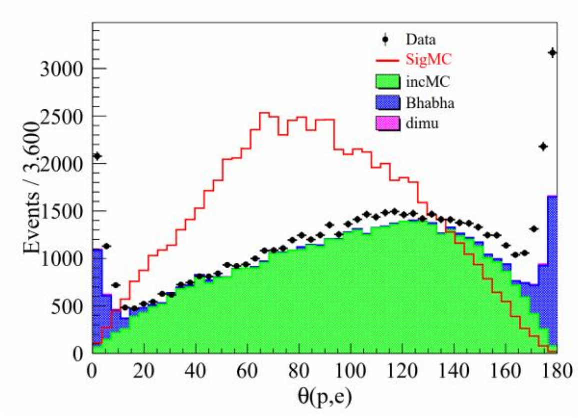


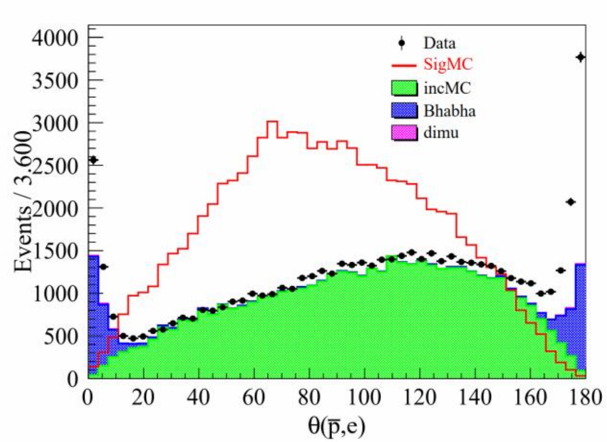










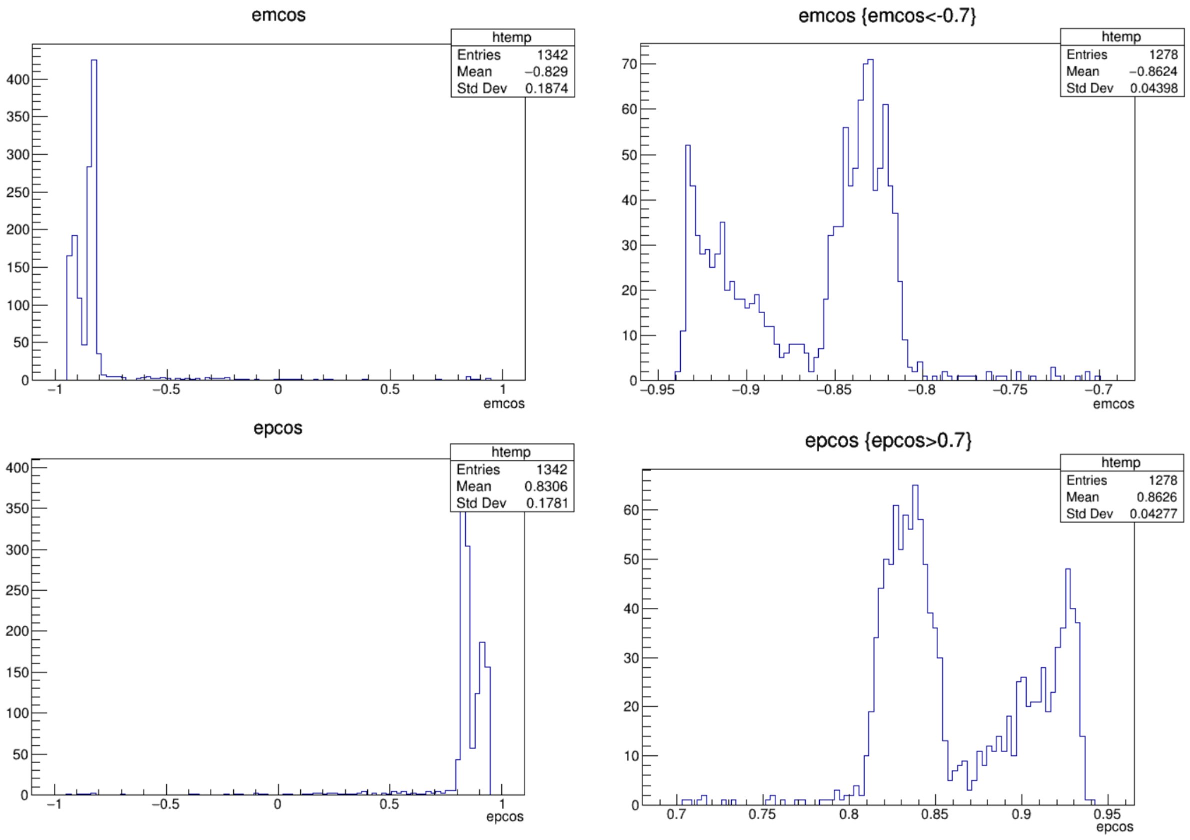


Further Event selection

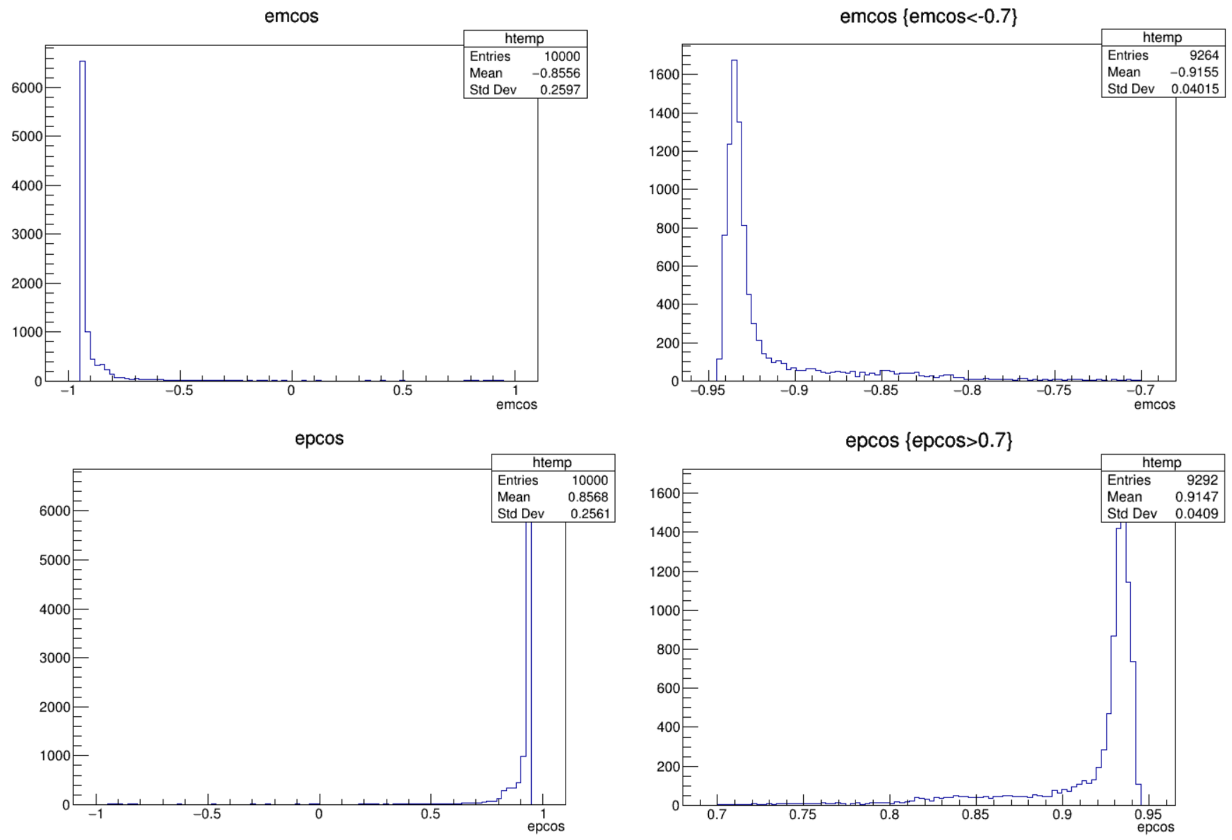
$cos\theta_{miss} * sign(e) < 0;$

为什么Bhabha MC描述不了数据：只产生了接收度范围的事例

事例挑选后Bhabha事例的Mctruth：



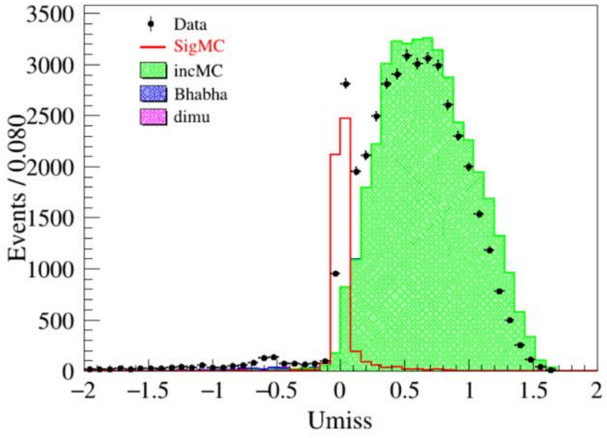
全部Bhabha事例的Mctruth：

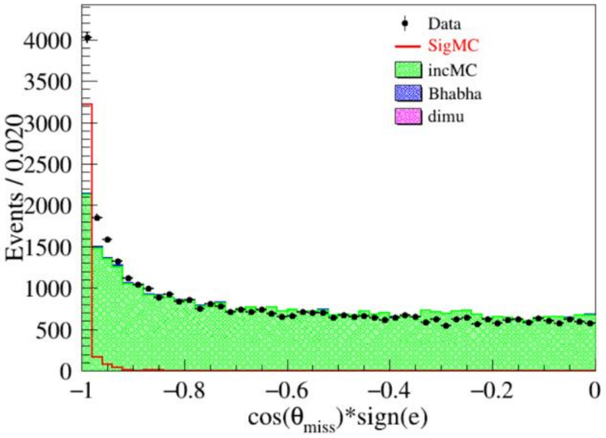


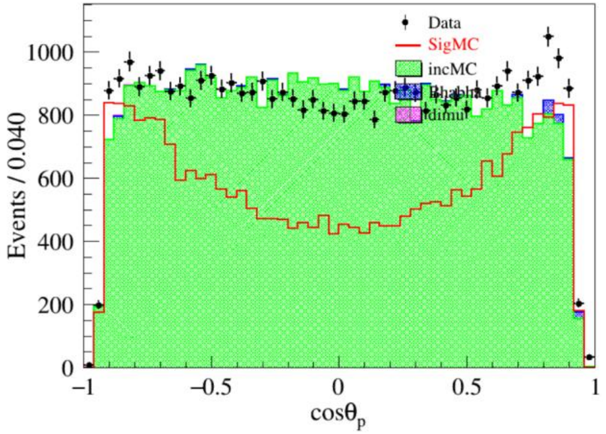
Further Event selection

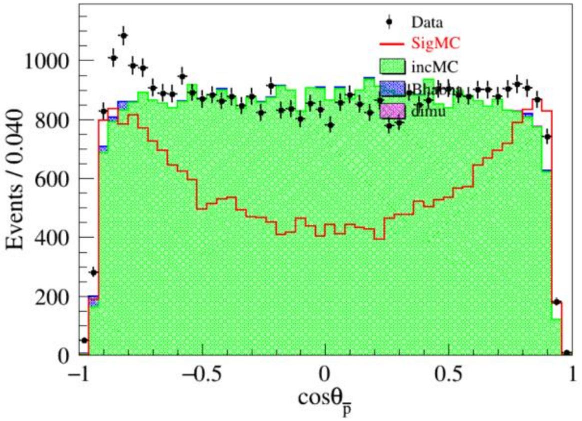
$cos\theta_{miss} * sign(e) < 0;$
$20 < \theta(p,\bar{p}) < 170;$
$10 < \theta(p/\bar{p},e) < 170;$

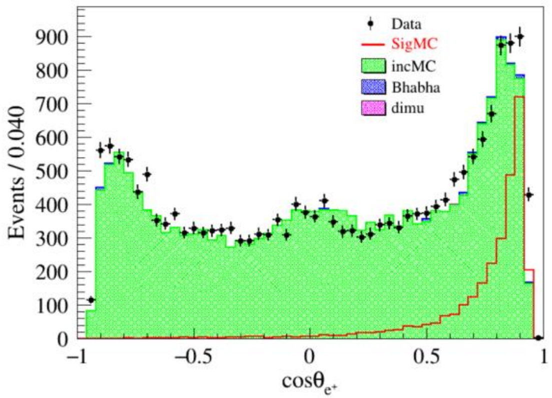
要求 $20 < \theta(p,\bar{p}) < 170$, $10 < \theta(p/\bar{p},e) < 170$

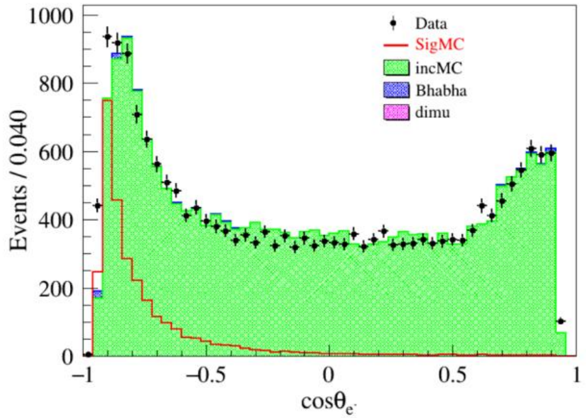












Further Event selection

$$cos\theta_{miss} * sign(e) < -0.92;$$
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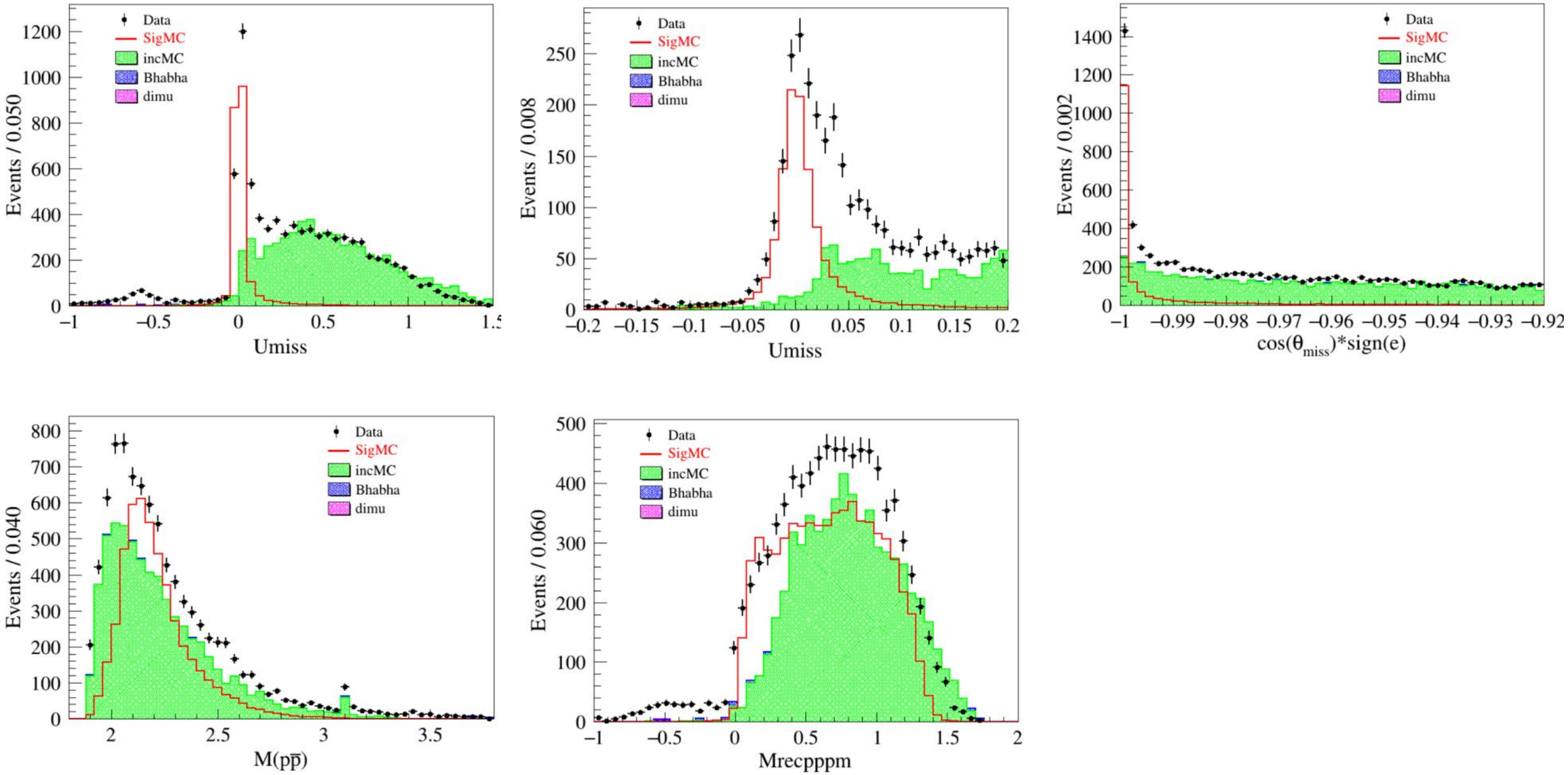

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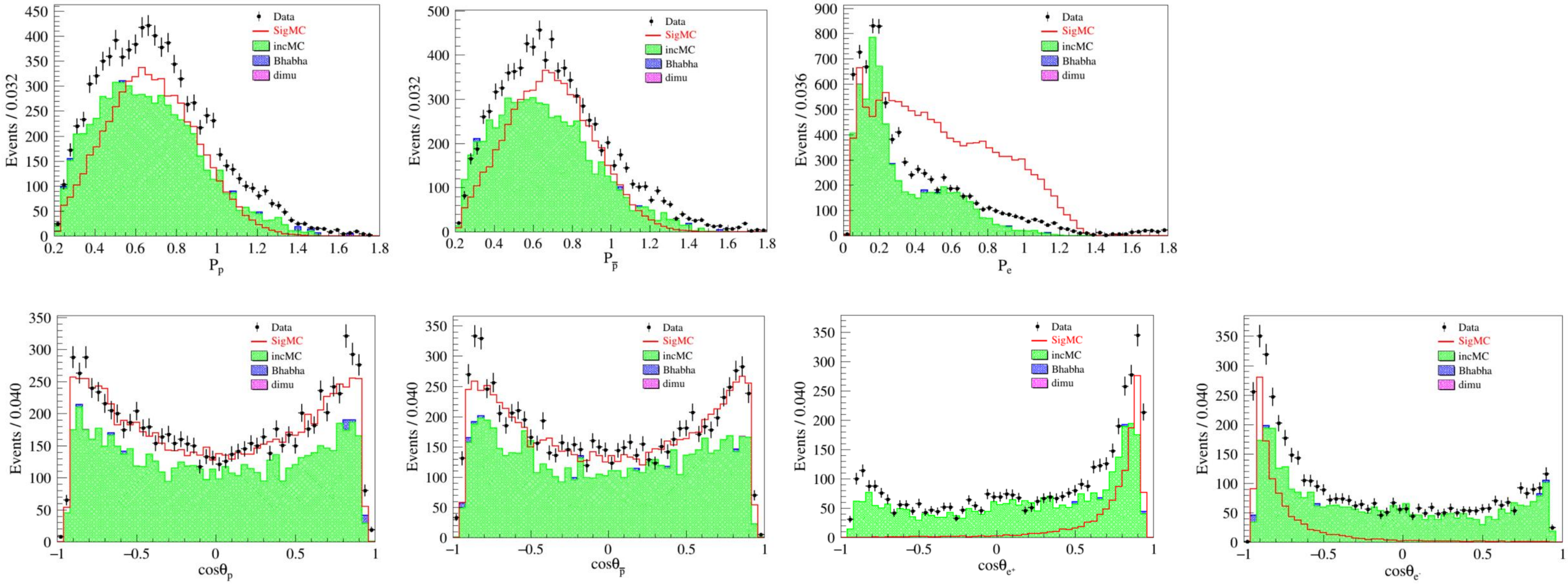

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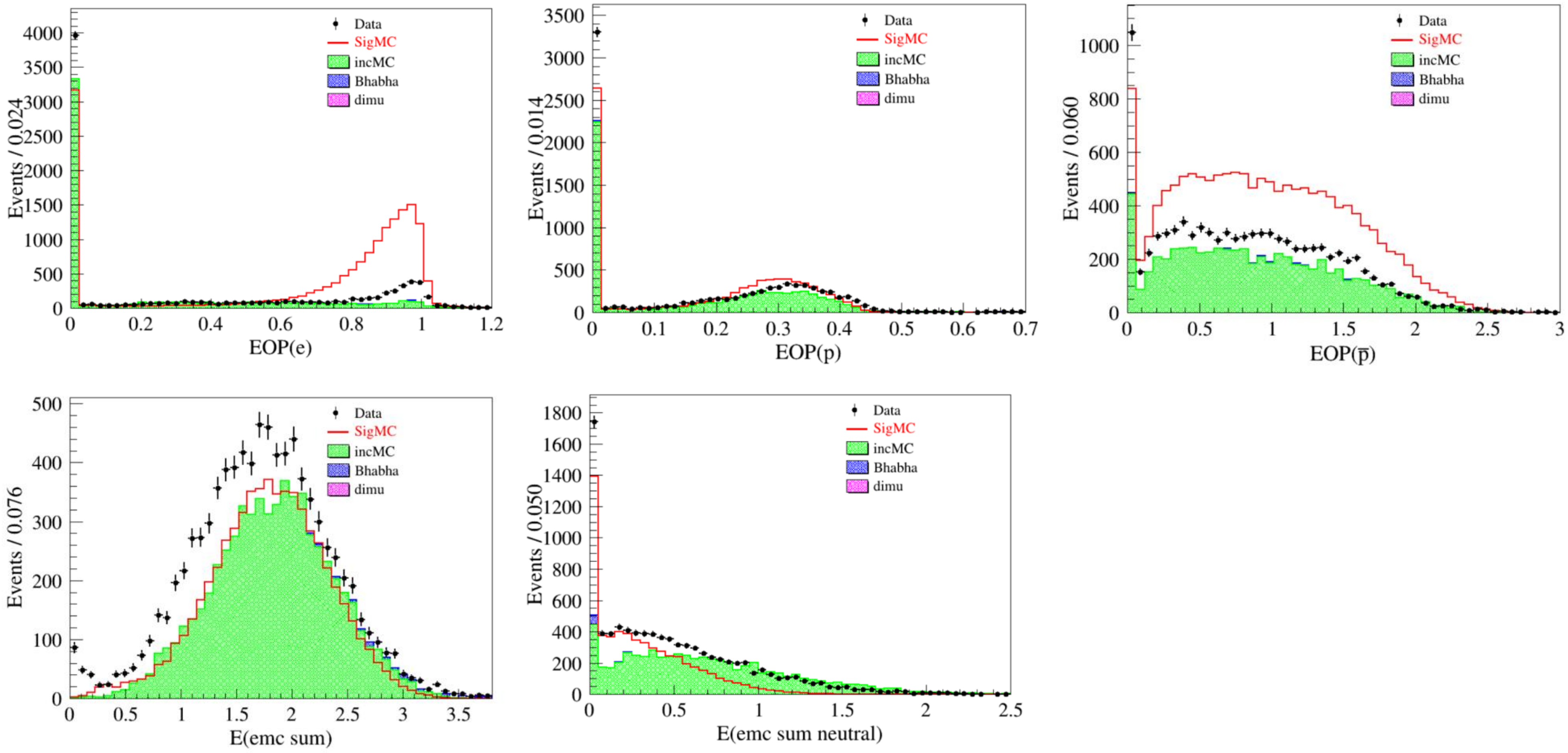

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rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$x \to K^- p\bar{\Lambda}\gamma^f, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+K^-p\bar{p}\gamma^f$	5	259	259
2	$x \to K^+\bar{p}\Lambda\gamma^f, \Lambda \to \pi^- p$	$\pi^-K^+p\bar{p}\gamma^f$	1	213	472
3	$x \to K^+K^-p\bar{p}\gamma^f$	$K^+K^-p\bar{p}\gamma^f$	3	194	666
4	$x \to \pi^+\pi^-p\bar{p}\gamma^F$	$\pi^+\pi^-p\bar{p}\gamma^F$	81	119	785
5	$x \to J/\psi\gamma, J/\psi \to \pi^+\pi^-p\bar{p}$	$\pi^+\pi^-p\bar{p}\gamma$	61	112	897
6	$x \to K^+K^-p\bar{p}$	$K^+K^-p\bar{p}$	67	87	984
7	$x \to J/\psi\gamma, J/\psi \to \pi^+p\bar{\Delta}^{--}, \bar{\Delta}^{--} \to \pi^-\bar{p}$	$\pi^+\pi^-p\bar{p}\gamma$	73	78	1062
8	$x \to p\bar{p}a_0^0\gamma^f, a_0^0 \to \pi^0\eta, \eta \to \pi^0\pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^0p\bar{p}\gamma^f$	22	76	1138
9	$x \to K^-p\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+K^-p\bar{p}$	99	68	1206
10	$x \to p\bar{p}a_0^0\gamma^f, a_0^0 \to \pi^0\eta, \eta \to \gamma\gamma$	$\pi^0p\bar{p}\gamma\gamma\gamma^f$	13	57	1263
11	$x \to K^+\bar{p}\Lambda, \Lambda \to \pi^-p$	$\pi^-K^+p\bar{p}$	23	53	1316
12	$x \to \Delta^{++}\bar{\Delta}^{--}\gamma^f, \Delta^{++} \to \pi^+p, \bar{\Delta}^{--} \to \pi^-\bar{p}$	$\pi^+\pi^-p\bar{p}\gamma^f$	59	51	1367
13	$x \to \pi^+p\bar{\Delta}^{--}\gamma^f, \bar{\Delta}^{--} \to \pi^-\bar{p}$	$\pi^+\pi^-p\bar{p}\gamma^f$	41	50	1417
14	$x \to J/\psi\gamma, J/\psi \to \pi^0\Delta^{++}\bar{\Delta}^{--}, \Delta^{++} \to \pi^+p, \bar{\Delta}^{--} \to \pi^-\bar{p}$	$\pi^0\pi^+\pi^-p\bar{p}\gamma$	71	47	1464
15	$x \to f_2(1270)p\bar{p}\gamma^f, f_2(1270) \to \pi^+\pi^-$	$\pi^+\pi^-p\bar{p}\gamma^f$	42	45	1509
16	$x \to \pi^+\pi^-p\bar{p}\gamma^f$	$\pi^+\pi^-p\bar{p}\gamma^f$	35	44	1553
17	$x \to p\bar{p}a_0^0, a_0^0 \to \pi^0\eta, \eta \to \pi^0\pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^0p\bar{p}$	40	43	1596
18	$x \to p\bar{p}a_1^0\gamma^f, a_1^0 \to \pi^-\rho^+, \rho^+ \to \pi^0\pi^+$	$\pi^0\pi^+\pi^-p\bar{p}\gamma^f$	90	41	1637
19	$x \to \Delta^{++}\bar{\Delta}^{--}, \Delta^{++} \to \pi^+p, \bar{\Delta}^{--} \to \pi^-\bar{p}$	$\pi^+\pi^-p\bar{p}$	198	41	1678
20	$x \to J/\psi\gamma, J/\psi \to \pi^0\Delta^+\bar{\Delta}^-, \Delta^+ \to \pi^0p, \bar{\Delta}^- \to \pi^0\bar{p}$	$\pi^0\pi^0\pi^0p\bar{p}\gamma$	14	40	1718
......					
1727	$x \to \psi'\gamma, \psi' \to \pi^0\pi^0J/\psi, J/\psi \to \Xi^-\bar{\Xi}^{*+}, \Xi^- \to \pi^-\Lambda, \bar{\Xi}^{*+} \to \pi^+\bar{\Xi}^0,$ $\Lambda \to \pi^-p, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma$	1726	1	6225

Further Event selection

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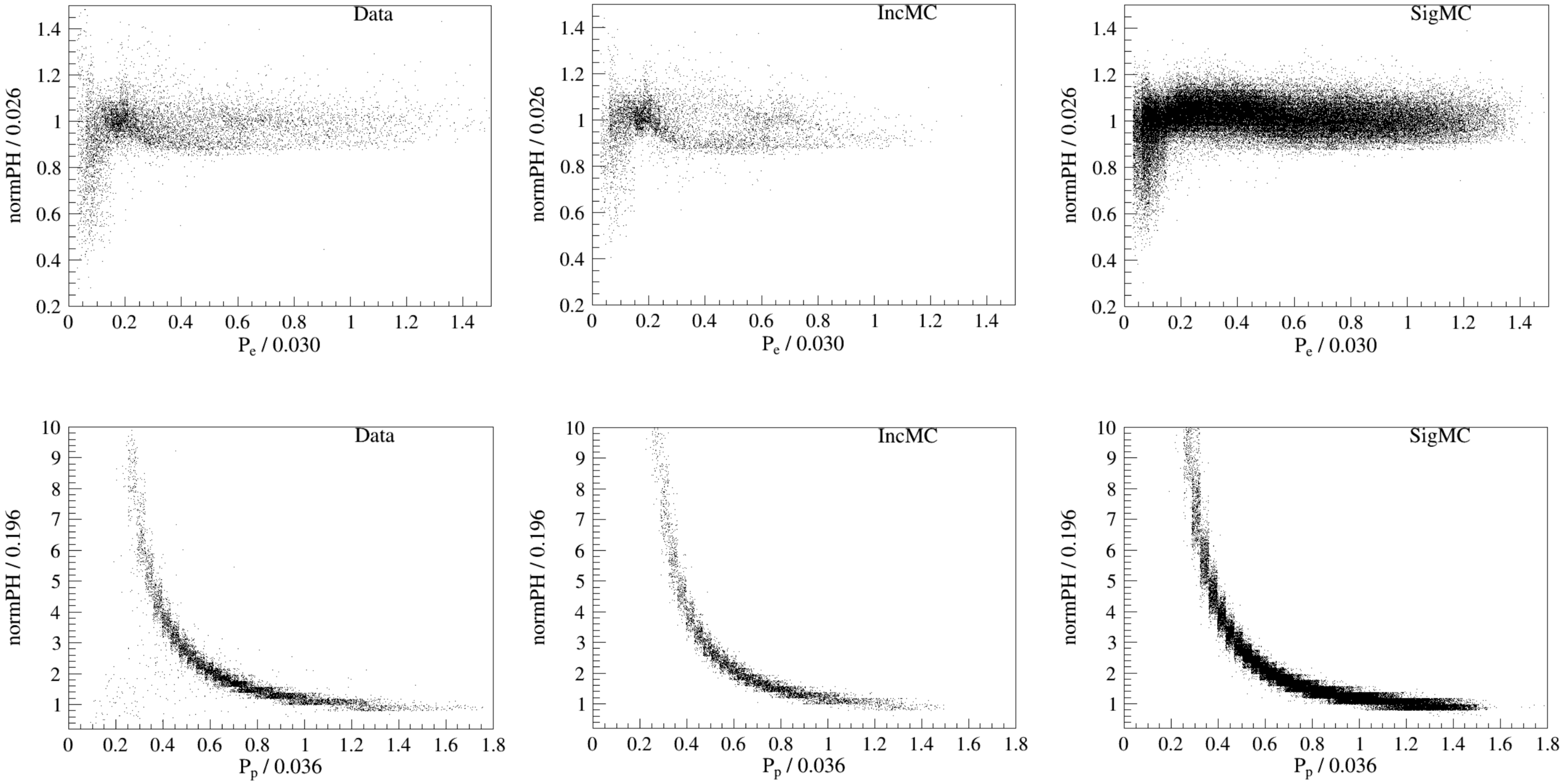

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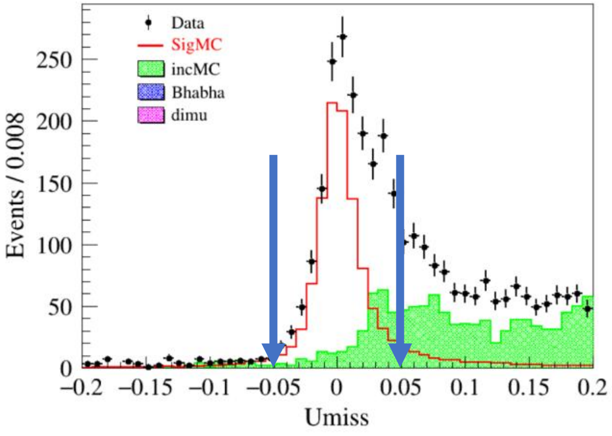
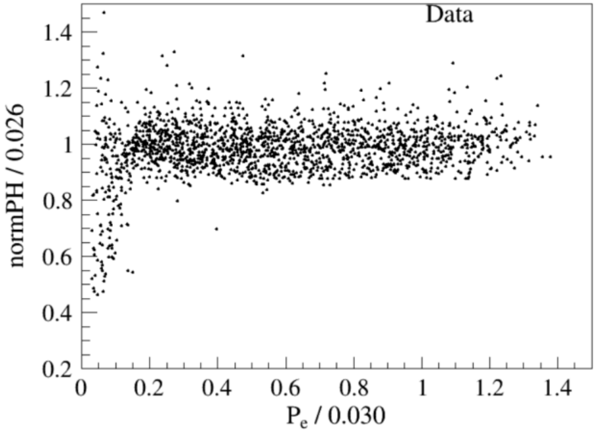
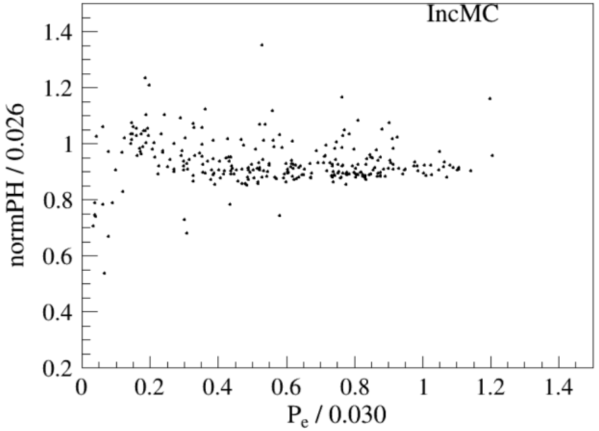
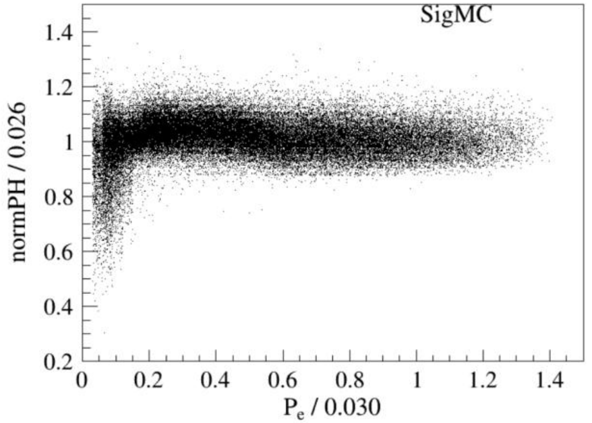
$$20 < \theta(p, \bar{p}) < 170;$$
$$10 < \theta(p/\bar{p}, e) < 170;$$



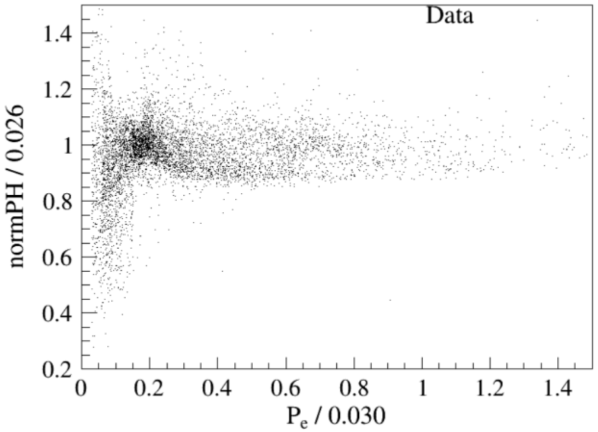
$-0.05 < Umiss < 0.05$

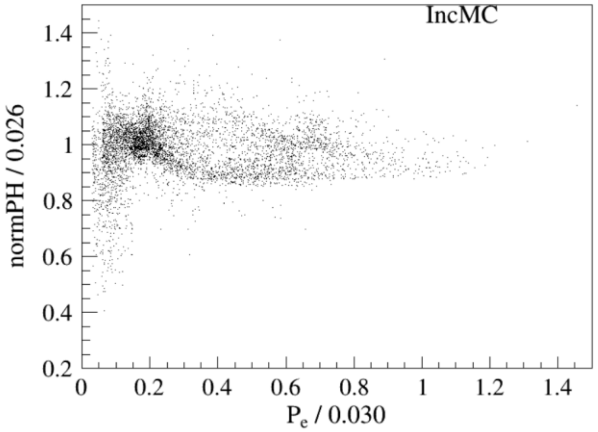


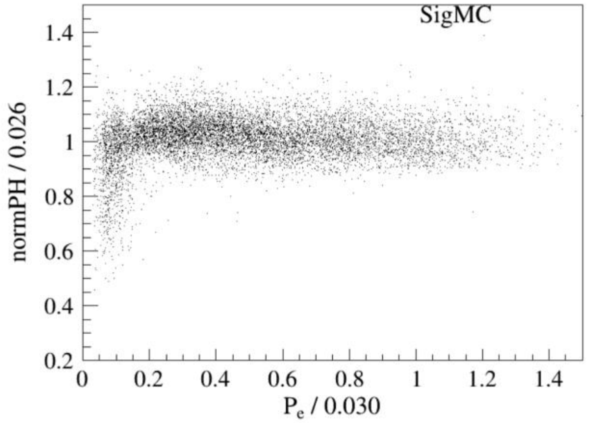




other



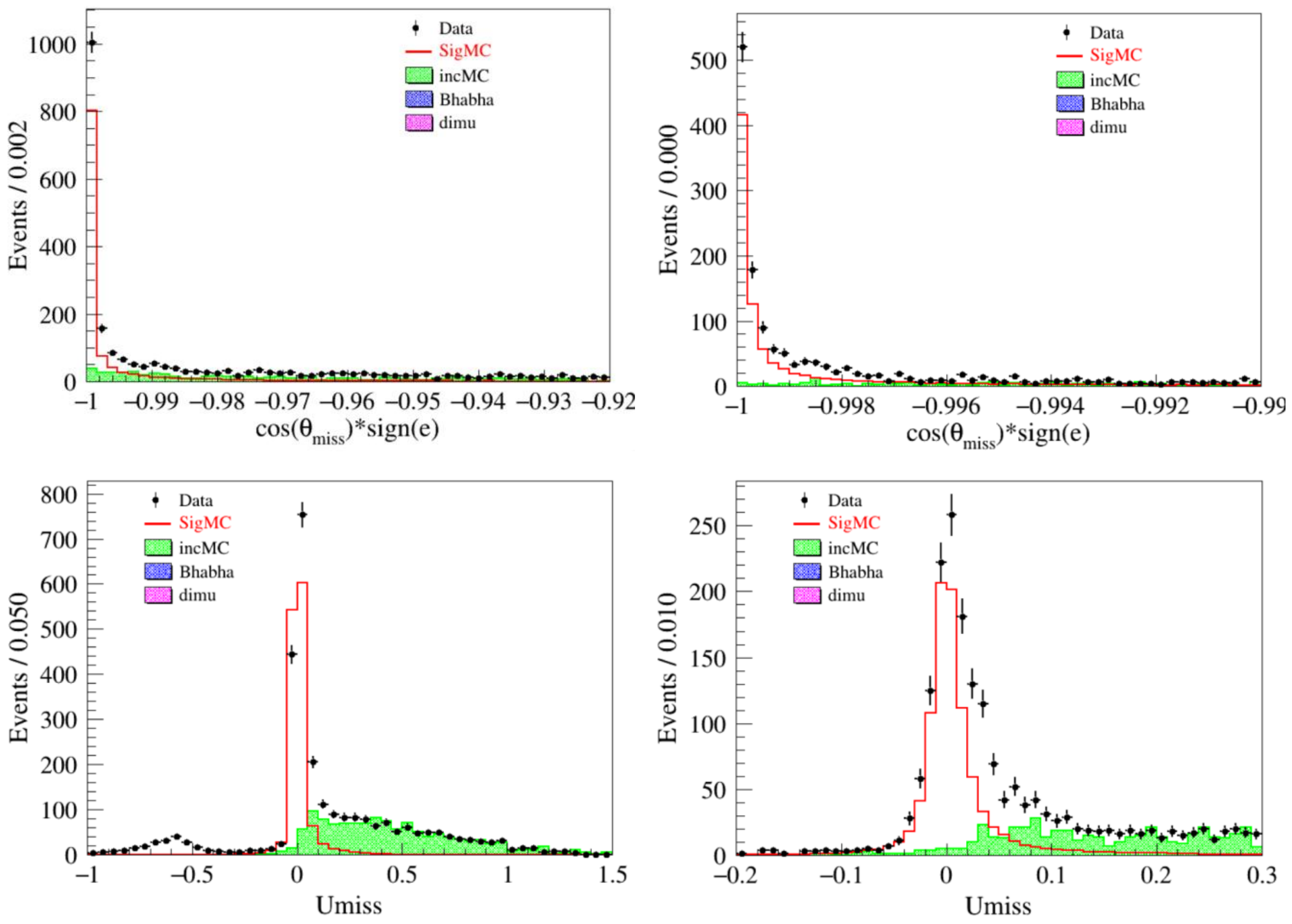




Further Event selection

$$cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p,\bar{p}) < 170;$$
$$10 < \theta(p/\bar{p},e) < 170;$$
$$-0.1 < Umiss < 0.1$$

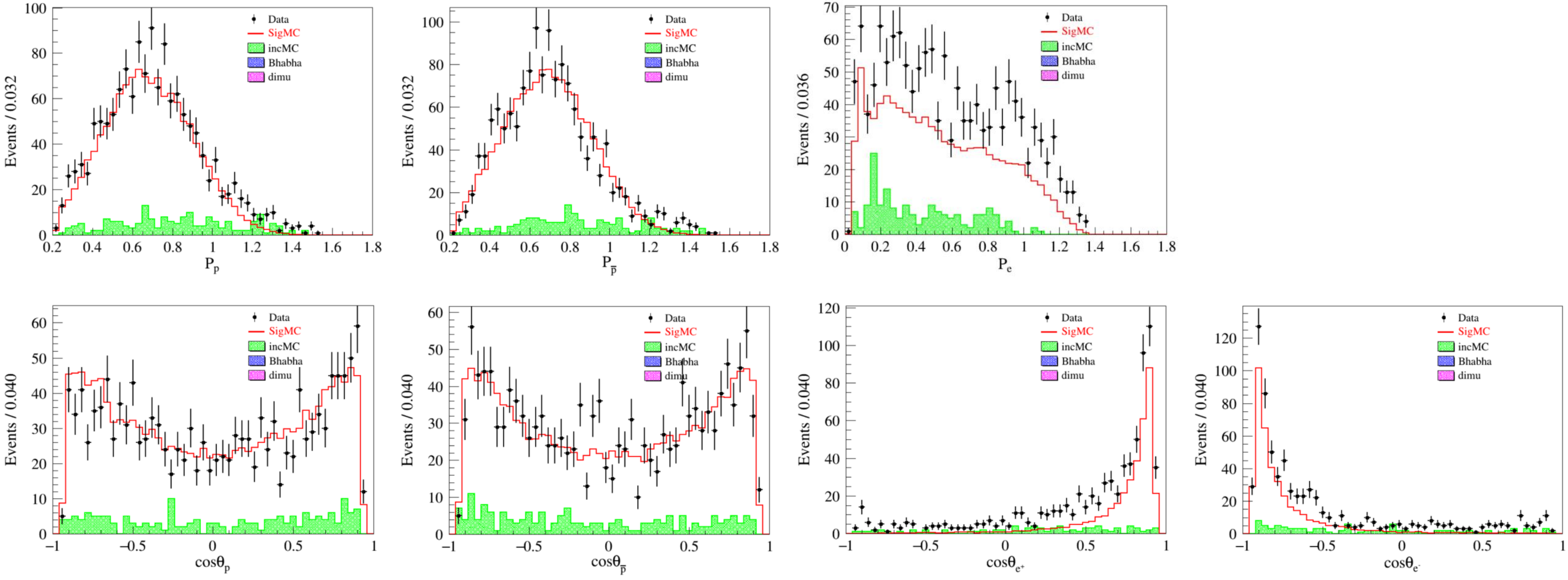
要求 $cos\theta_{miss} * sign(e) < -0.99$, $-0.1 < Umiss < 0.1$



剩余的事例数：1434
MC估计本底率：13%

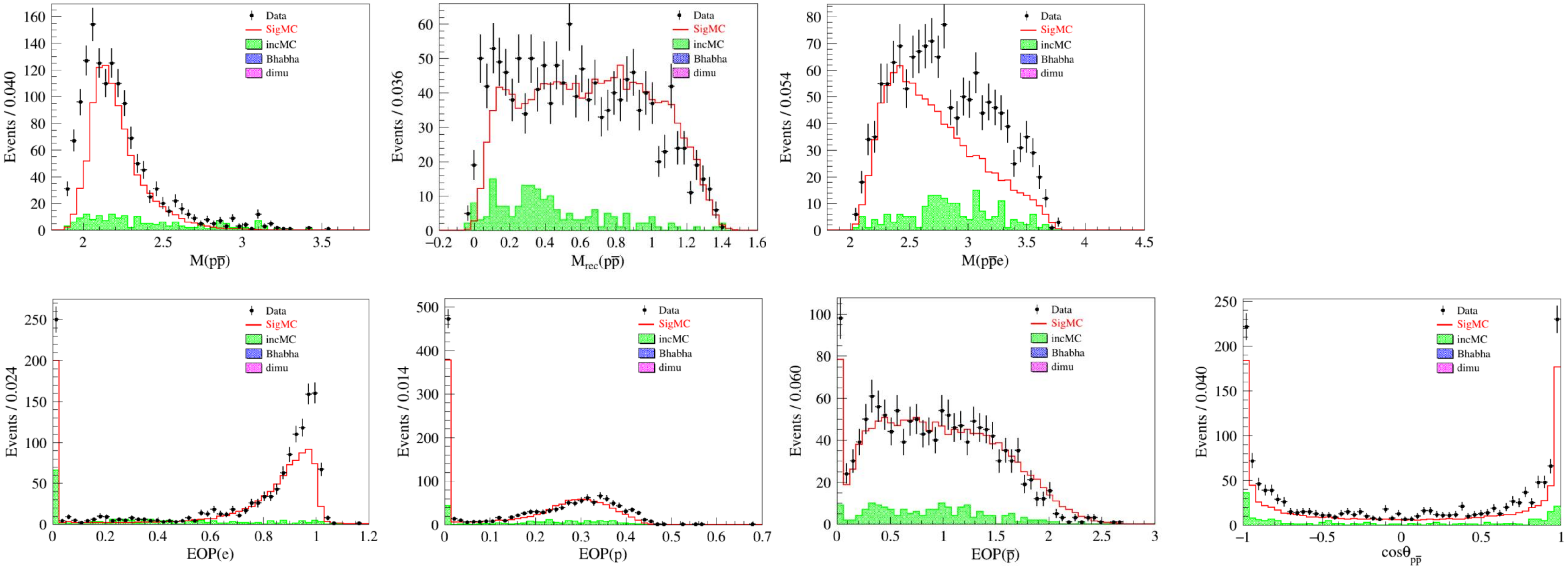
Further Event selection

$$cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p, \bar{p}) < 170;$$
$$10 < \theta(p/\bar{p}, e) < 170;$$
$$-0.1 < Umiss < 0.1$$



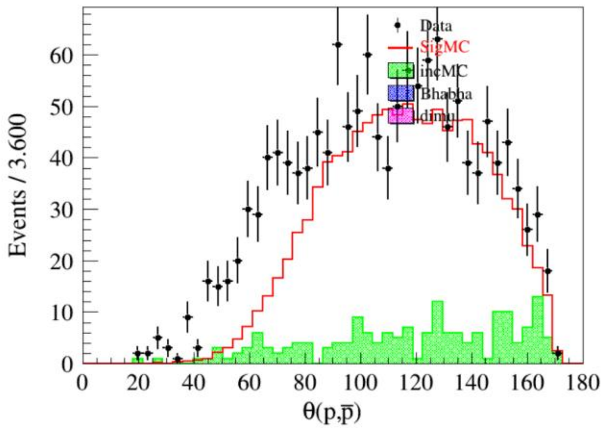
Further Event selection

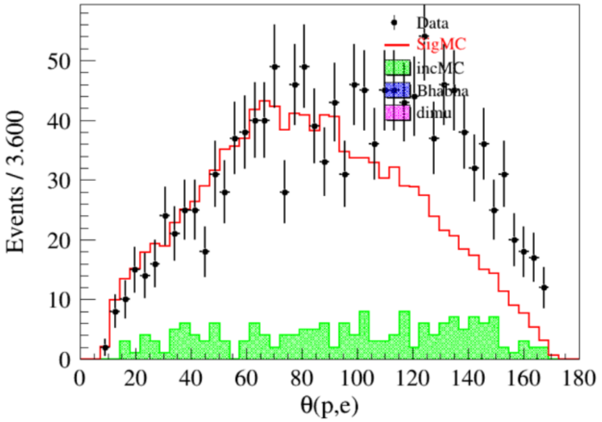
$$\cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p,\bar{p}) < 170;$$
$$10 < \theta(p/\bar{p},e) < 170;$$
$$-0.1 < Umiss < 0.1$$

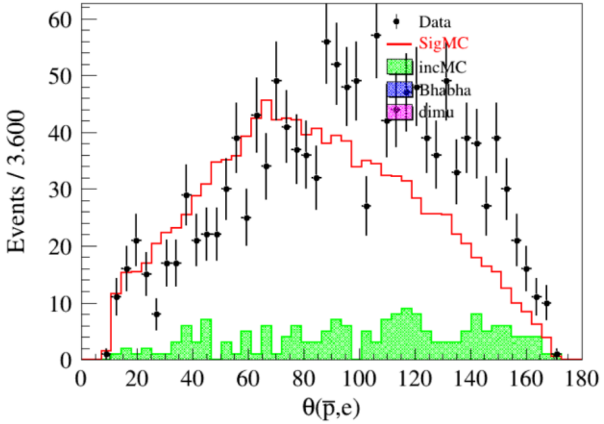


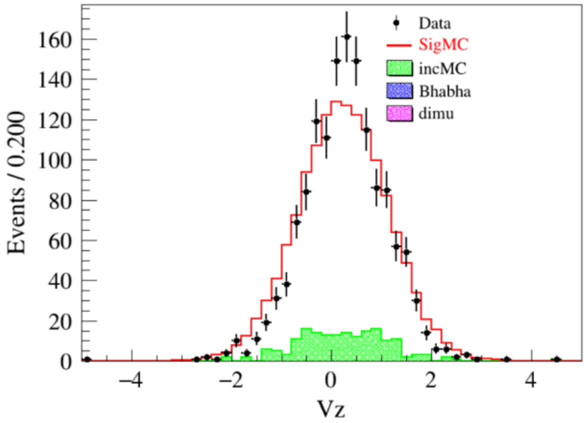
Further Event selection

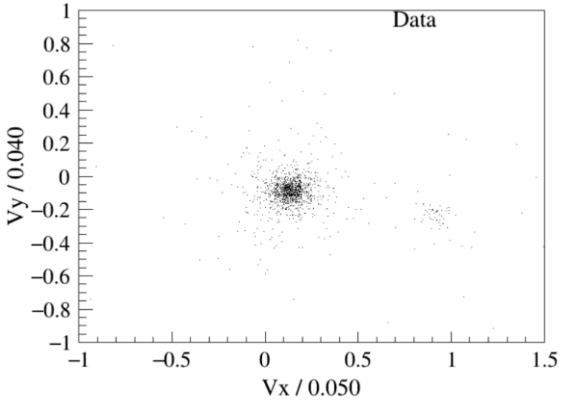
$$cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p,\bar{p}) < 170;$$
$$10 < \theta(p/\bar{p},e) < 170;$$
$$-0.1 < Umiss < 0.1$$





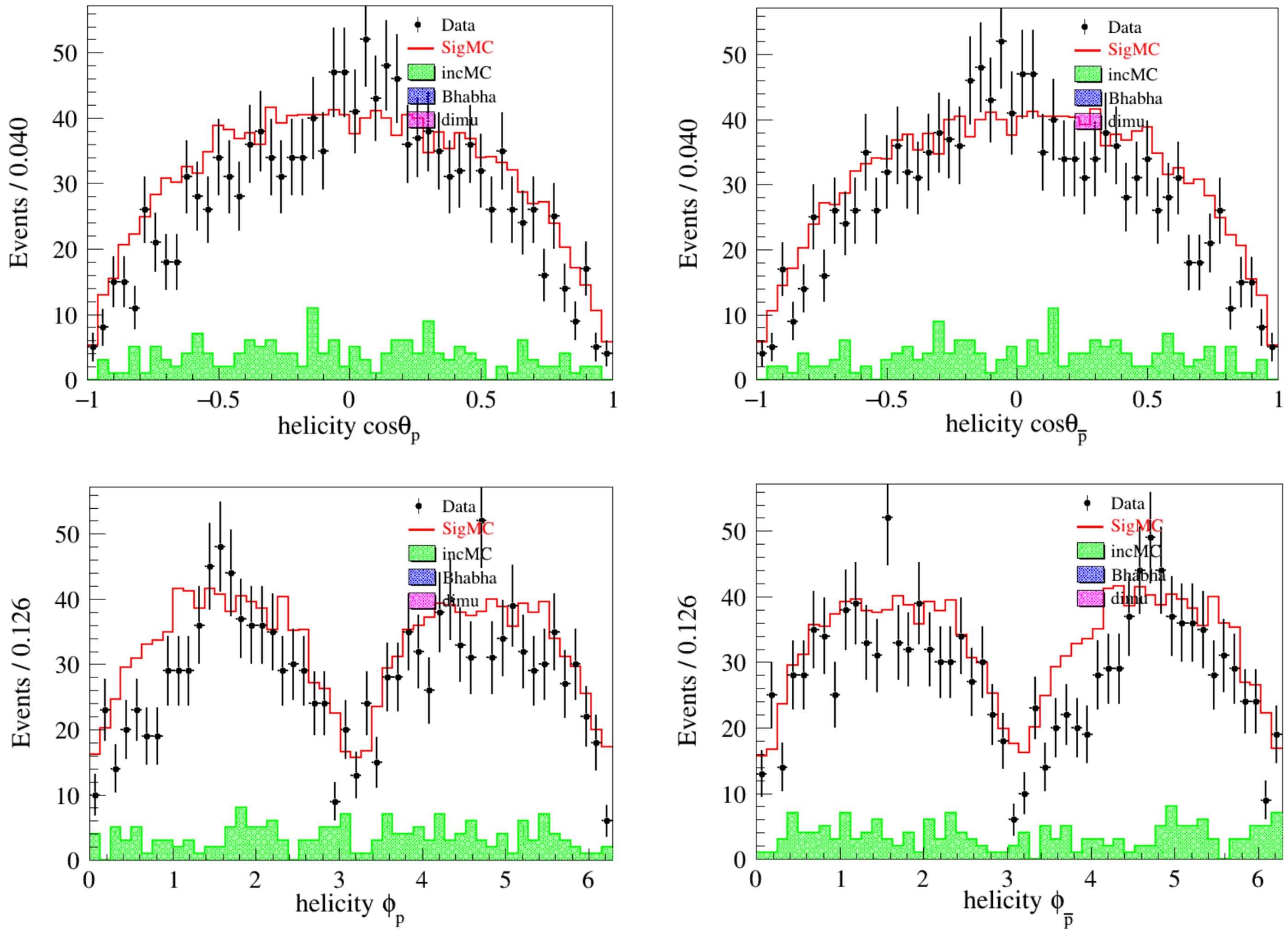






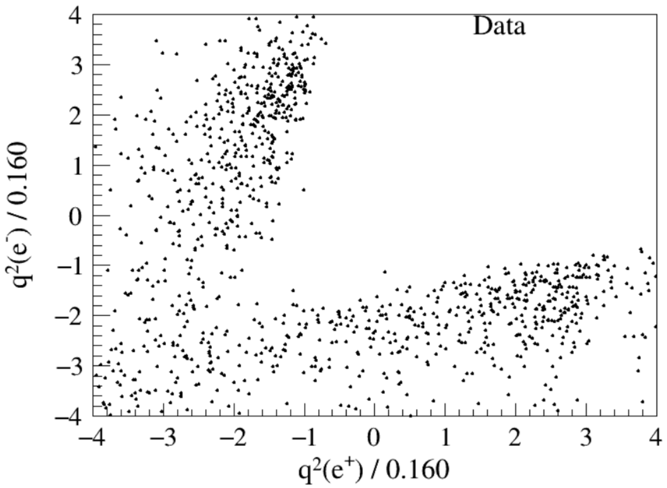
Further Event selection

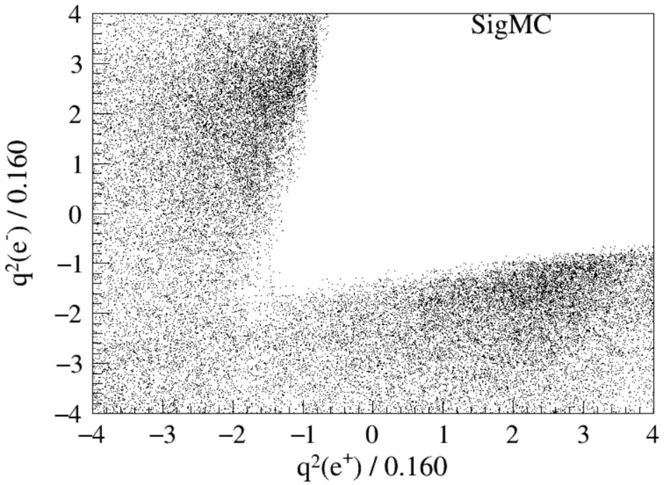
$$cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p,\bar{p}) < 170;$$
$$10 < \theta(p/\bar{p},e) < 170;$$
$$-0.1 < Umiss < 0.1$$



Further Event selection

$$cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p, \bar{p}) < 170;$$
$$10 < \theta(p/\bar{p}, e) < 170;$$
$$-0.1 < Umiss < 0.1$$

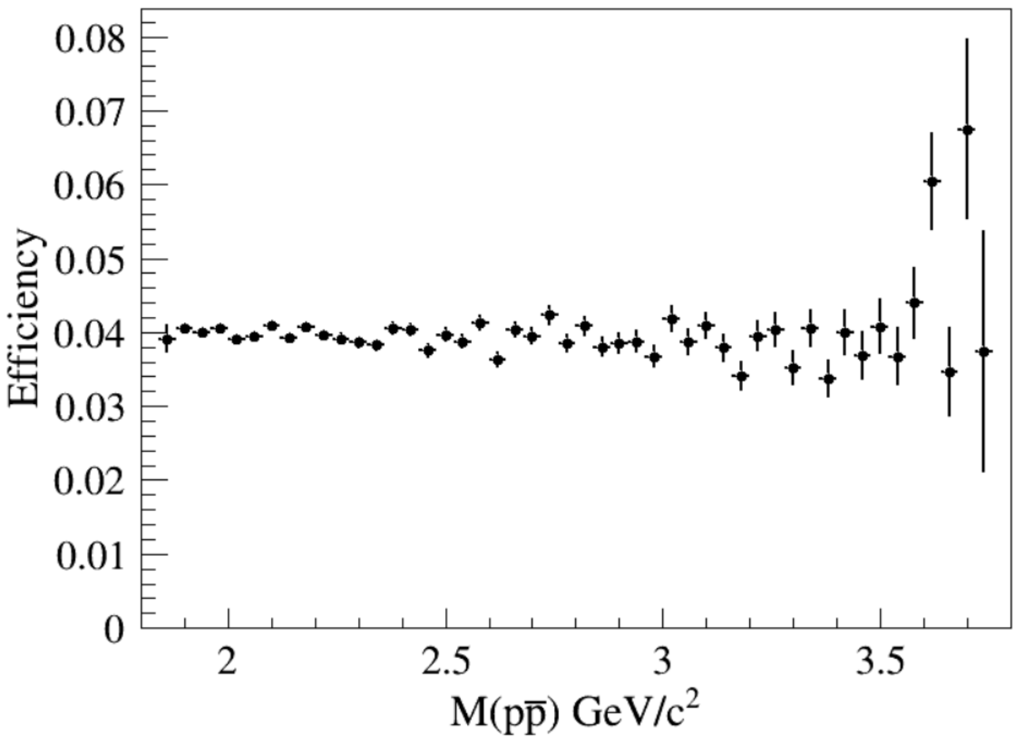




Efficiency

Cut flow 根据没有对$M_{p\bar{p}}$质量reweight的MC给出

	Event	Rel eff (%)
total	1490000	\
$\boldsymbol{N_{good} = 3}$	113512	7.6
Pass PID	88803	78.2
Pass Vtxfit	88391	99.5
$\boldsymbol{cos\theta_{miss} * sign(e) < -0.99}$	69708	78.8
$\boldsymbol{20 < \theta(p,\bar{p}) < 170}$ $\boldsymbol{10 < \theta(p/\bar{p},e) < 170}$	62036	89.0
$\boldsymbol{-0.1 < Umiss < 0.1}$	59008	95.1
eff	3.96%	



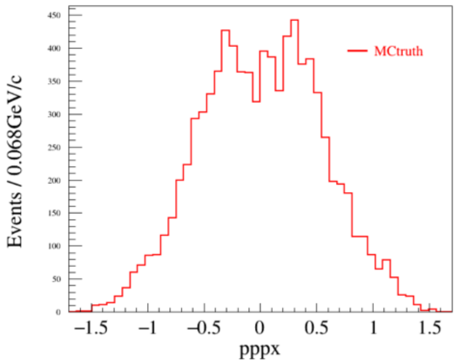
Summary

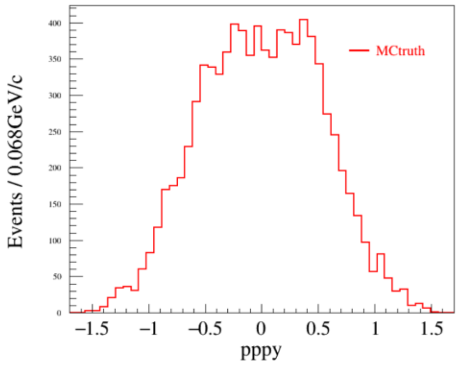
- **如何确认信号MC可靠性，之后如何调整信号MC?**
- $\boldsymbol{e,\pi}$ **PID研究。**
- **本底如何估计与描述?**

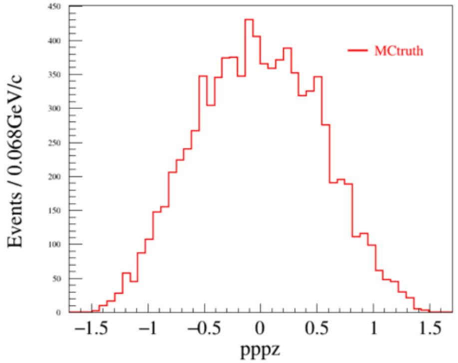
Back Up

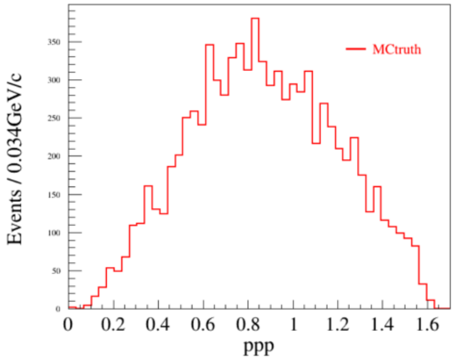
MCtruth information for single-tag acceptance

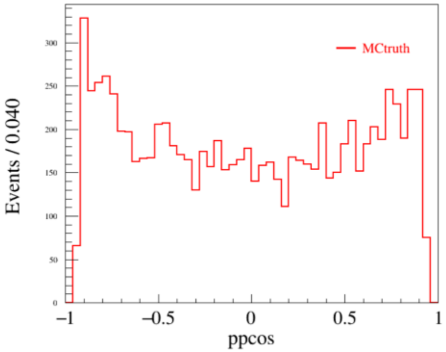
Mctruth information (before selection), Ecms = 3.773GeV, Generator: cpp_gamgam + TrackGen



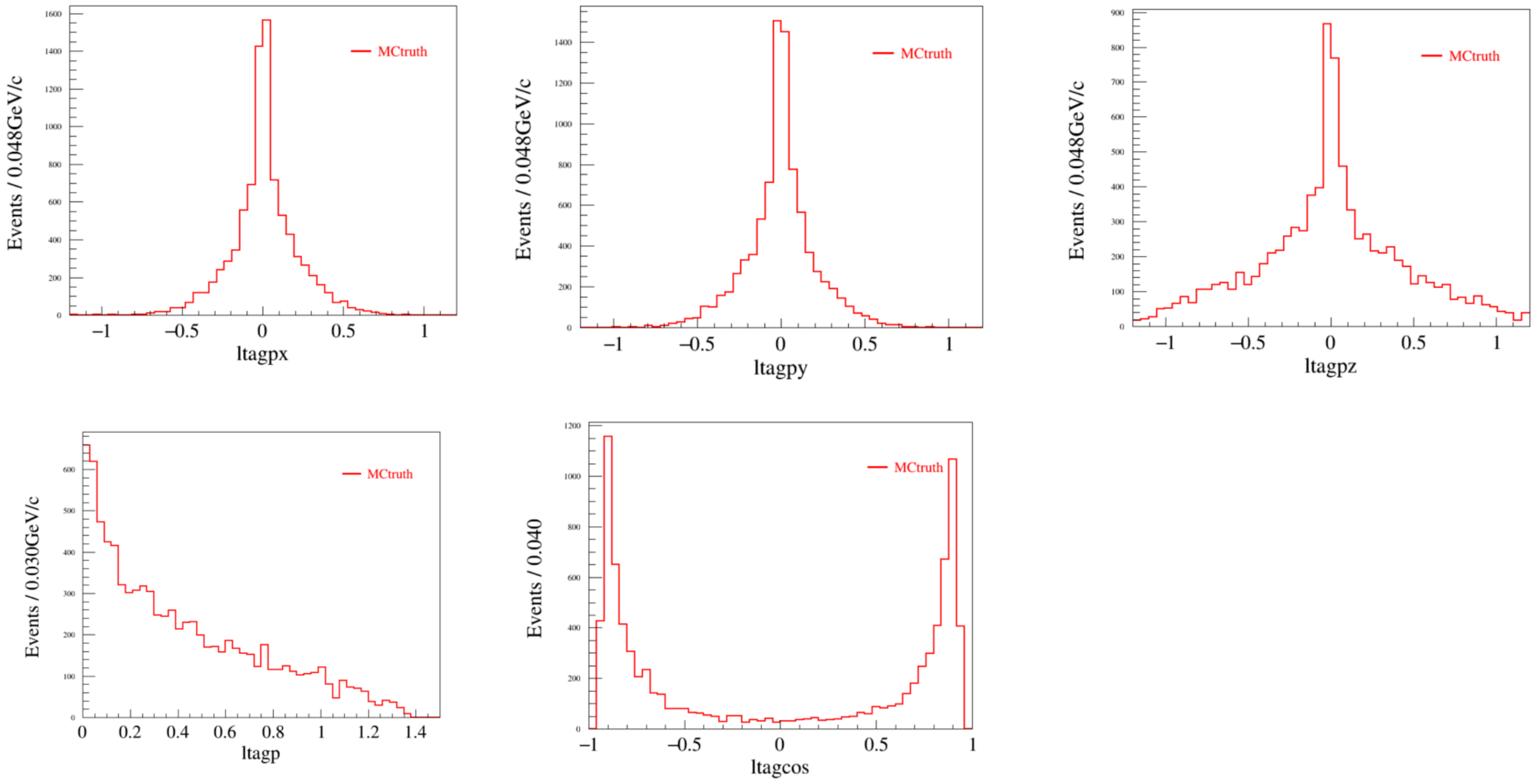








Mctruth information (no selection), Ecms = 3.773GeV, Generator: cpp_gamgam + TrackGen



Outline

- Motivation
- MC Generation
- Single-tag method
- Un-tag method
- Summary and Next to do

Motivation

- A novel theoretical prediction [1] states that a $\cos(2\phi)$ azimuthal asymmetry exists in the $\gamma\gamma \to \pi\pi$ production process, and a similar phenomenon may also occur in $\gamma\gamma \to p\bar{p}$ production.

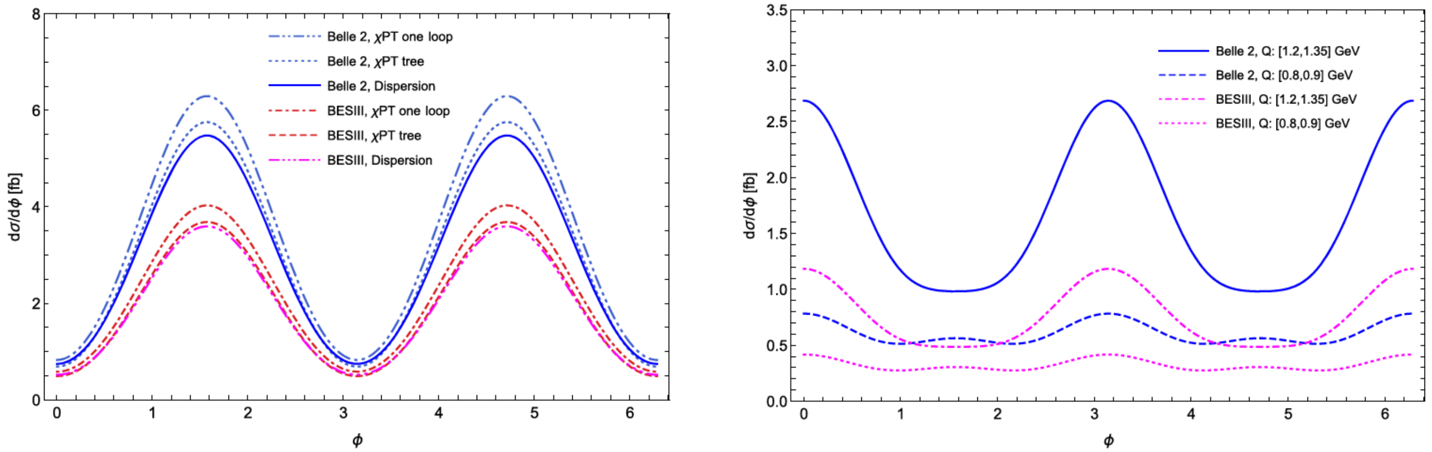


Fig. The differential cross section of $ee \to \gamma\gamma ee \to \pi\pi ee$ with respect to the azimuthal angle ϕ.

- BESIII has collected 41fb $^{-1}$ data samples in the $\sqrt{s}$ = 3.510 – 4.946 GeV.

[1] PHYSICAL REVIEW LETTERS 134, 141901 (2025)

Futher event selection

Cos(p4miss.theta())*ltagsign<-0.92;

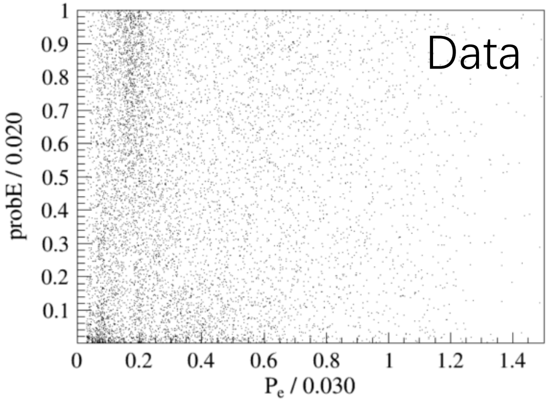
$$20 < \theta(p,\bar{p}) < 170,$$

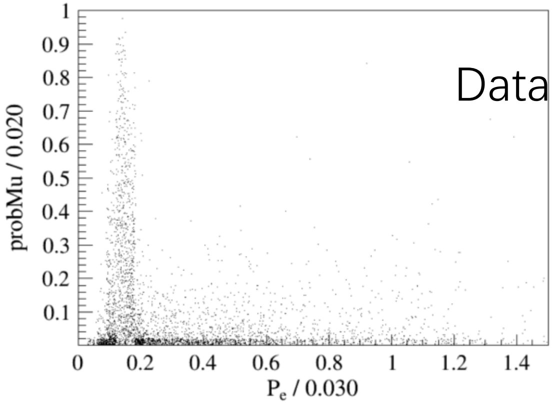
$$10 < \theta(p/\bar{p},e) < 170$$

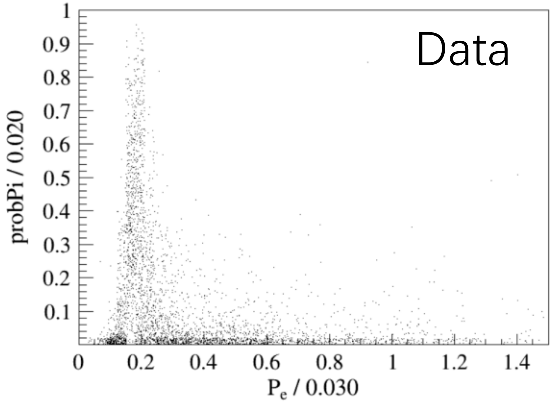
还可以尝试:

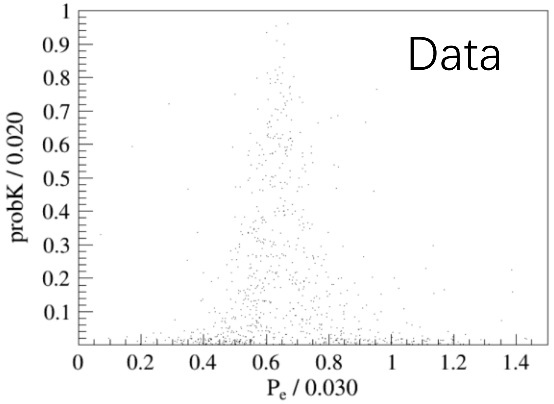
1.继续收紧miss系统的角度约束

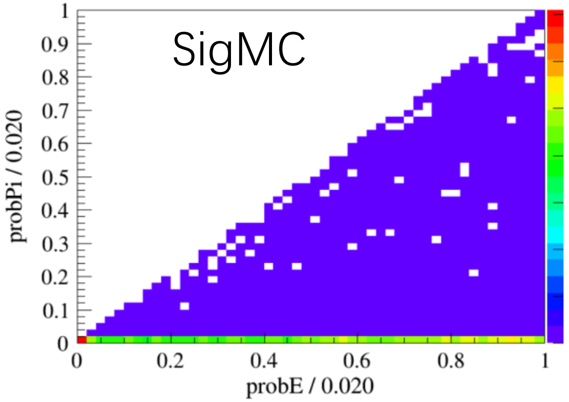
2.提升pi，e，K鉴别

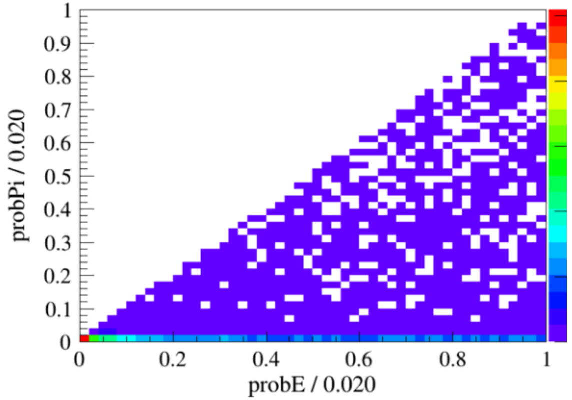


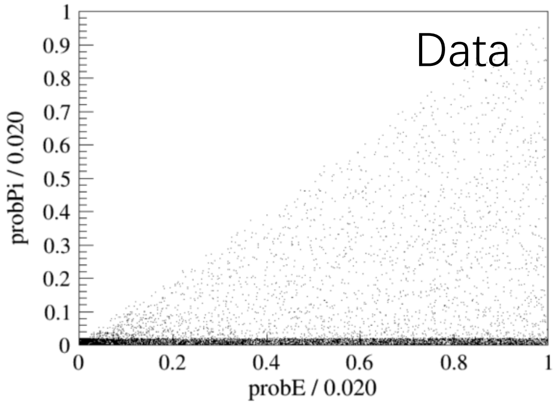


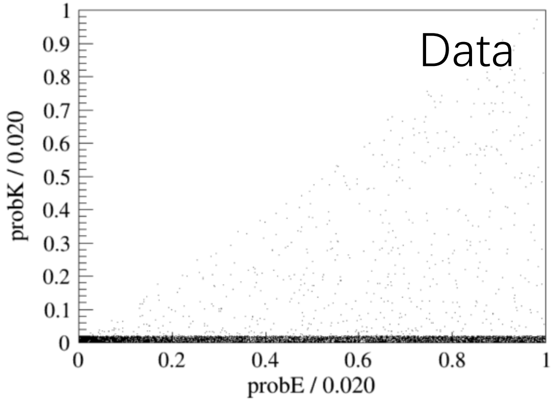






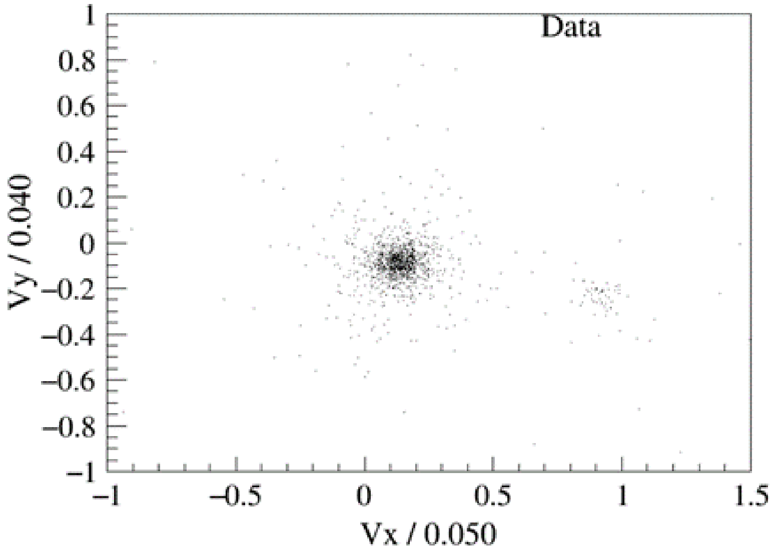




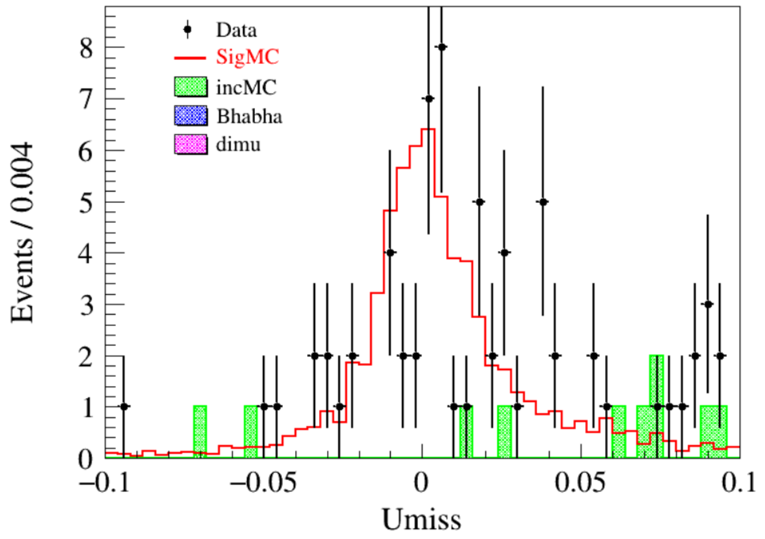


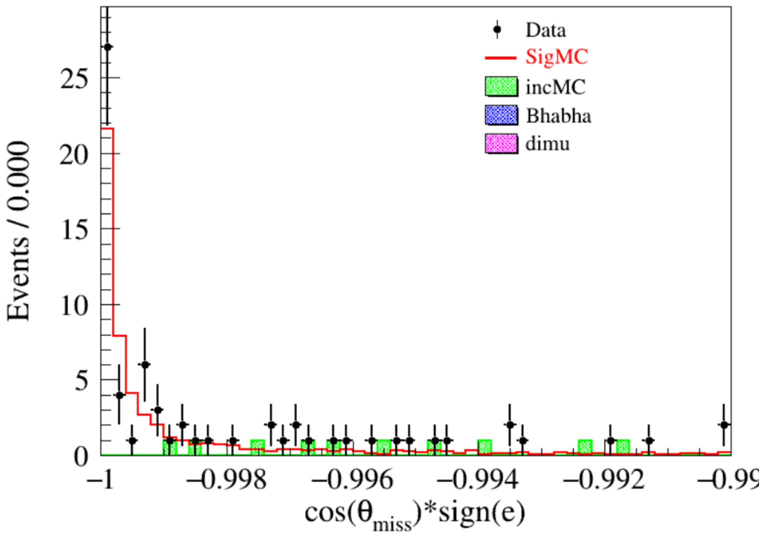
Futher event selection

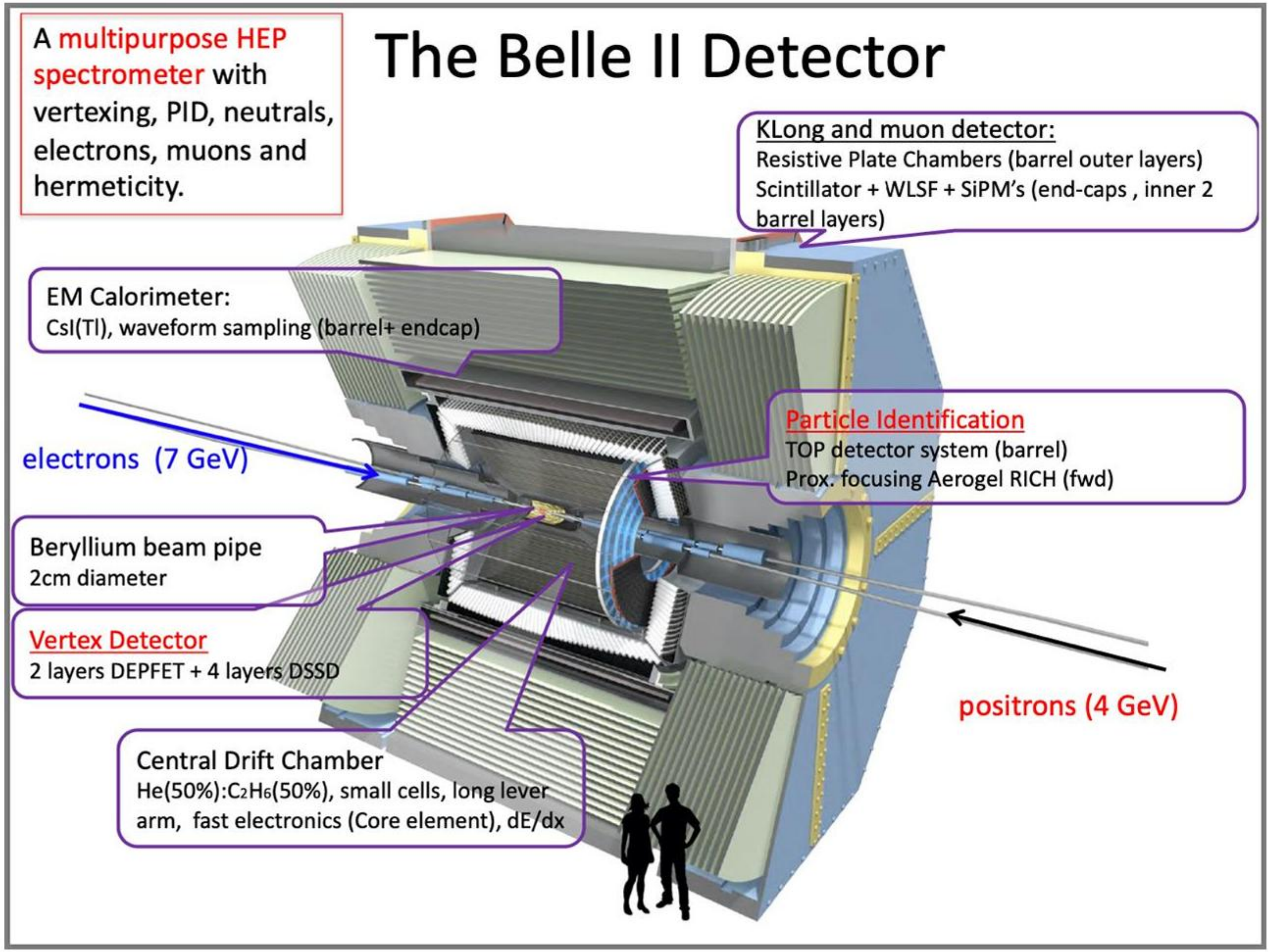
$$\cos\theta_{miss} * sign(e) < -0.99;$$
$$20 < \theta(p, \bar{p}) < 170;$$
$$10 < \theta(p/\bar{p}, e) < 170;$$
$$-0.1 < Umiss < 0.1$$



要求Vx>0.7:







接收度(角度)： **BESIII: 23~157**

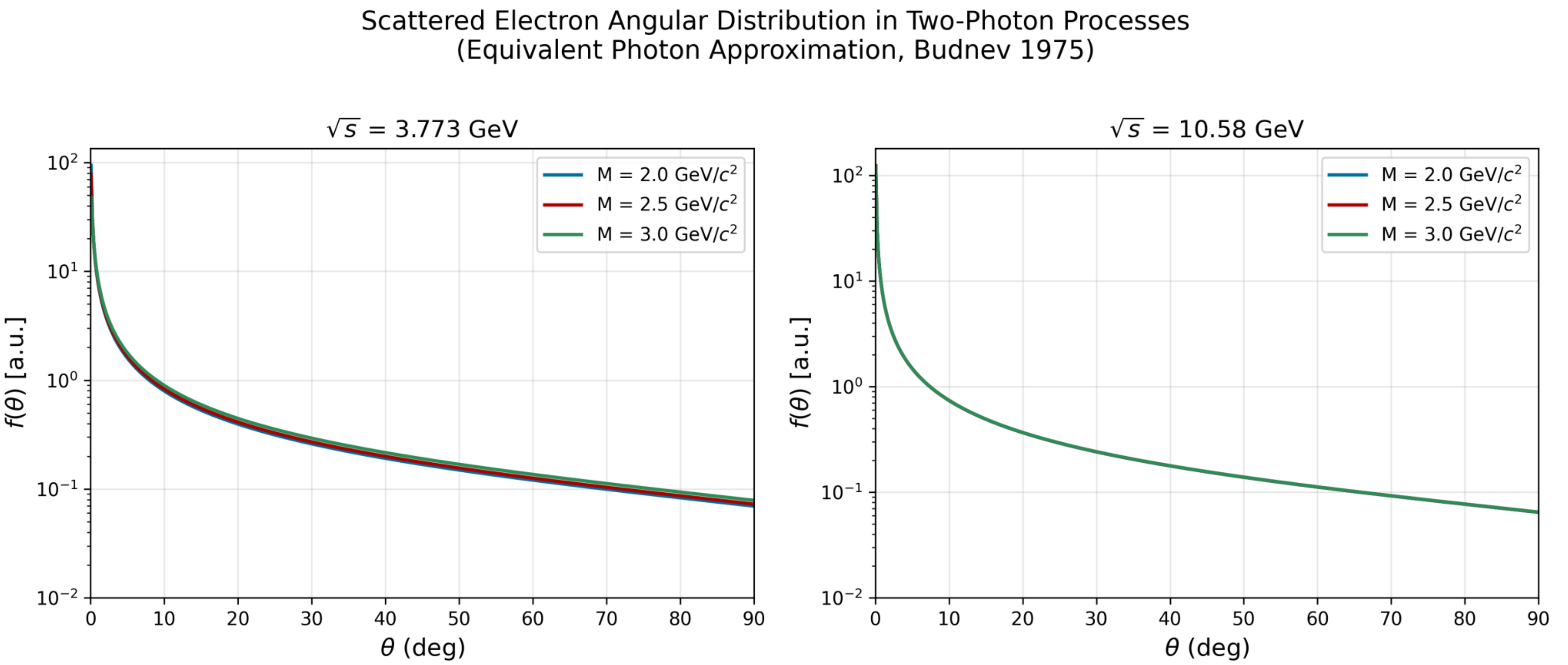
KLM: 18~155
KLM: 24~161

ECL: 12.4~31.4, 32.2~128.7, 130.7~155.1
ECL: 16.4~40.8, 41.8~140.0, 141.7~161.0

ARICH: 14~30
ARICH: 18.5~39.0
TOP: 31~128
TOP: 40~140

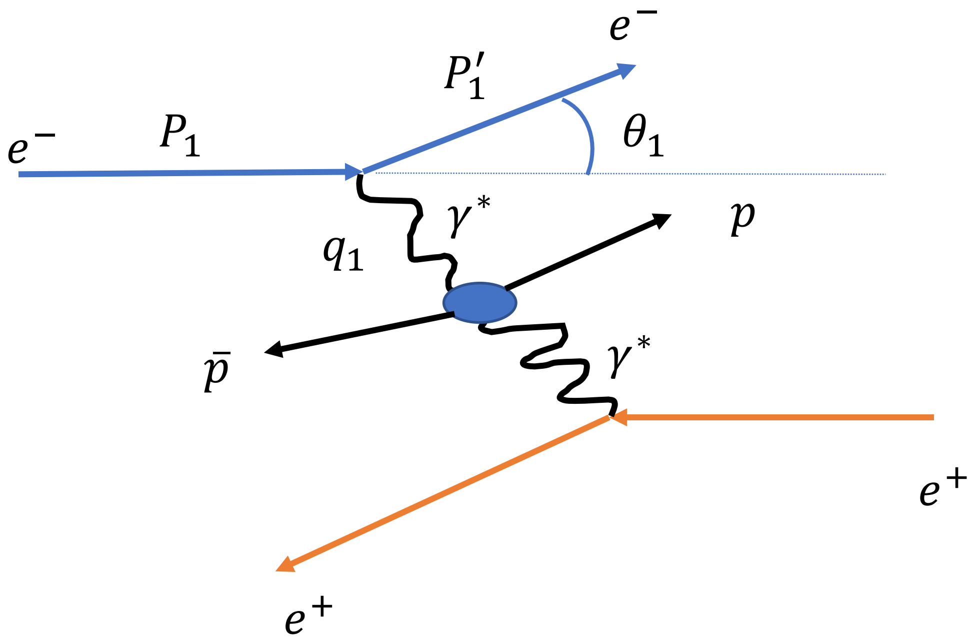
CDC: 17~150
CDC: 22~157

BELLE: 22~140 (157)



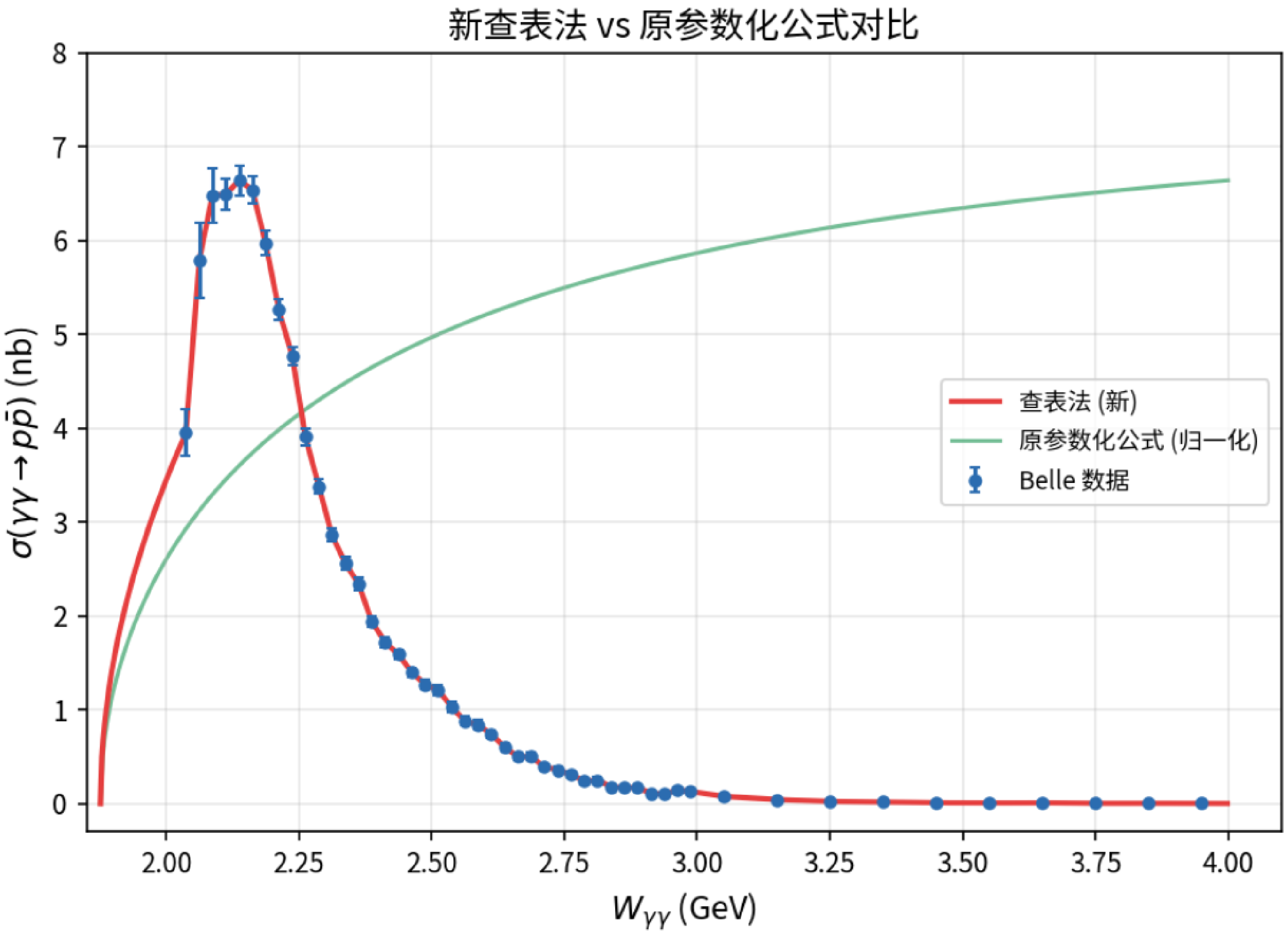
$P(cos\theta > 0.92)$:
0.84 for 2.0GeV
0.82 for 2.5GeV
0.81 for 3.0GeV

$P(cos\theta > 0.92)$:
0.88 for 2.0GeV
0.87 for 2.5GeV
0.87 for 3.0GeV



$$\mathbf{q_1} = (\mathbf{E_1} - \mathbf{E_1'}, \mathbf{P_1} - \mathbf{p_1'}),$$

$$\mathbf{q_1^2} \approx -2\mathbf{P_1}\mathbf{P_1'}(1 - \cos\theta_1) + \mathbf{m}^2\left(2 - \frac{\mathbf{P_1'}}{\mathbf{P_1}} - \frac{\mathbf{P_1}}{\mathbf{P_1'}}\right);$$



新查表法 vs 原参数化公式对比
$\sigma(\gamma\gamma \to p\bar{p})$ (nb)
$W_{\gamma\gamma}$ (GeV)
0
1
2
3
4
5
6
7
8
2.00
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
查表法 (新)
原参数化公式 (归一化)
Belle 数据