SUN YAT-SEN UNIVERSITY

超级陶粲装置 Super Tau-Charm Facility

Exotic States

$e^+e^- \to J/\psi\,\eta_c, J/\psi p\bar{p}$

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超级陶粲装置研讨会

2025.9.20

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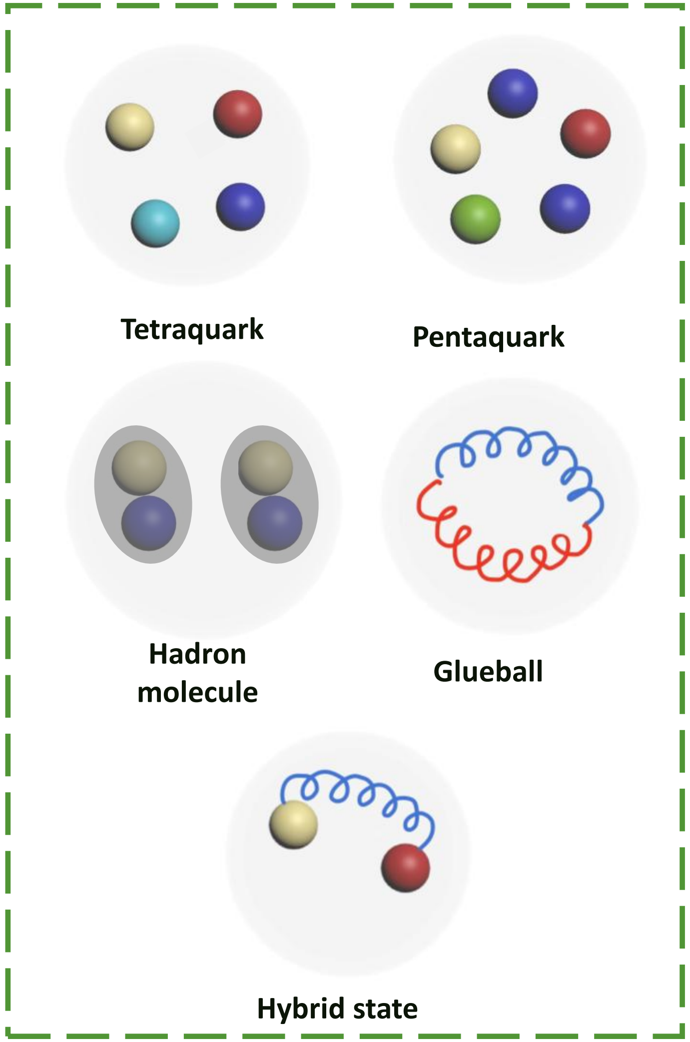
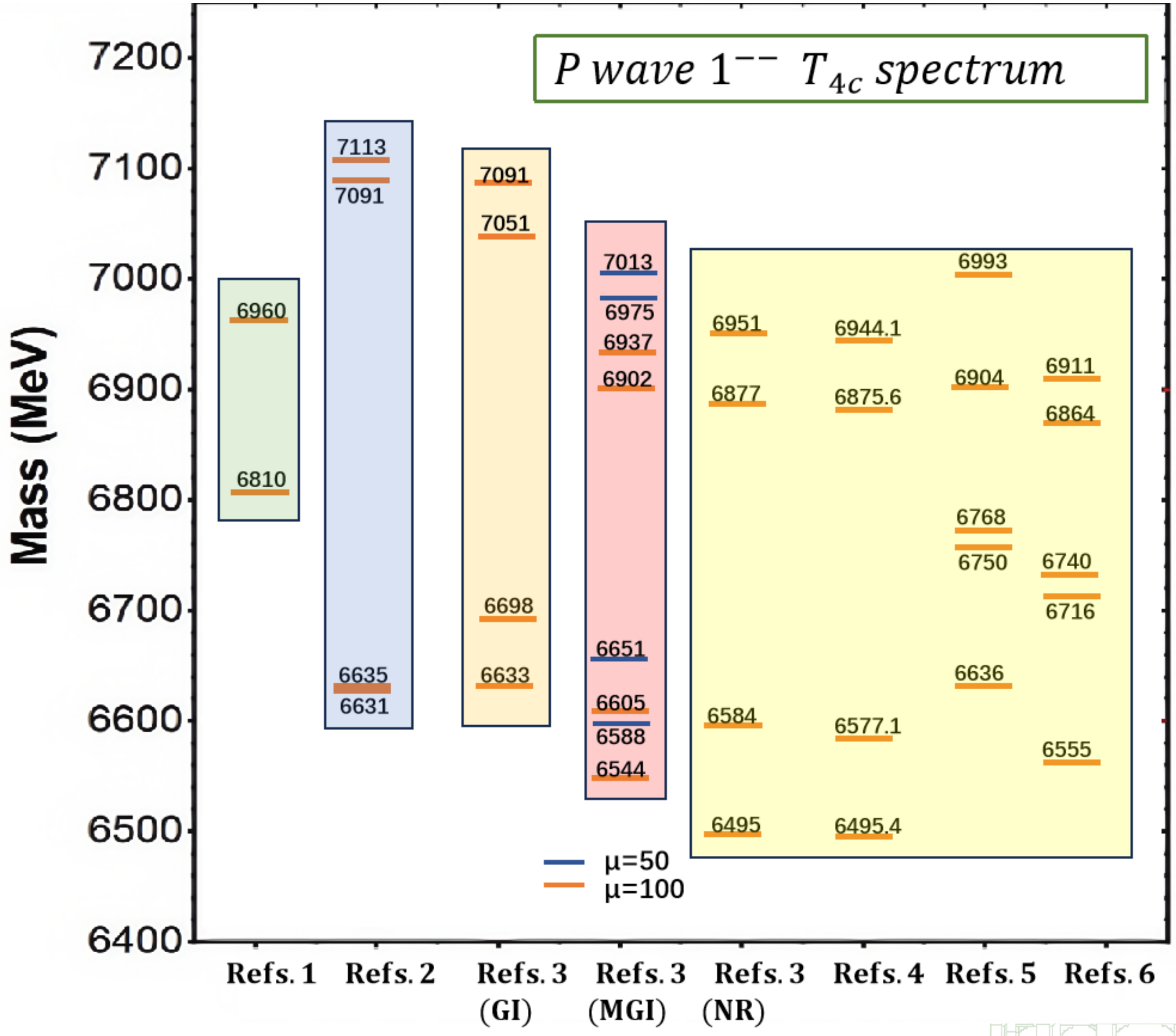
双粲偶素理论与实验现状

- **2003年以前，人们认为粲偶素是粲夸克和反粲夸克的束缚态，应该用非相对论的势能夸克模型来描述。然而，自2003年Belle发现X(3872)以来，通过各种实验包括BESIII、BaBar、Belle、CDF、DO、ATLAS、CMS 和 LHCb，在粲偶素质量区观测到大量新的共振态结构，这些共振态称为奇特态，即XYZ粒子。**
- 奇特强子态包括强子分子态、四夸克态、五夸克态以及混杂态等。
- 双粲偶素也称全粲四夸克态，夸克组成为$\bar{c}\bar{c}cc$。



双粲偶素理论与实验现状

➢ **目前与全粲四夸克态相关的五个理论模型理论研究调研结果**

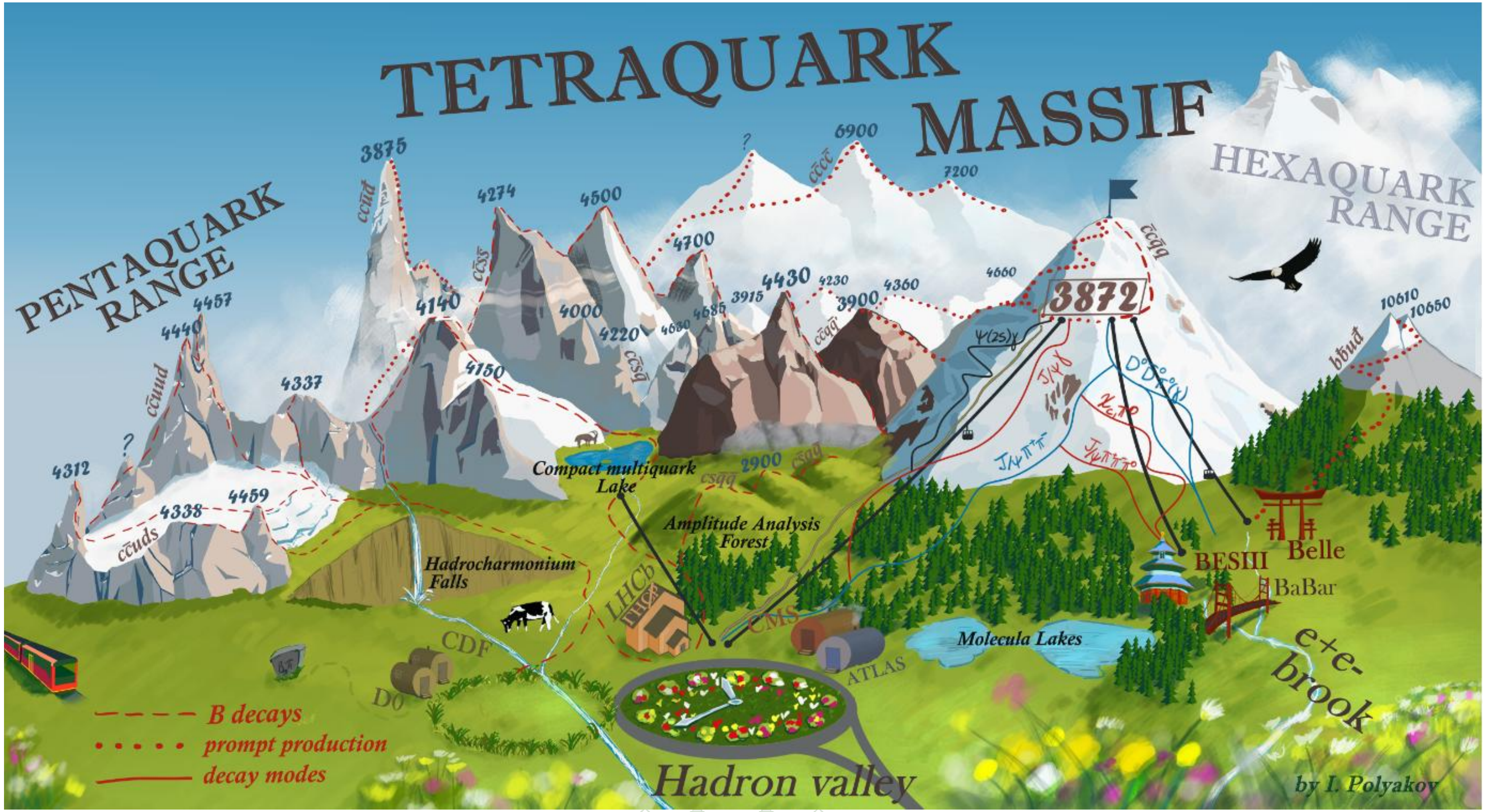


- QCD Sum Rules
- Relativistic Quark Model
- Godfrey-Isgur relativized diquark model
- The modified Godfrey-Isgur relativized diquark model with the color screening effects
- Nonrelativistic Quark Model

➢ 量子数为1^{--}的全粲四夸克态的质量理论预言范围在：**6.495~7.113** GeV

双粲偶素理论与实验现状

➢ 目前奇特强子态的实验研究成果

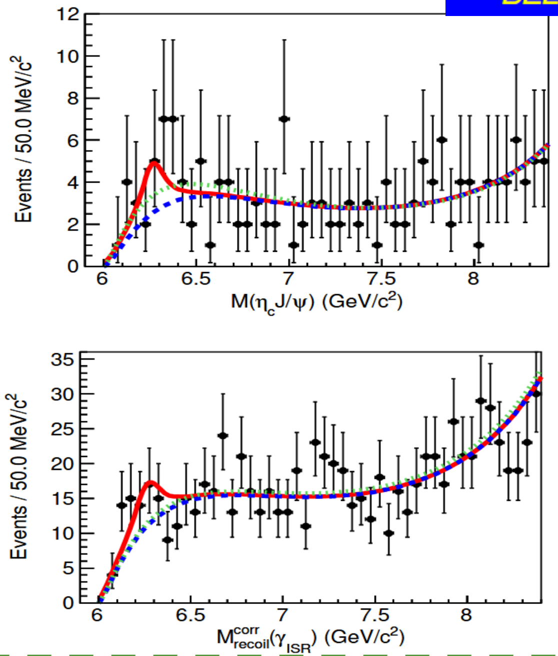


★ Hüsken N, Norella E S, Polyakov I. A Brief Guide to Exotic Hadrons[J]. arXiv:2410.06923, 2024.

双粲偶素理论与实验现状

➢ Search for the double-charmonium state with $\eta_c J/\psi$ @ Belle

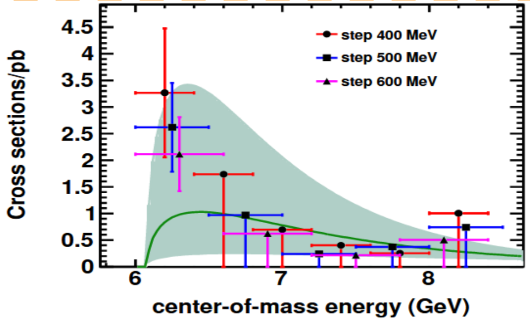
- 产生过程： $e^+e^- \to (\gamma_{ISR})\eta_c J/\psi$
- 能区： $10.52\,GeV$
- 衰变模型：
  - J/ψ： $e^+e^-, \mu^+\mu^-$
  - η_c： $p\bar{p}, p\bar{p}\pi^0, K_0^S K^\pm \pi^\mp, K^+K^-\pi^0,\ K^+K^-K^+K^-, 2(\pi^+\pi^-\pi^0)$
- 积分亮度： $980\,fb^{-1}$
- 质量： $6267 \pm 43\ MeV/c^2$
- 衰变宽度： $121 \pm 72\ MeV$
- 显著度结果：2.1σ （阈值附近）



图A

- $\eta_c J/\psi$质量区间： $[6.0, 6.6]\ GeV/c^2$
- 截面结果：2.1 ± 0.7 ± 0.2 pb
- Continuum产生截面拟合函数： $\sigma = A\frac{\sqrt{2\mu\Delta M}}{\left(\frac{s}{s0}\right)^n}$

$$\Delta M = \sqrt{s} - m(\eta_c) - m(J/\psi)$$



图B

双标η_c和J/ψ（以$\sqrt{s}=6.73$ GeV作为展示）

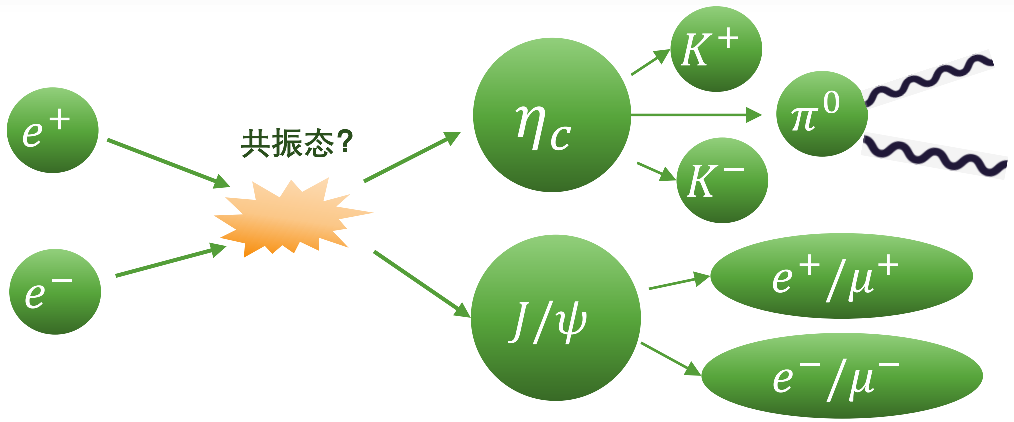
Exclusive MC production under OSCAR 2.6.2

产生子：ConExc

$\sqrt{s}$：**6.73GeV**　　　　**事例数: 100000**

信号道：$e^+e^- \to T_{4c} \to \eta_c J/\psi$,

- $\eta_c \to K^+K^-\pi^0$, $\pi^0 \to \gamma\gamma$
- $J/\psi \to \mu^+\mu^-$ *and* e^+e^-



- **衰变卡**

```
Particle vpho 6.7300 0.0
Decay vpho
1.0000  gamma   gamma* ConExc -2  443  441;
Enddecay
#
Decay gamma*
1.0000    eta_c  J/psi       PHSP;
Enddecay
#
Decay J/psi
1.0000    e+   e-                PHOTOS  VLL;
Enddecay

#
Decay eta_c
1.0000    pi0  K+  K-        PHSP;
Enddecay
#
Decay pi0
1.0000    gamma gamma                   PHSP;
Enddecay

End
```

- **利用Breit-Wigner公式获得输入截面分布模拟共振态**
- **公式:**$\sigma(e^+e^- \to T_{4c}) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to \eta_c J/\psi}\dfrac{12\pi\Gamma_0^2}{\left(s-m_{T_{4c}}^2\right)^2+m_{T_{4c}}^2\Gamma_0^2}$

6.72000	1.74915	0.0
6.72500	2.48728	0.0
6.73000	3.80113	0.0
6.73500	6.45682	0.0
6.74000	12.90311	0.0
6.74500	32.23149	0.0
6.75000	64.43911	0.0
6.75500	32.20762	0.0
6.76000	12.87256	0.0
6.76500	6.43104	0.0
6.77000	3.77999	0.0
6.77500	2.46962	0.0
6.78000	1.73409	0.0
6.78500	1.28226	0.0
6.79000	0.98561	0.0

事例选择条件

选择带电径迹:

- $|d_0| \leq 1.0cm$, $|d_z| \leq 10.0cm;$

选择光子：

- 桶部: $|cos\theta| \leq 0.8325$, $E_{ecal} \geq 25MeV,$
- 端盖: $0.8325 \leq |cos\theta| \leq 0.9445, E_{ecal} \geq 50\ MeV$ ；
- 飞行时间：$0 \leq |T_0| \leq 50\ ns$

选择 Kaon：

- Global PID： $prob(K) \geq prob(\pi)\&\&prob(K) \geq prob(\mu)\&\&prob(K) \geq prob(e)$

选择缪子:

- $0.1 \leq E_{ecal} \leq 0.3$ ， $|p_\mu| \geq 0.9\ GeV$

选择电子:

- $0.8 \leq \frac{E_e}{p_e} \leq 1.2$ ， $|p_e| \geq 0.9\ GeV$

重建π^0：

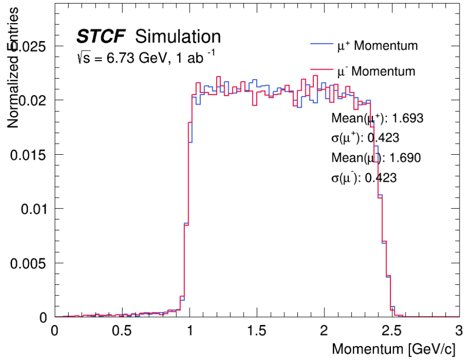
- $0.12GeV \leq M_{\gamma\gamma} \leq 0.15GeV$
- $1C$ 运动学拟合_$\chi^2 \leq 60$

重建 η$_c$：

- $2.78GeV \leq M_{K^+K^-\pi^0} \leq 3.08GeV$

重建 J/ψ：

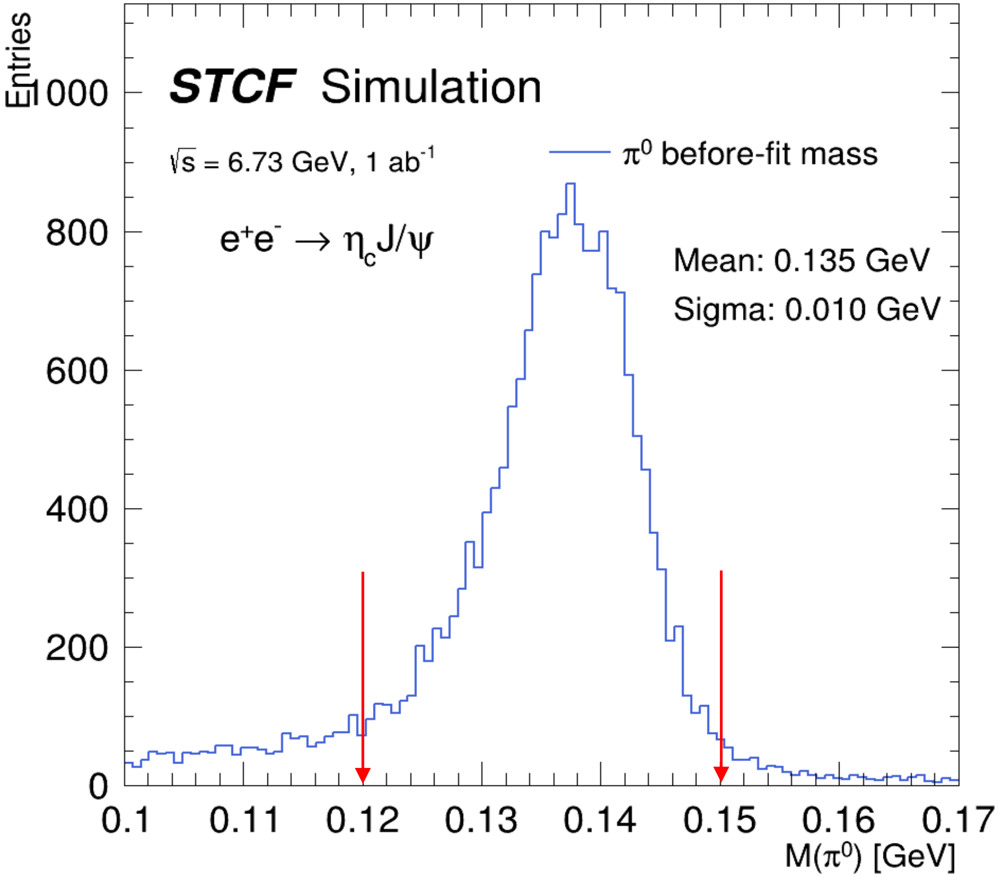
- 顶点拟合_$\chi^2 \leq 60$
- $3.05GeV \leq M_{\mu^+\mu^-} \leq 3.15GeV$
- $3.05GeV \leq M_{e^+e^-} \leq 3.15GeV$



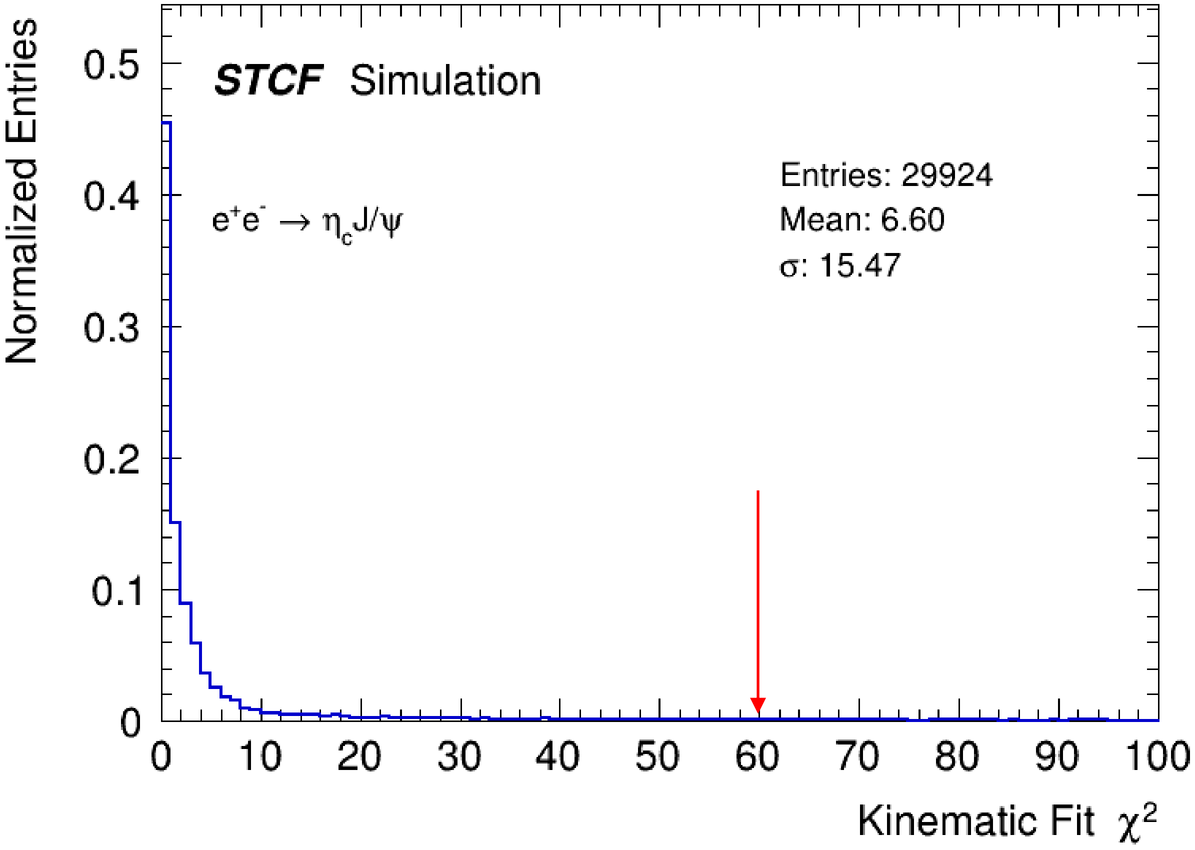
π^0重建

- $0.12GeV \leq M_{\gamma\gamma} \leq 0.15GeV$
- 1C运动学拟合_$\chi^2 \leq 60$

$\sqrt{S} = 6.73$ GeV



找质量最接近pi0 mass的光子组合



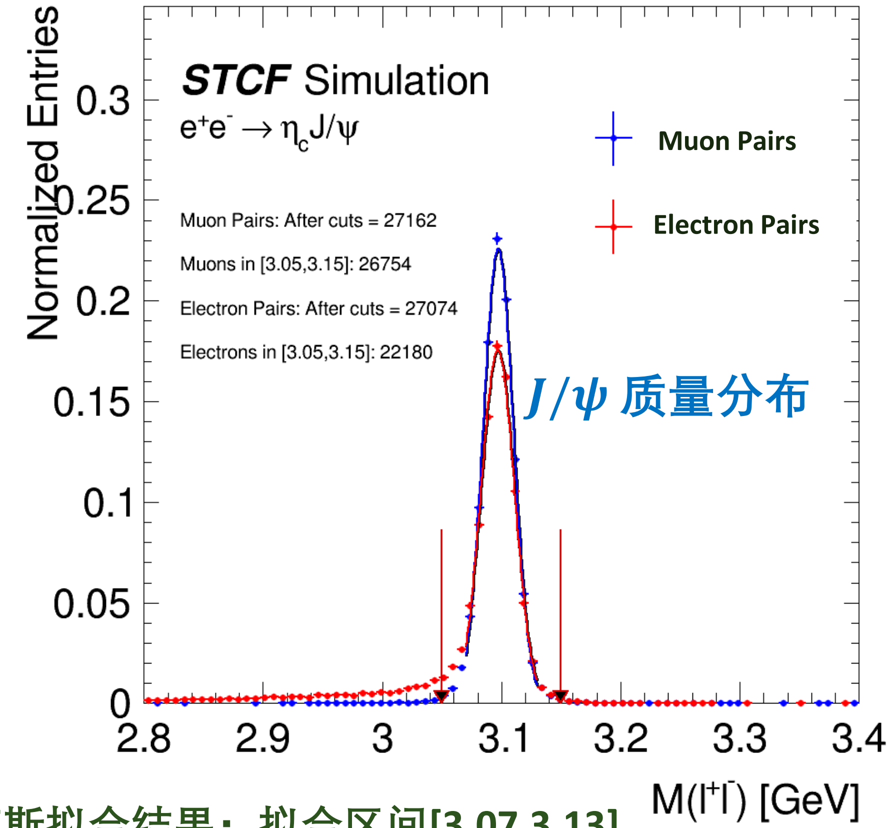
双标η_c和J/ψ

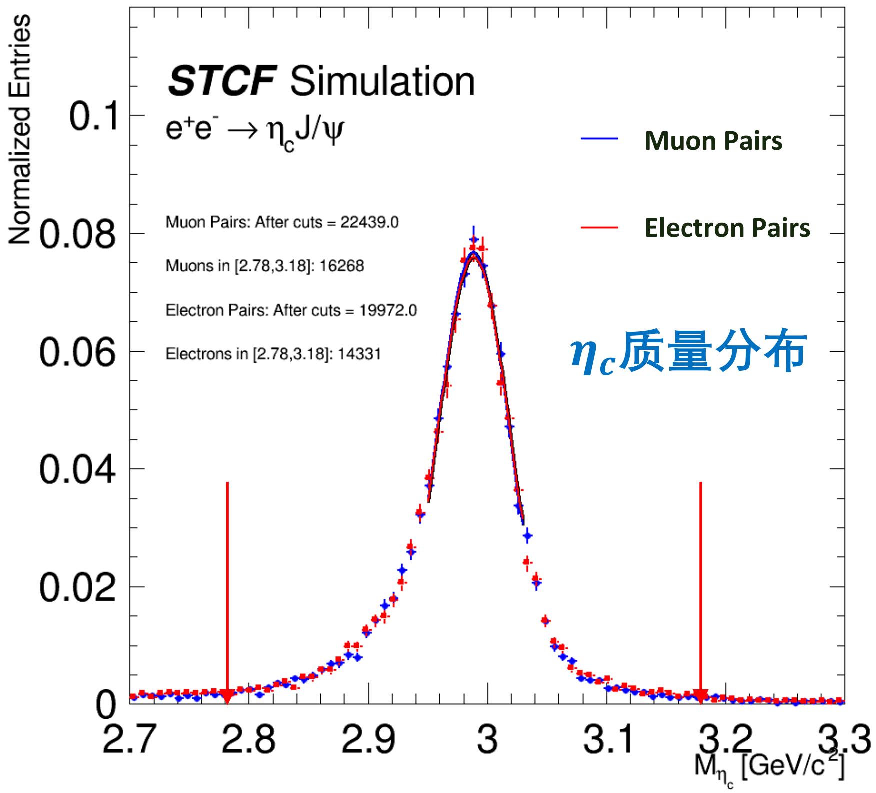
- $\sqrt{S} = 6.73$ GeV

➢ $J/\psi \to \mu^+\mu^-$和$J/\psi \to e^+e^-$的质量分布对比

J/ψ Mass cut： $3.05GeV < M_{Le^+Le^-} < 3.15GeV$

η_c Mass cut： $2.78GeV < M_{K^+K^-\pi^0} < 3.18GeV$





单高斯拟合结果：拟合区间[3.07,3.13]

- μ: $\sigma = 12.79 \pm 0.07MeV$, 峰值 $= 3.097 \pm 0.001$
- e: $\sigma = 14.05 \pm 0.10MeV$, 峰值 $= 3.096 \pm 0.001$

单高斯拟合结果：拟合区间[2.95,3.03]

- μ: $\sigma = 30.31 \pm 0.6MeV$, 峰值 $= 2.988 \pm 0.001$
- e: $\sigma = 30.67 \pm 0.7MeV$, 峰值 $= 2.989 \pm 0.001$

双标η_c和J/ψ

- Cut Flow 对比

$\sqrt{S}$ = 6.73 GeV

Cut Flow(J/ψ->$\mu\mu$)	N_{obs}	相对效率	Cut Flow($J/\psi\rightarrow ee$)	N_{obs}	相对效率
$total\ number$:	50000	100.00%	$total\ number$:	50000	100.00%
$nGood\mathrm{m} \geq 2\&nGood\mathrm{p} \geq 2$:	34432	68.86%	$nGood\mathrm{m} \geq 2\&nGood\mathrm{p} \geq 2$:	33918	67.84%
$nGood\gamma \geq 2$:	29762	86.44%	$nGood\gamma \geq 2$:	29832	87.95%
$n\mu_p \geq 1\ and\ n\mu_m \geq 1$:	26712	89.75%	$ne_p \geq 1\ and\ ne_m \geq 1$:	26677	89.42%
$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	26321	98.54%	$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	21956	82.30%
$nK_m \geq 1\ and\ nK_p \geq 1$:	23150	87.95%	$nK_m \geq 1\ and\ nK_p \geq 1$:	19503	88.83%
$\pi^0 mass\ cut\ \&\ km\_\chi^2 < 60$:	20436	88.28%	$\pi^0 mass\ cut\ \&\ km\_\chi^2 < 60$:	17061	87.48%
$\eta_c$mass cut	17363	84.96%	$\eta_c$mass cut	14378	84.27%
$total\ cut$:	32.48%		$total\ cut$:	28.76%	

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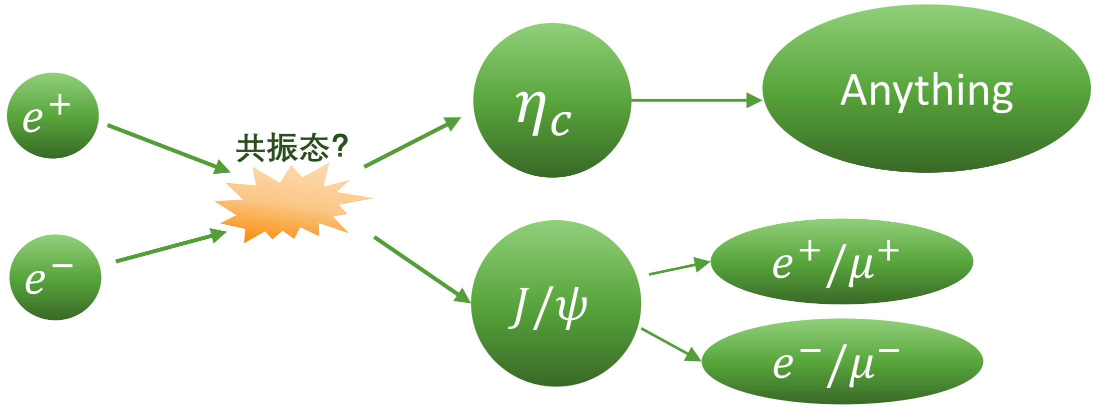
Exclusive MC production under OSCAR 2.6.2

产生子：ConExc

$\sqrt{s}$：6.73GeV   事例数: 100000

信号道：$e^+e^- \to T_{4c} \to \eta_c J/\psi$,

- $\eta_c \to anything$
- $J/\psi \to \mu^+\mu^-\ and\ e^+e^-$



- 衰变卡

```
noPhotos
Particle vpho 6.7300 0.0
Decay vpho
1.0000  gamma   gamma* ConExc -2  443  441;
Enddecay
#
Decay gamma*
1.0000     eta_c  J/psi       PHSP;
Enddecay
#
Decay J/psi
0.0594     e+    e-                 PHOTOS  VLL;
Enddecay
#
Decay eta_c
0.027      eta' pi+ pi-                          PHSP;
0.014      eta' pi0 pi0                          PHSP;
0.006      rho0 rho0                             HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.012      rho+ rho-                             HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0100     K*0 K- pi+                            PHSP;
0.0100     anti-K*0 K+ pi-                       PHSP;
0.0034     K*+ K*-                               HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0034     K*0 anti-K*0                          HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0 ;
0.011      K*0 anti-K*0  pi+ pi-                 PHSP;
0.0029     phi K+ K-                             PHSP;
0.00194    phi phi                               HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0288     K+ anti-K0  pi-                       PHSP;
0.0288     K- K0 pi+                             PHSP;
0.0144     K0 anti-K0 pi0                        PHSP;
0.0117     pi0  K+  K-                           PHSP;
0.0326     eta pi+ pi-                           PHSP;
0.0163     eta pi0 pi0                           PHSP;
```

- 利用Breit-Wigner公式获得输入截面分布模拟共振态
- 公式:$\sigma(e^+e^- \to T_{4c}) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to\eta_c J/\psi}\dfrac{12\pi\Gamma_0^2}{\left(s-m_{T_{4c}}^2\right)^2+m_{T_{4c}}^2\Gamma_0^2}$

```
6.72000 1.74915 0.0
6.72500 2.48728 0.0
6.73000 3.80113 0.0
6.73500 6.45682 0.0
6.74000 12.90311 0.0
6.74500 32.23149 0.0
6.75000 64.43911 0.0
6.75500 32.20762 0.0
6.76000 12.87256 0.0
6.76500 6.43104 0.0
6.77000 3.77999 0.0
6.77500 2.46962 0.0
6.78000 1.73409 0.0
6.78500 1.28226 0.0
6.79000 0.98561 0.0
```

单标J/ψ

$\sqrt{S} = 6.73$ GeV

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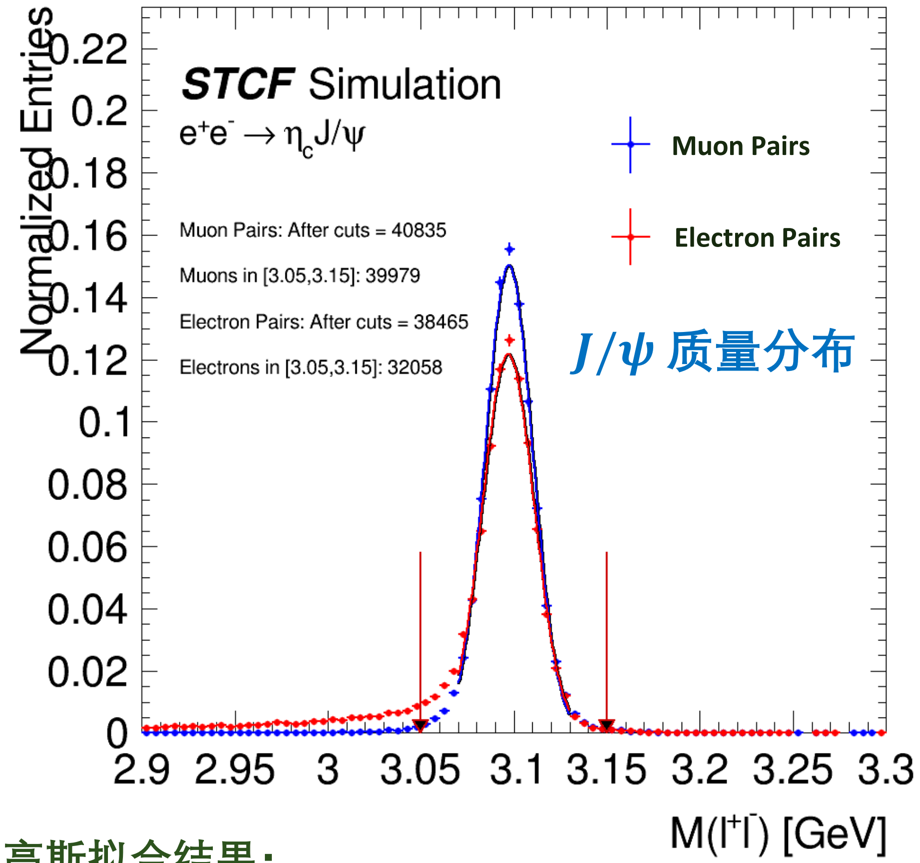
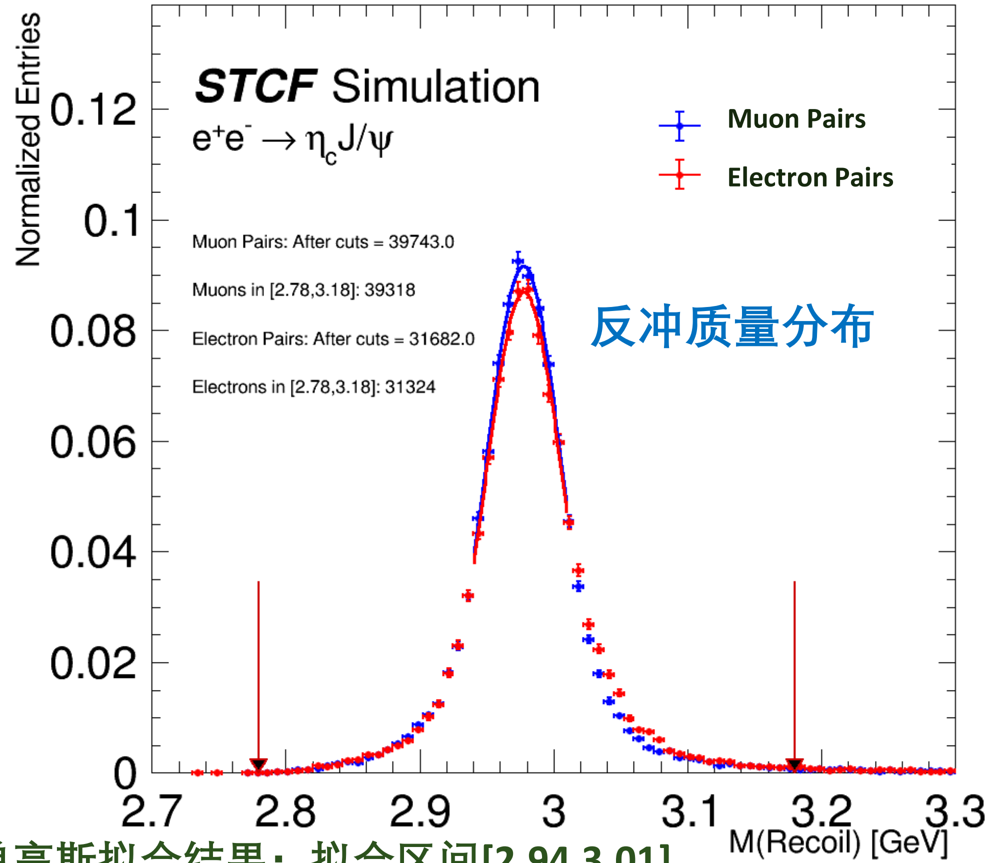
➢ $J/\psi \to \mu^+\mu^-$ 和 $J/\psi \to e^+e^-$ 的质量分布对比

$$M_{\mathrm{recoil}}(J/\psi) \equiv \sqrt{|p_{e^+e^-} - p_{J/\psi}|^2}/c$$

J/ψ *Mass cut*： $3.05GeV < M_{l e^+ l e^-} < 3.15GeV$

Recoil *Mass cut*： $2.78GeV < M_{\mathrm{recoil}} < 3.18GeV$





单高斯拟合结果：

- $\mu: \sigma = 13.40 \pm 0.06 MeV$, 峰值 $= 3.097 \pm 0.007$
- $e: \sigma = 15.05 \pm 0.08 MeV$, 峰值 $= 3.096 \pm 0.009$

单高斯拟合结果：拟合区间[2.94,3.01]

- $\mu: \sigma = 28.38 \pm 0.46 MeV$, 峰值 $= 2.977 \pm 0.001$
- $e: \sigma = 28.93 \pm 0.56 MeV$, 峰值 $= 2.978 \pm 0.001$

单标J/ψ

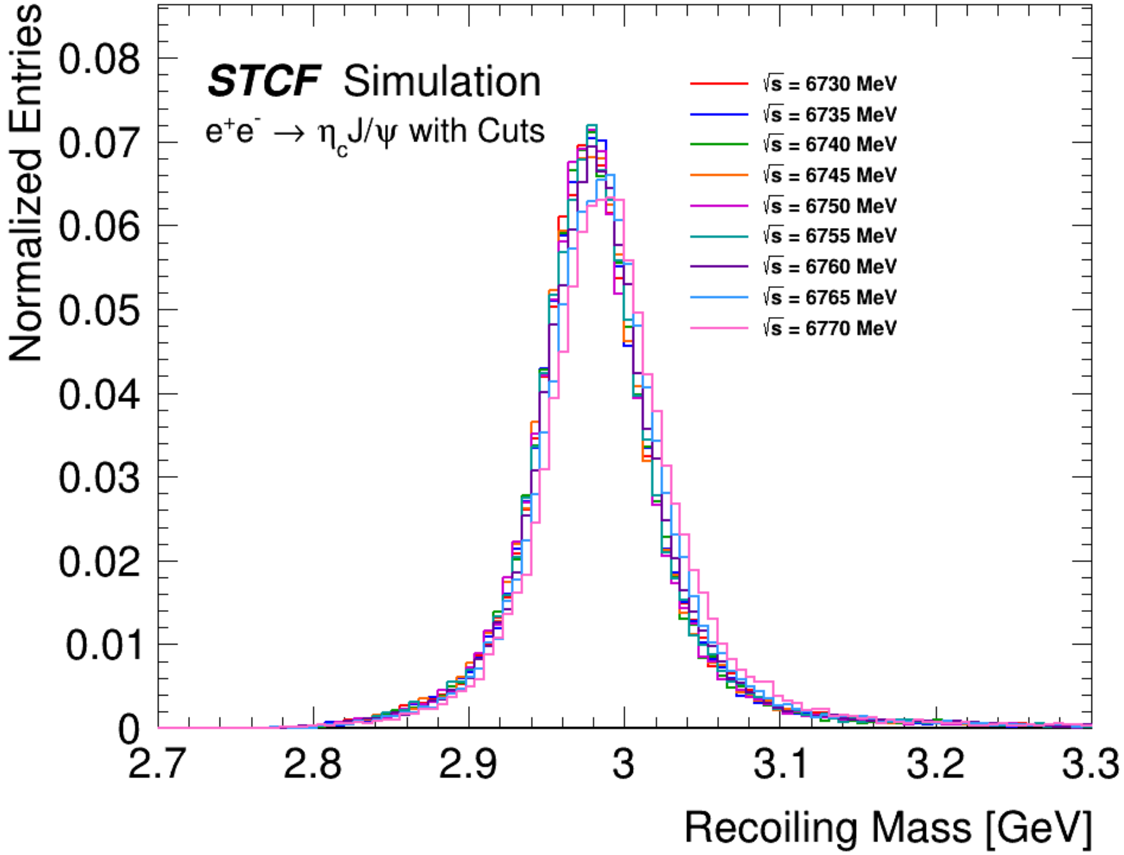
➢ Cut Flow 对比

Cut Flow(J/ψ->$\mu\mu$)	N_{obs}	相对效率	Cut Flow($J/\psi\rightarrow ee$)	N_{obs}	相对效率
$total\ number$:	50000	100.00%	$total\ number$:	50000	100.00%
$nGood\mathrm{m} \geq 1\&\&nGood\mathrm{p} \geq 1$:	49582	99.16%	$nGood\mathrm{m} \geq 1\&\&nGood\mathrm{p} \geq 1$:	49522	99.04%
$n\mu_p \geq 1\ and\ n\mu_m \geq 1$:	40436	81.55%	$ne_p \geq 1\ and\ ne_m \geq 1$:	39242	79.24%
$J/\psi\ vtxfit\_\chi^2 \leq 60$:	40404	99.99%	$J/\psi\ vtxfit\_\chi^2 \leq 60$:	39225	99.96%
$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	39743	98.36%	$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	32452	82.73%
Recoil mass cut:	39099	98.38%	Recoil mass cut:	31886	98.26%
$total\ cut$:	78.20%		$total\ cut$:	63.77%	

单标J/ψ

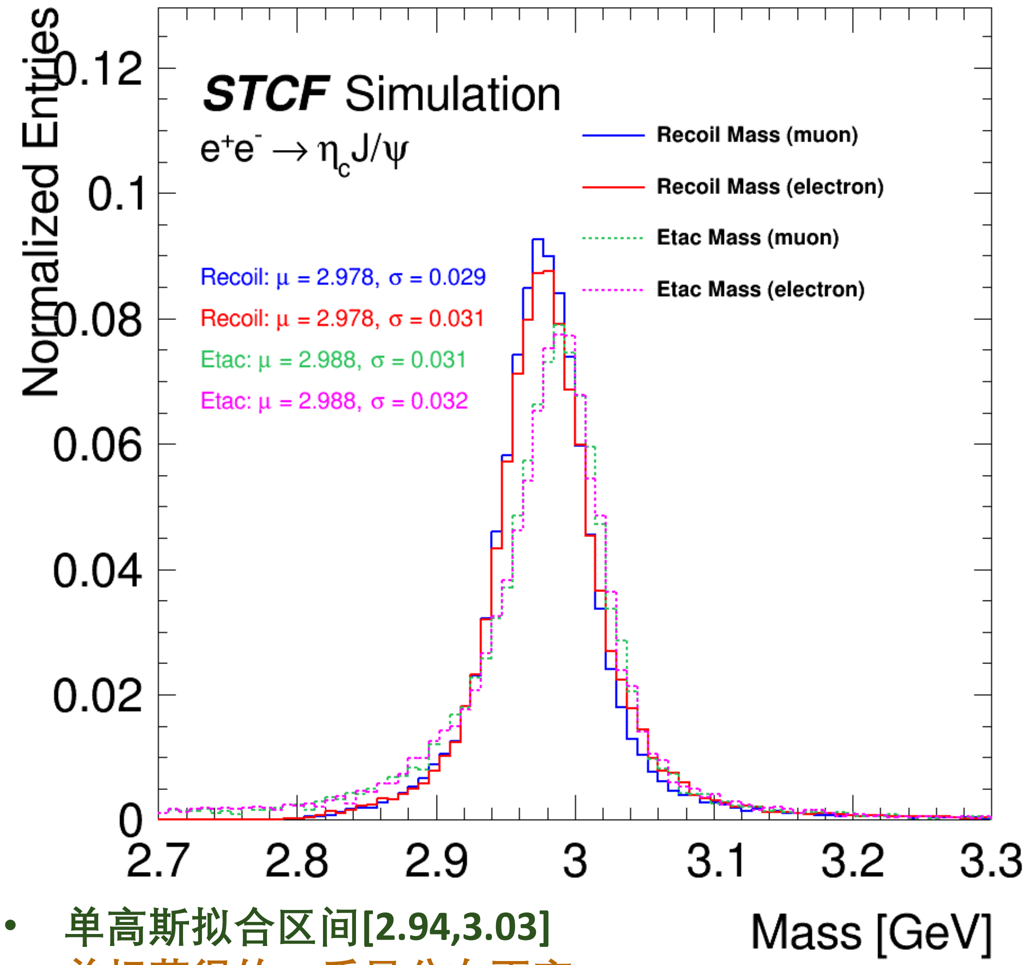
$\sqrt{s}$:6.73GeV~6.77GeV   Step size:5MeV 9个能量点

不同能量点下的反冲质量分布



- 随着能量点的变化，反冲质量的峰值只有很微小的偏移

单标获得的反冲质量分布 VS 双标获得的η_c 质量分布



- 单高斯拟合区间[2.94,3.03]
- 单标获得的η_c质量分布更窄
- 双标获得的η_c质量更接近PDG上的值

本底分析

- **Continuum本底截面：**

Belle拟合截面函$\sigma = A\frac{\sqrt{2\mu\Delta M}}{\left(\frac{s}{s0}\right)^n}$

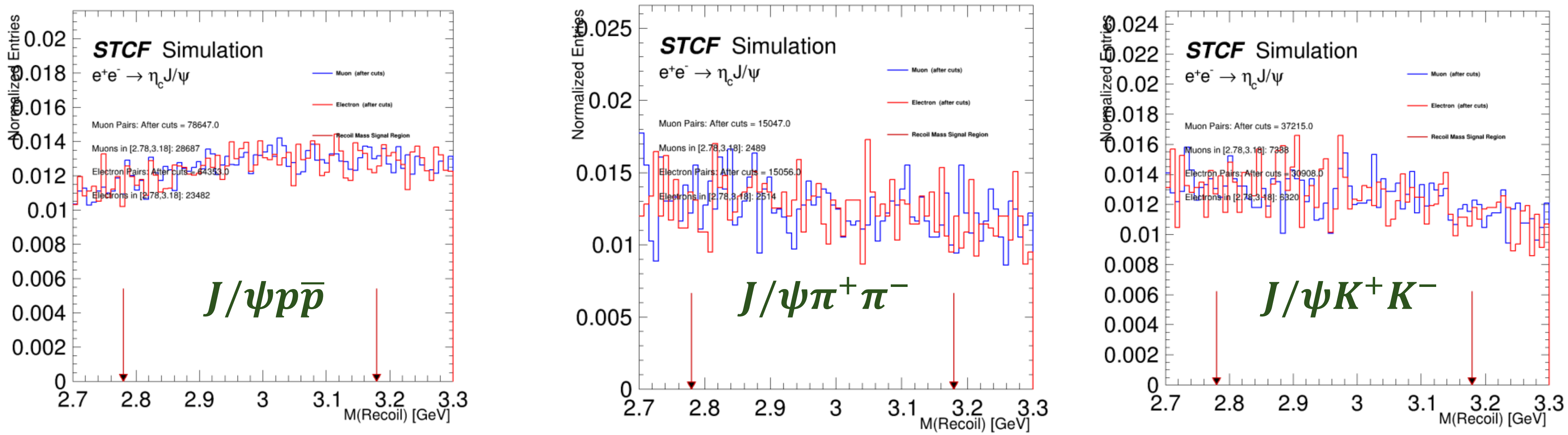
- $J/\psi p\bar{p}$本底、$J/\psi\pi^+\pi^-$本底和$J/\psi K^+K^-$本底的截面都是根据目前在5GeV以下的结果，按照1/100预估质心能量在6.75GeV下对应的截面。

$$N_{obs} = \sigma\varepsilon L\mathcal{B}$$

$\sqrt{S}$=6.75GeV	双标J/ψ 和η_c			单标J/ψ		
	选择效率	预估截面(fb)	事例数	选择效率	预估截面(fb)	事例数
信号	31.00%	64.43	3	70.50%	64.43	548
Continuum本底	31.00%	819.26	35	70.50%	819.26	6886
$J/\psi p\bar{p}$本底	1.38%	20	3	11.40%	20	27
$J/\psi\pi^+\pi^-$本底	0.42%	30	2	4.88%	30	18
$J/\psi K^+K^-$本底	1.41%	30	5	14.23%	30	51
强子本底	0.00%		0	0.00%		0

分别用5×10^5不同的本底样本进行本底分析获得的Recoil Mass分布

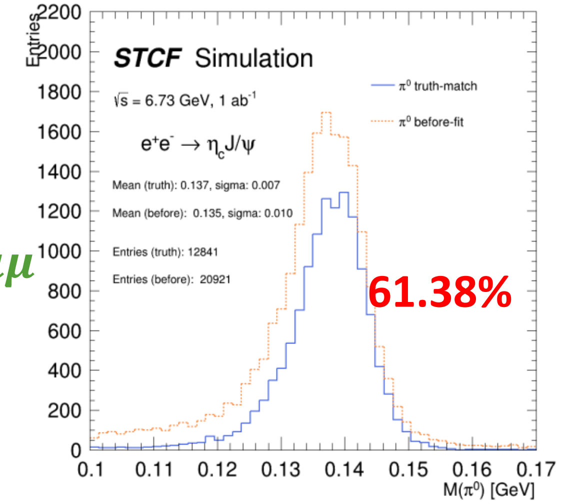
平本底

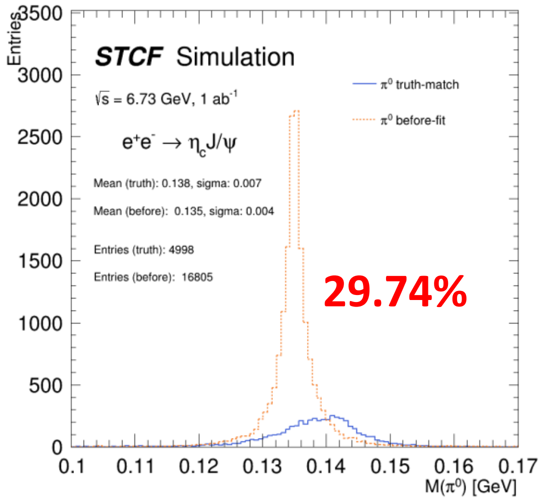


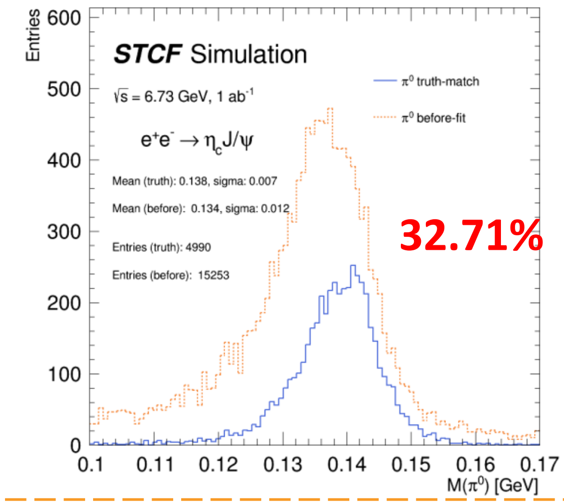
本底分析

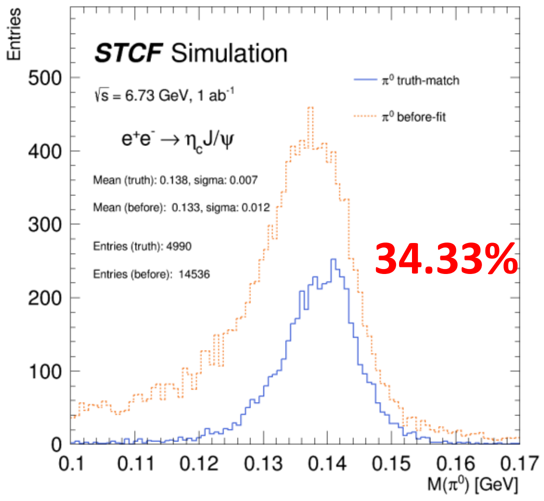
- $\pi^0\ kmfit$ $0.12GeV \le M_{\gamma\gamma} \le 0.15GeV$ 找chi2最小的光子组合

$\mu\mu$









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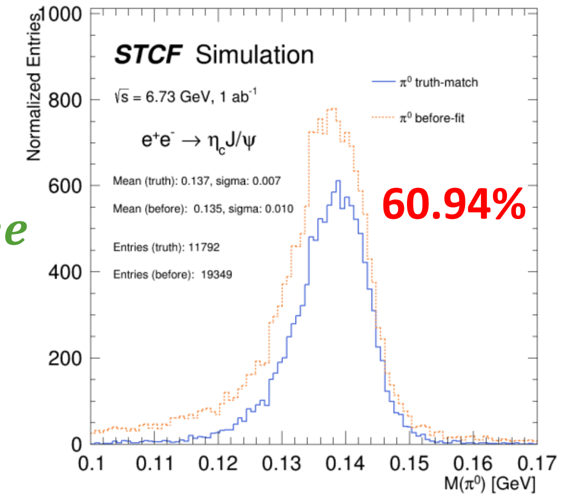
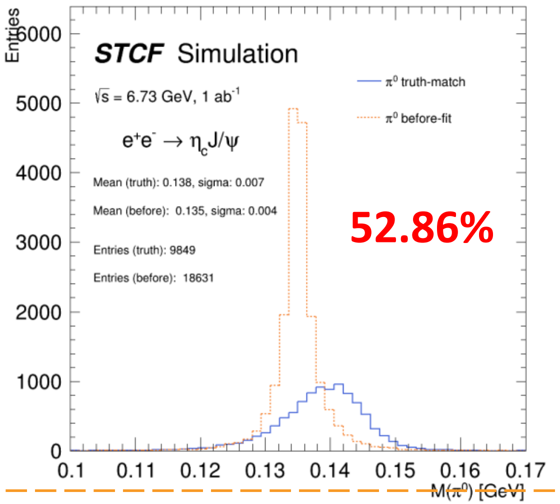
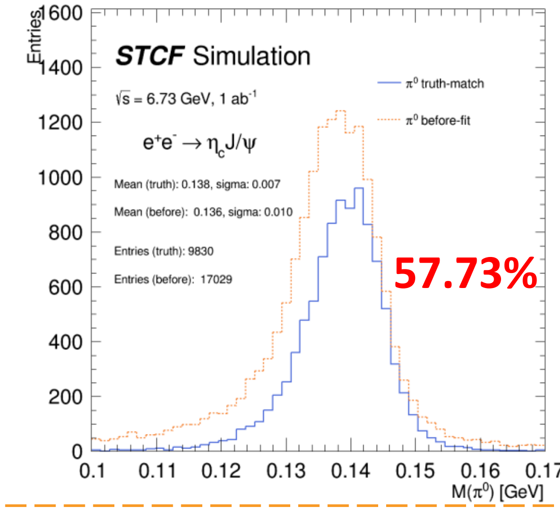
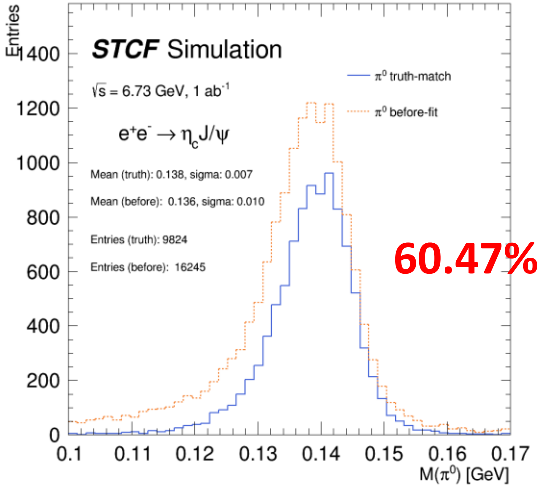








w/o beambackground

w/ background
No time cut

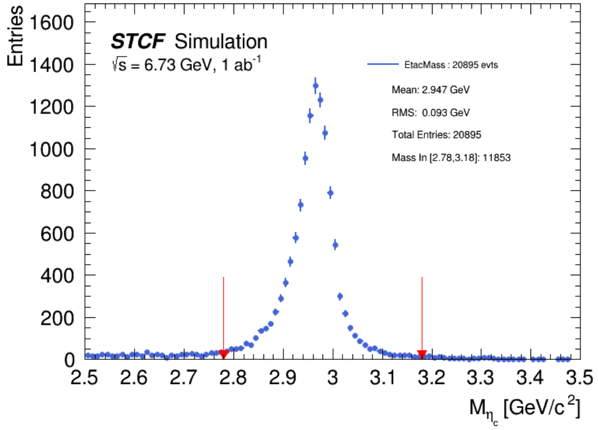
$w/\ background$
$Time\ cut\ |t0| \le 50$

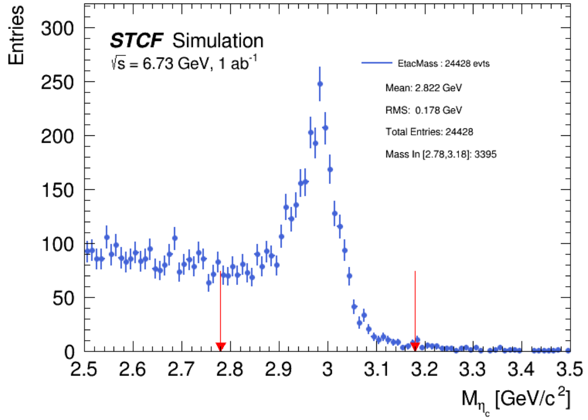
$w/\ background$
$Time\ cut\ |t0| \le 10$

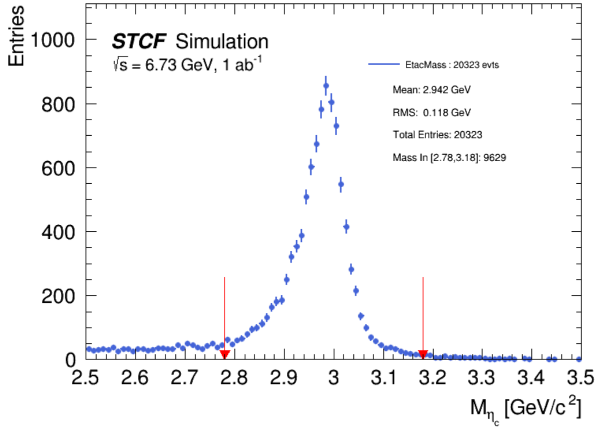
本底分析

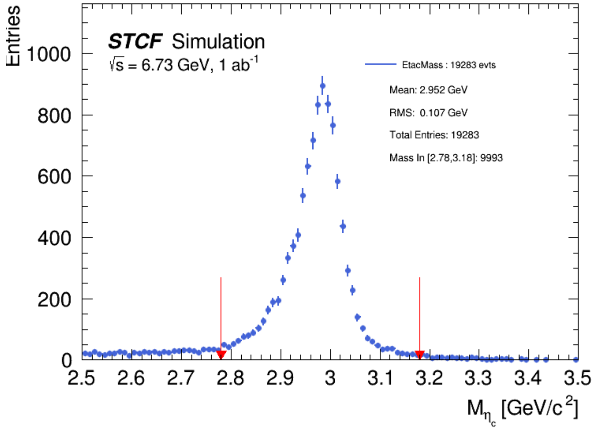
- $\pi^0\ kmfit$ $0.12GeV \le M_{\gamma\gamma} \le 0.15GeV$ 找chi2最小的光子组合

$\mu\mu$

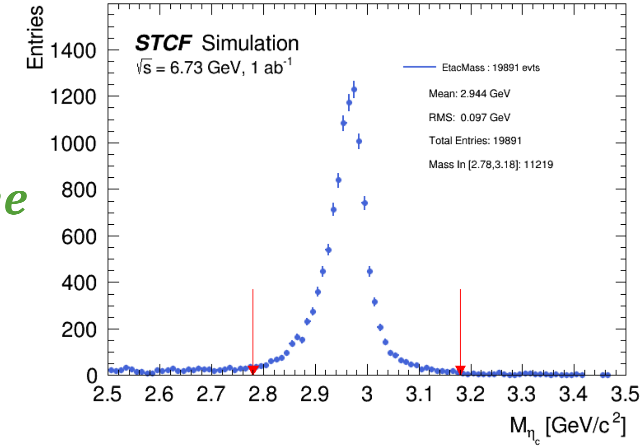


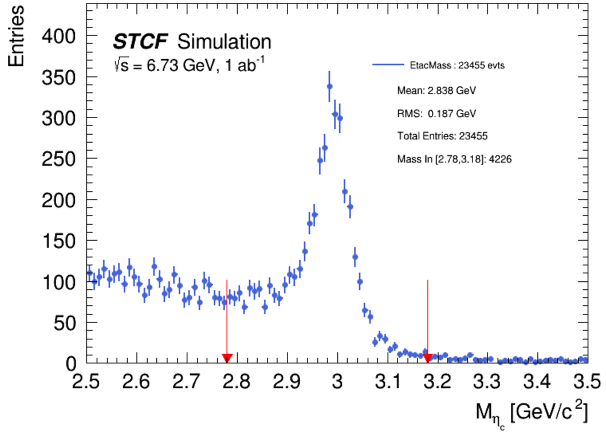


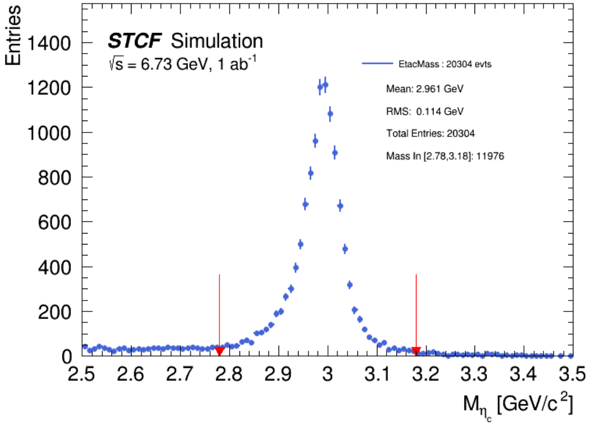


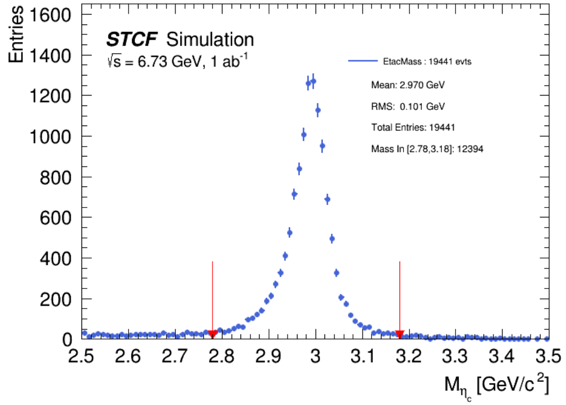


ee









w/o beambackground

w/ background
No time cut

$w/\ background$
$Time\ cut\ |t0| \le 50$

$w/\ background$
$Time\ cut\ |t0| \le 10$

$\sqrt{s}$ = 6.73 GeV

cut flow

$J/\psi \rightarrow \mu^+\mu^-$

Cut Flow	N_{obs}	Rel. eff. (%)	N_{obs}	Rel. eff. (%)	N_{obs}	Rel. eff. (%)	N_{obs}	Rel. eff. (%)
total number:	50000	100.00%	50000	100.00%	50000	100.00%	50000	100.00%
nGood $\geq$ 4 ：	34011	68.02%	41523	83.04%	33521	67.04%	33521	67.04%
nGoodγ $\geq$ 2:	29207	85.88%	33519	80.72%	30317	90.44%	28839	86.03%
$n\mu_p \geq 1$ and $n\mu_m \geq 1$:	22786	78.02%	24973	74.50%	22605	74.56%	21521	74.62%
J/φ mass cut:	22427	98.42%	24530	98.23%	22198	98.20%	21133	98.20%
$nK_m \geq 1$ and $nK_p \geq 1$:	15855	70.70%	16840	68.65%	15285	68.86%	14565	68.92%
π^0masscut & kmfit $\leq$ 60:	13649	86.09%	16789	99.70%	12927	84.57%	12009	82.45%
$\eta_c$mass cut	11599	84.98%	3293	19.61%	9334	72.21%	9684	80.64%
total cut:	23.20%		6.59%		**18.67%**		**19.37%**	

w/o beambackground

w/ background
No time cut

w/ background
Time cut $|t0| \leq 50$

w/ background
Time cut $|t0| \leq 10$

本底分析

$\sqrt{s}$ = 6.73 GeV

cut flow

J/ψ→e^+e^-

Cut Flow	N_{obs}	Rel. eff. (%)	N_{obs}	Rel. eff. (%)	N_{obs}	Rel. eff. (%)	N_{obs}	Rel. eff. (%)
total number:	49048	100.00%	50000	100.00%	50000	100.00%	50000	100.00%
$\mathbf{nGood \geq 4}$:	33096	68.02%	33464	67.29%	33464	67.29%	33464	67.29%
$\mathbf{nGood\gamma \geq 2}$:	28917	87.37%	33460	99.99%	30630	91.53%	29313	87.60%
$\mathbf{n\mu_p \geq 1}$ **and** $\mathbf{n\mu_m \geq 1}$:	25941	89.71%	28776	86.00%	26282	85.80%	25106	85.65%
J/φ mass cut:	21305	82.13%	23619	82.08%	21580	82.11%	20602	82.06%
$\mathbf{nK_m \geq 1}$ **and** $\mathbf{nK_p \geq 1}$:	15408	72.32%	19010	80.49%	17369	80.49%	16569	80.42%
π^0**masscut & kmfit** $\leq$ **60**:	13119	85.14%	18652	98.12%	15180	87.40%	14428	87.08%
η_c**mass cut**	10943	83.41%	4077	21.86%	11576	76.26%	11981	83.04%
total cut:	23.20%		8.15%		23.15%		23.96%	

w/o beambackground

w/ background
No time cut

w/ background
Time cut $|t0| \leq 50$

w/ background
Time cut $|t0| \leq 10$

预估截面与事例数

$\Gamma^{ee}_{T_{4c}} = 20eV,$

$\Gamma_{T_{4c}} = 10MeV$

$\Gamma_{\eta_c J/\psi} = 1MeV$

$\mathcal{B}_{T_{4c}\to e^+e^-} \approx 2 * 10^{-6}$,$\mathcal{B}_{T_{4c}\to \eta_c J/\psi} = \frac{1}{10} \approx 0.1$

$$\sigma(e^+e^- \to T_{4c} \to \eta_c J/\psi) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to \eta_c J/\psi}\frac{12\pi\Gamma^2_{T4c}}{\left(s-m^2_{T_{4c}}\right)^2+m^2_{T_{4c}}\Gamma^2_{T4c}}$$

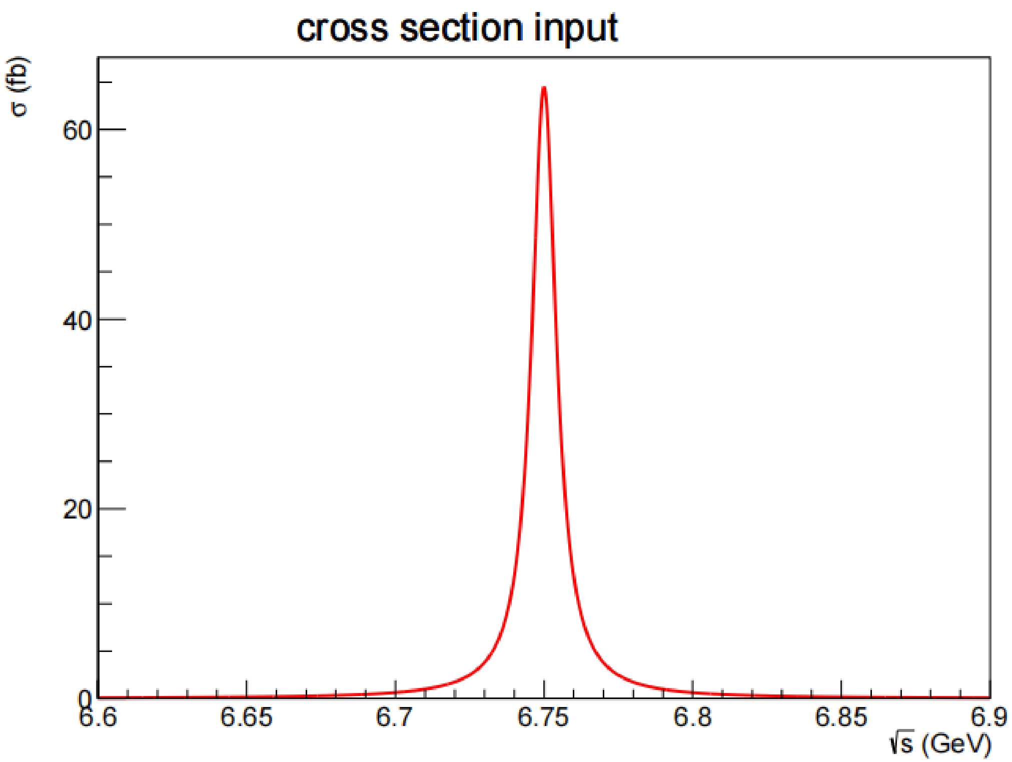
≅64.43fb(峰值)

$L = 100\ fb^{-1}$

$\mathcal{B}(J/\psi \to e^+e^-,\mu^+\mu^-)$ =0. 11932=11.932%

$\mathcal{B}(\eta_c \to K^+K^-\pi^0)$ =0. 0115=1.15%

$N_{obs} = \sigma\varepsilon L\mathcal{B}(J/\psi \to e^+e^-,\mu^+\mu^-)\mathcal{B}(\eta_c \to K^+K^-\pi^0) \cong 3(peak)$

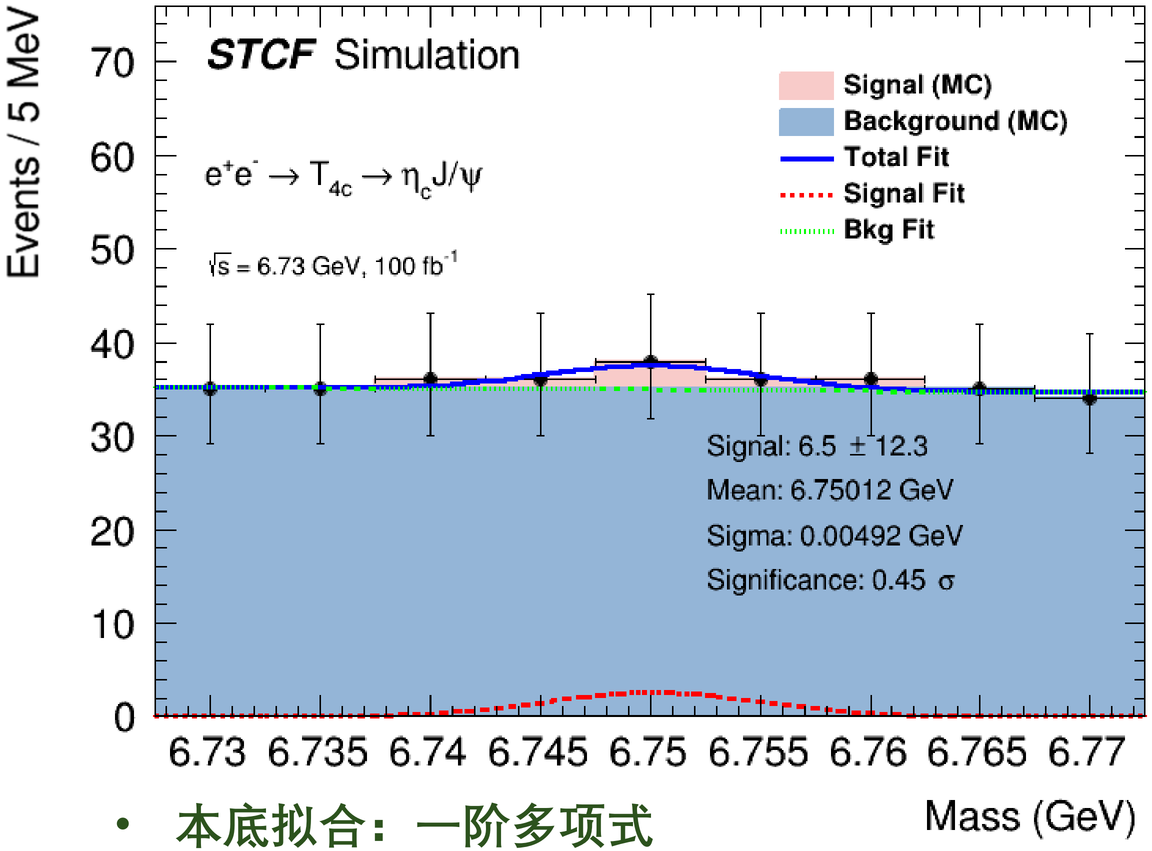


- 以$100fb^{-1}$积分亮度预估STCF每年可产生约$1 * 10^5$个T_{4c}（$N_{obs} = \sigma L$）

A. Badalian, B. Ioffe and A. V. Smilga, Nucl. Phys. B281 (1987) 85

信号与本底拟合

双标 $\sqrt{S}$：6.73GeV~6.77GeV Step size:5MeV 8 steps



- 本底拟合：一阶多项式
- 信号拟合：高斯

- *significance* 计算公式：

$$S = [2(\boxed{lnL_m(s+b)} - \boxed{lnL_m(b)})]^{1/2}.$$

log likelihood value from the fit w/o signal

log likelihood value from the fit

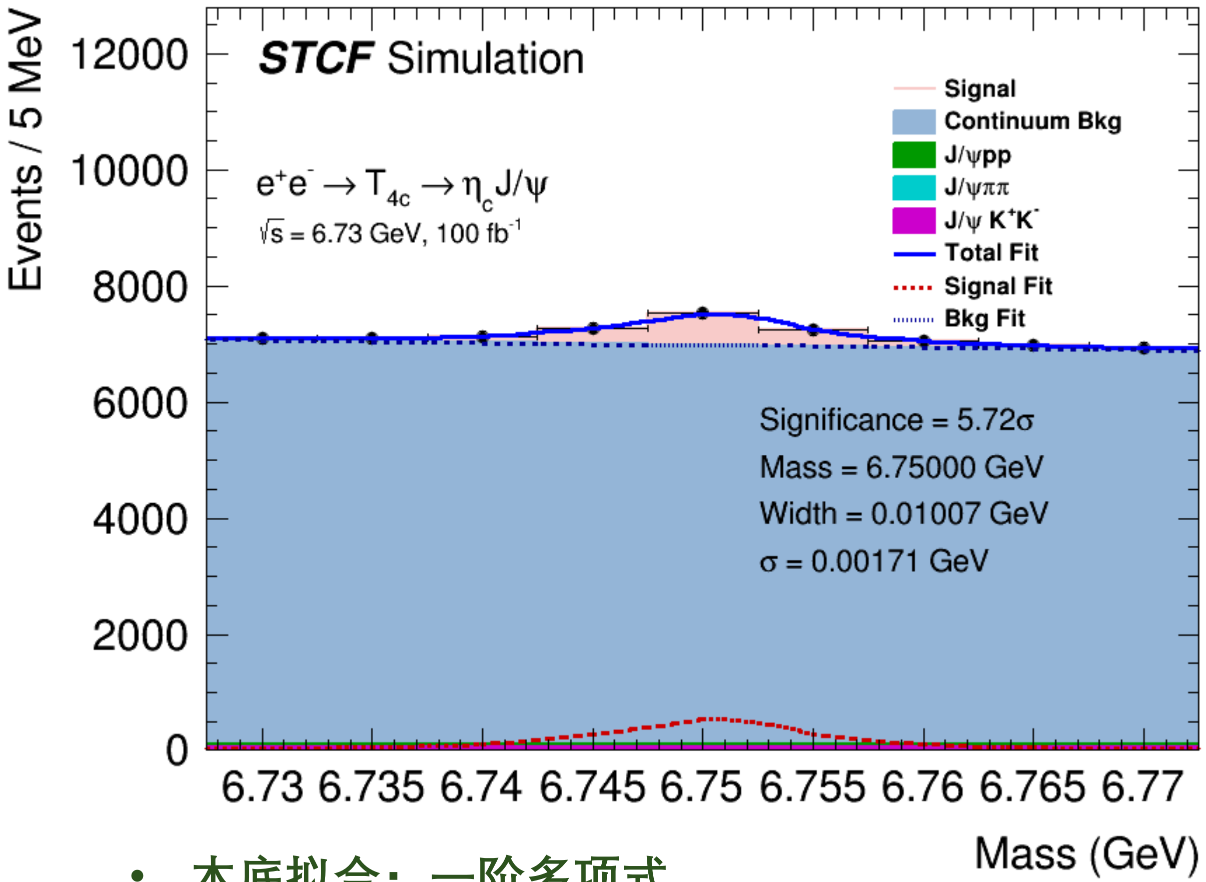
- $L = 100\ fb^{-1}$
- $significance = 0.45\sigma$

拟合结果：
- $N_{sig} = 6.5 \pm 12.3$
- $N_{back} = 314.4 \pm 24.6$
- $Mean = 6.75 \pm 0.01\ GeV$
- $\sigma = 4.92 \pm 1.82\ MeV$

统计结果：
- $N_{sig} = 8$
- $N_{back} = 313$

信号与本底拟合

单标J/ψ $\sqrt{S}$：6.73GeV~6.77GeV Step size:5MeV 8 steps



- 本底拟合：一阶多项式
- 信号拟合：高斯卷积BW函数

- *significance* 计算公式：

log likelihood value from the fit w/o signal

$$S = [2(\boxed{lnL_m(s+b)} - \boxed{lnL_m(b)})]^{1/2}.$$

log likelihood value from the fit

- $L = 100\ fb^{-1}$
- $significance = 5.72\sigma$

拟合结果：
- $N_{sig} = 1530.3 \pm 473.4$
- $N_{back} = 62791.7 \pm 299.6$
- $Mean = 6.75 \pm 0.001\ GeV$
- $\sigma = 1.7 \pm 2.0\ MeV$

统计结果：
- $N_{sig} = 1487$
- $N_{back} = 62377$

不同截面预估下的结果

➢ 双标

	能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77	significance
	input截面(fb)	3.8	6.5	12.9	32.2	64.4	32.2	12.9	6.4	3.8	0.45σ
	N_{obs}(信号)	0	0	1	1	3	1	1	0	0	
5倍	input截面(fb)	19.0	32.3	64.5	161.2	322.2	161.0	64.4	32.2	18.9	1.97σ
	N_{obs}(信号)	1	1	3	7	14	7	3	1	1	
10倍	input截面(fb)	38.0	64.6	129.0	322.3	644.4	322.1	128.7	64.3	37.8	3.58σ
	N_{obs}(信号)	2	3	6	14	28	14	6	3	2	

➢ 单标

	能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77	significance
	input截面(fb)	3.8	6.5	12.9	32.2	64.4	32.2	12.9	6.4	3.8	5.72σ
	N_{obs}(信号)	32	55	109	274	548	273	109	55	32	
5倍	input截面(fb)	19.0	32.3	64.5	161.2	322.2	161.0	64.4	32.2	18.9	26.76σ
	N_{obs}(信号)	161	274	547	1370	2738	1366	547	273	160	
10倍	input截面(fb)	38.0	64.6	129.0	322.3	644.4	322.1	128.7	64.3	37.8	57.66σ
	N_{obs}(信号)	323	548	1094	2740	5476	2732	1094	546	320	

目录

content

Introduction

- The theoretical prediction of pentaquark states can be traced back to the quark model proposed by Murray Gell-Mann in 1964. In 1979, Daniel Stauffer constructed a four-quark plus one antiquark model, and in 1997, the team of Markov and Polyakov predicted the existence of a particle called Θ+ with a mass of 1530 MeV. In 2003, the Japan LEPS experiment detected a resonance signal at 1540 MeV. After 2015, the LHCb experiment validated its existence through high-statistics data.

- In July 2015, the **LHCb collaboration** at CERN observed this type of particle for the first time in the decay of bottom lambda (Λ) baryons. Subsequent experiments have discovered multiple pentaquark states, including Pc(4312), Pc(4440), and Pc(4457).

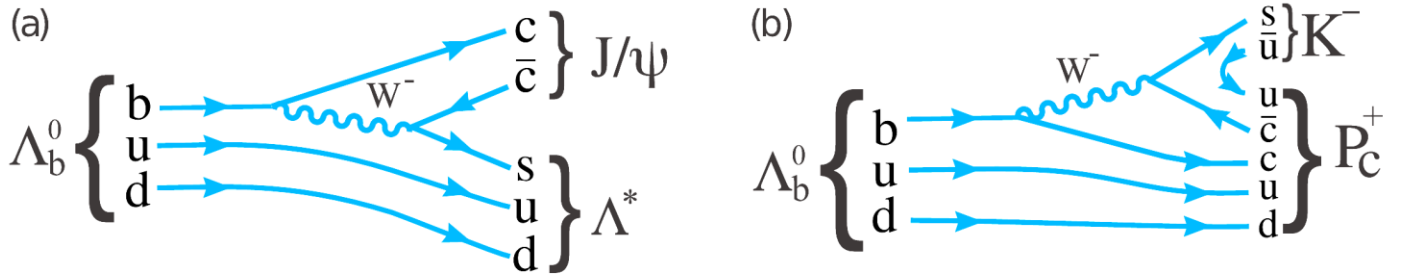


Figure 1: Feynman diagrams for (a) $\Lambda_b^0 \to J/\psi\, \Lambda^*$ and (b) $\Lambda_b^0 \to P_c^+ K^-$ decay.

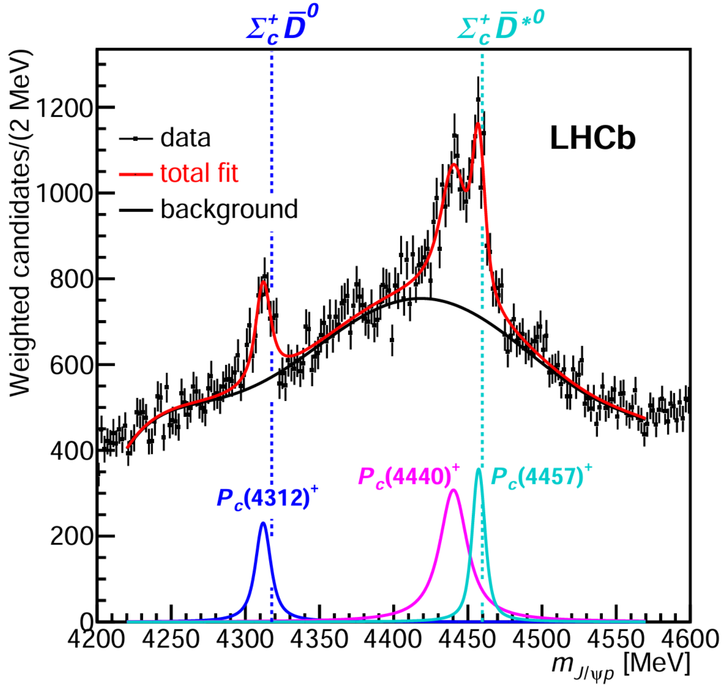


Figure 6: Fit to the $\cos\theta_{P_c}$-weighted $m_{J/\psi p}$ distribution with three BW amplitudes and a sixth-order polynomial background. This fit is used to determine the central values of the masses and widths of the P_c^+ states. The mass thresholds for the $\Sigma_c^+ \bar{D}^0$ and $\Sigma_c^+ \bar{D}^{*0}$ final states are superimposed.

Event Selection

Study Channel: $e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p}$

Good charged tracks：

- $|V_{xy}| \leq 1cm$, $|V_z| \leq 10cm$

PID：

- p:prob(p)>prob(e, π, K, μ)
- e:prob(e)>prob(p, π, K, μ)
- μ:prob(μ)>prob(p, π, K, e)

Other selections:

- Number of $p = 1$ and $\bar{p} = 1$
- Number of $\mu^+ = \mu^- = 1$ or $e^+ = e^- = 1$

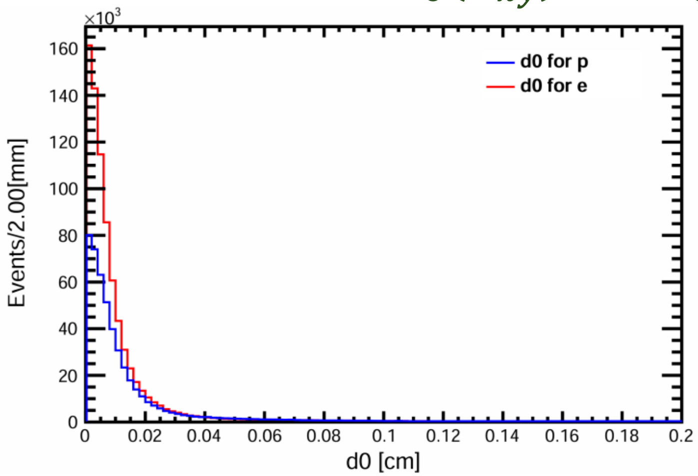
Vertex Fit:

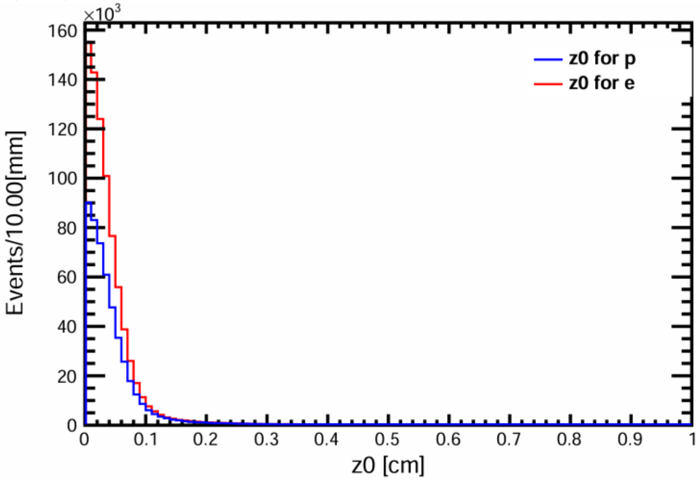
- $p, \bar{p}$ and two lepton(e or μ) come from the same point.

Kmfit Fit:

- p, $\bar{p}$ and two lepton(e or μ) restrain to center-of-mass.

$d_0(V_{xy})$ and $z_0(V_z)$ distribution





Cut Flow for offline 2.6.2

	Energy [GeV]	5.2	5.5	5.8	6.2	6.5	6.8
	Total number	200000	200000	200000	200000	200000	200000
$J/\psi \to e^+e^-$	Match Tracks	56.52%	70.00%	72.98%	74.03%	74.68%	74.70%
	nGoodp = nGoodm = 2	48.21%	65.35%	69.49%	71.32%	72.34%	72.43%
	$p = 1 \&\& \bar{p} = 1$	41.43%	62.38%	66.17%	66.74%	66.50%	65.62%
	$e^+ = 1 \&\& e^- = 1$ (PID)	41.24%	62.14%	65.90%	66.47%	66.25%	65.34%
	After Vertex Fit	40.71%	61.43%	65.15%	65.71%	65.48%	64.56%
	After Kmfit Fit	33.06%	46.48%	47.31%	46.65%	45.92%	44.98%
	$J/\psi \in [3.05, 3.15]\ GeV$	32.72%	45.82%	46.60%	45.80%	45.03%	44.01%
$J/\psi \to \mu^+\mu^-$	Match Tracks	56.57%	70.22%	73.02%	74.52%	74.54%	75.05%
	nGoodp = nGoodm = 2	48.79%	66.22%	70.15%	72.41%	72.76%	73.50%
	$p = 1 \&\& \bar{p} = 1$	41.99%	63.29%	66.81%	67.85%	66.91%	66.59%
	$\mu^+ = 1 \&\& \mu^- = 1$ (PID)	39.45%	59.45%	62.71%	63.47%	62.30%	61.94%
	After Vertex Fit	39.13%	59.00%	62.25%	63.00%	61.86%	61.44%
	After Kmfit Fit	36.97%	51.80%	52.73%	51.93%	50.31%	49.51%
	$J/\psi \in [3.05, 3.15]\ GeV$	36.54%	51.01%	51.91%	51.04%	49.42%	48.63%

Study of $P_c(4450)^+$

Process: $e^+e^- \rightarrow P_c(4450)^+\bar{p} \rightarrow J/\psi p\bar{p} \rightarrow e^+e^-(\mu^+\mu^-)\, p\bar{p}$

- **Threshold:**
- $Width = 39 \pm 5 \pm 19 MeV$
- $J^{PC} = 5/2^+$

Introduction in LHCb (2015)

Observations of exotic structures in the $J/\psi p$ channel, which we refer to as charmonium-pentaquark states, in $\Lambda_b^0 \rightarrow J/\psi K^- p$ decays are presented. The data sample corresponds to an integrated luminosity of 3 fb^{-1} acquired with the LHCb detector from 7 and 8 TeV pp collisions. An amplitude analysis of the three-body final-state reproduces the two-body mass and angular distributions. To obtain a satisfactory fit of the structures seen in the $J/\psi p$ mass spectrum, it is necessary to include two Breit-Wigner amplitudes that each describe a resonant state. The significance of each of these resonances is more than 9 standard deviations. One has a mass of $4380 \pm 8 \pm 29$ MeV and a width of $205 \pm 18 \pm 86$ MeV, while the second is narrower, with a mass of $4449.8 \pm 1.7 \pm 2.5$ MeV and a width of $39 \pm 5 \pm 19$ MeV. The preferred J^P assignments are of opposite parity, with one state having spin 3/2 and the other 5/2.

Decay Card

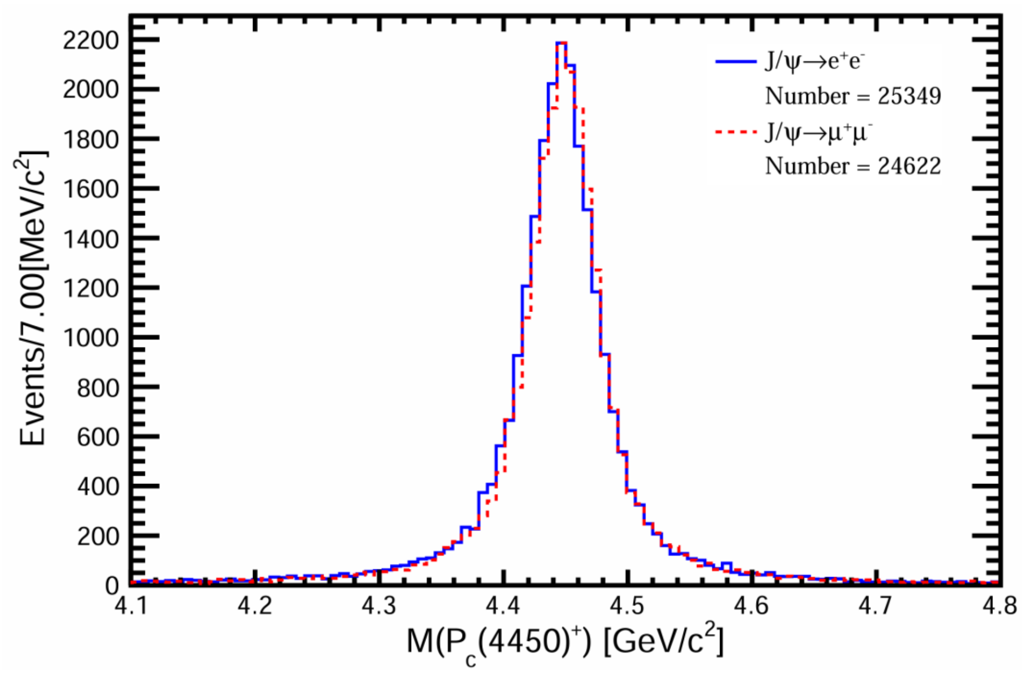
```
noPhotos
Particle vpho 6.500 0.0
Decay vpho
1.0000  gamma   gamma* ConExc -2  443  2212 -2212;
Enddecay
#
Decay gamma*
1.0000    Pc(4450)+  anti-p-      PHSP;
Enddecay
#
Decay Pc(4450)+
1.0000    J/psi  p+       PHSP;
Enddecay
#
Decay J/psi
0.0594    e+   e-                  PHOTOS  VLL;
0.0593    mu+  mu-                 PHOTOS  VLL;
Enddecay
```

$P_c(4450)^+$ distribution

Cutting Criteria: $3.05 \leq M_{J/\psi} \leq 3.15$ GeV

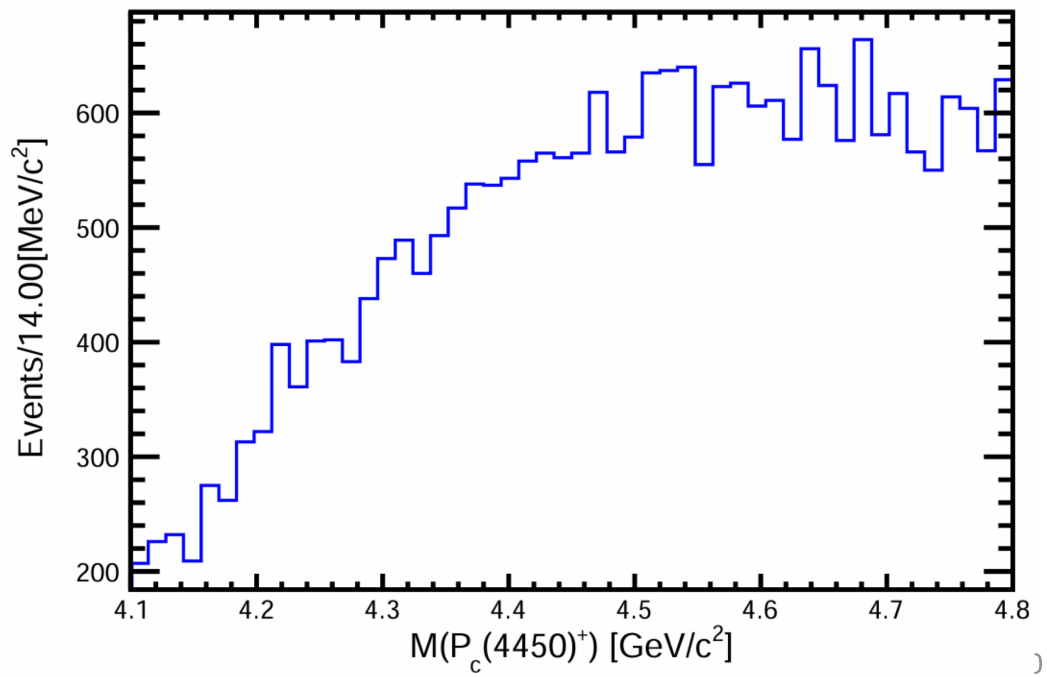
Add $P_c(4450)^+$ Resonance

Signal Shape



No $P_c(4450)^+$ Resonance

Background Shape ($J/\psi p$)



$P_c(4450)^+$截面假设 $(\sqrt{s} = 6.5GeV)$

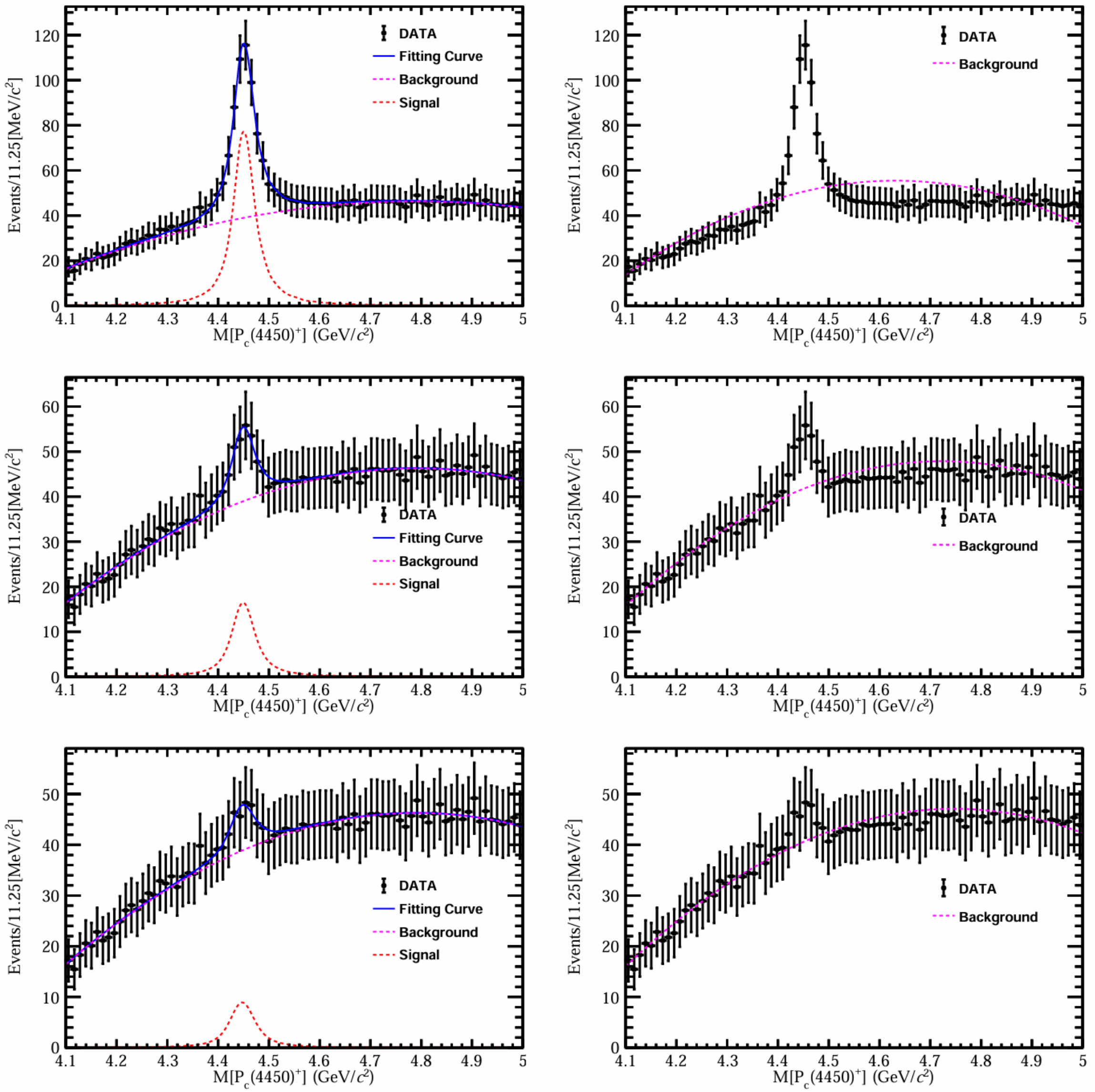
假设$e^+e^- \to J/\psi p\bar{p} = 1pb$, $e^+e^- \to P_c(4450)^+\bar{p} \to J/\psi p\bar{p} = 0.1/0.02/0.01\ pb$, 考虑到探测效率为$\epsilon = 47.2\%$

假设亮度为 **$10fb^{-1}$**，则本底事例数为1w(在[4.1,5.0]上为6550)，$P_c(4450)^+$事例数为1000/200/100

观察到的事例数为：本底数3090，信号数472/94.4/47.2

$$Significance = \sqrt{2(NLL_{model1} - NLL_{model2})}$$

信号本底混合比例	10比1	50比1	100比1
Signal NLL	-11087.80	-8010.83	-7640.22
Bkg NLL	-10980.50	-8002.73	-7637.26
Significance	14.65σ	4.02σ	2.43σ



$P_c(4450)^+$截面假设 ($\sqrt{s} = 6.5GeV$)

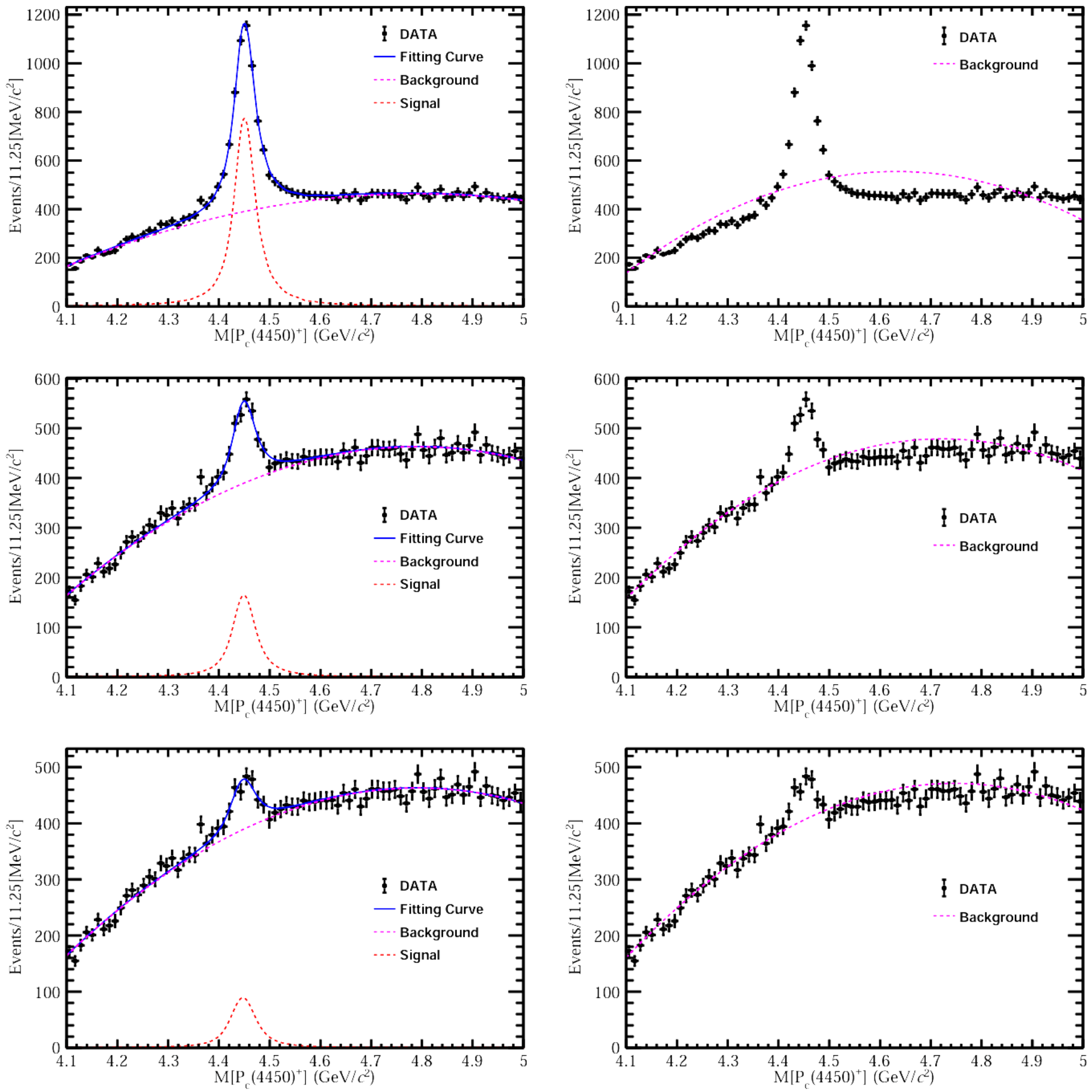
假设$e^+e^- \to J/\psi p\bar{p} = 1pb$, $e^+e^- \to P_c(4450)^+\bar{p} \to J/\psi p\bar{p}$ $= 0.1/0.02/0.01\ pb$, 考虑到探测效率为$\epsilon = 47.2\%$

假设亮度为 **$100fb^{-1}$**，则本底事例数为10w(在[4.1,5.0]上为6.55w)，$P_c(4450)^+$事例数为1w/2000/1000

观察到的事例数为：本底数3.09w，信号数4720/944/472

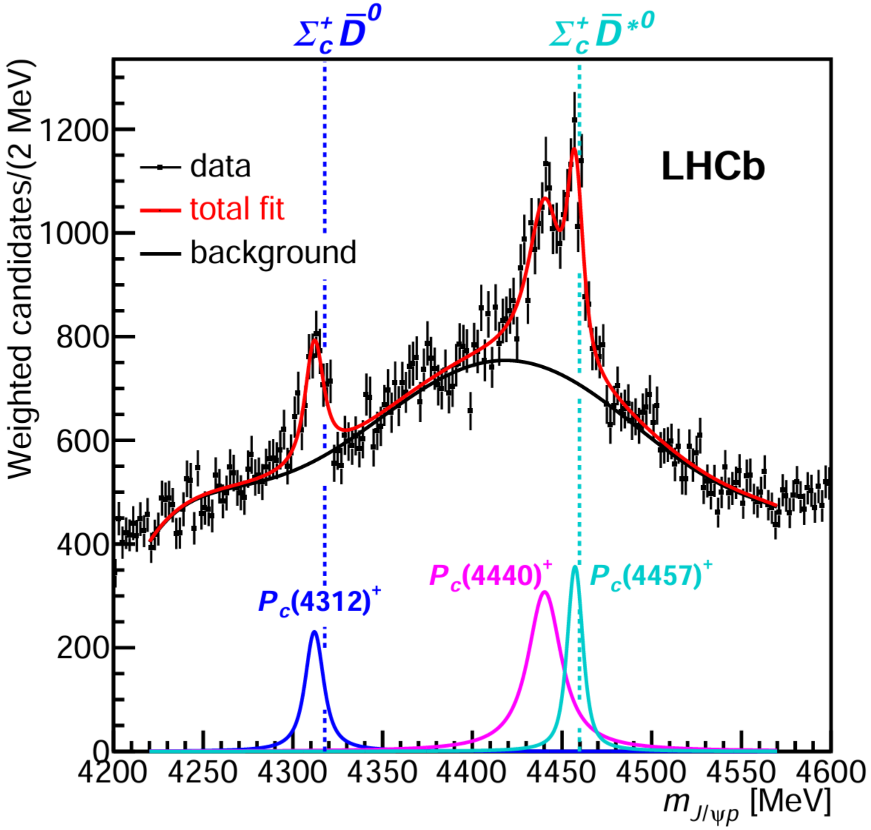
$$Significance = \sqrt{2(NLL_{model1} - NLL_{model2})}$$

信号本底混合比例	10比1	50比1	100比1
Signal NLL	-144607	-105636	-100904
Bkg NLL	-143534	-105555	-100875
Significance	46.32σ	12.73σ	7.62σ



Compare with LHCb result ($\sqrt{s} = 6.5GeV$)

LHCb Fitting Result



State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

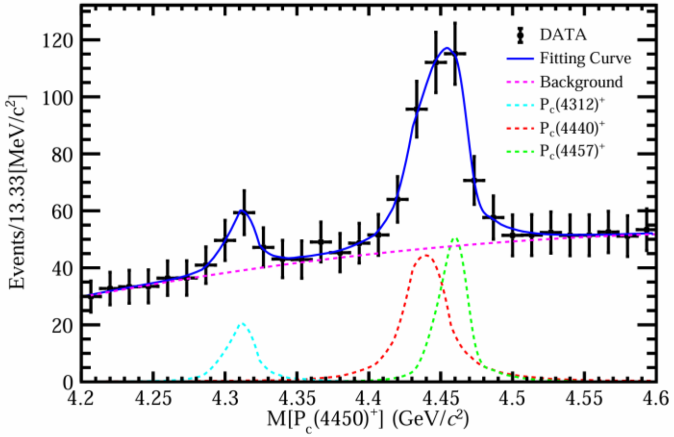
假设$e^+e^- \to J/\psi p\bar{p} = 1pb$, 考虑到探测效率为$\epsilon = 47.2\%$

	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$
截面	0.1pb	0.37pb	0.176pb
事例数	472	1746.4	833.9

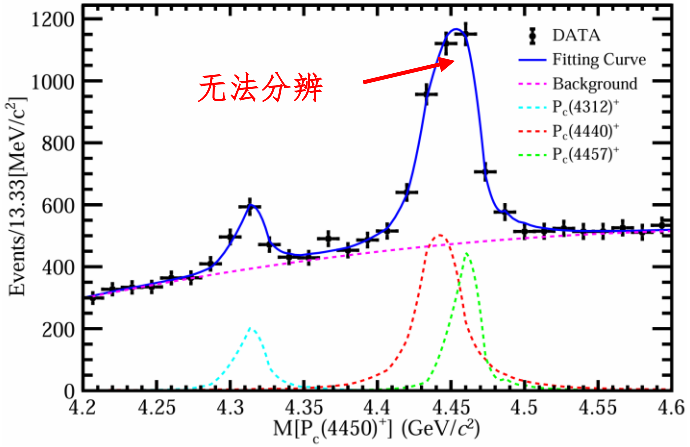
假设亮度为$100fb^{-1}$，则本底事例数为10w(在[4.2,4.6]上为27640)，观察到的本底事例数为：13046

Bins = 30

卷积高斯($10fb^{-1}$)

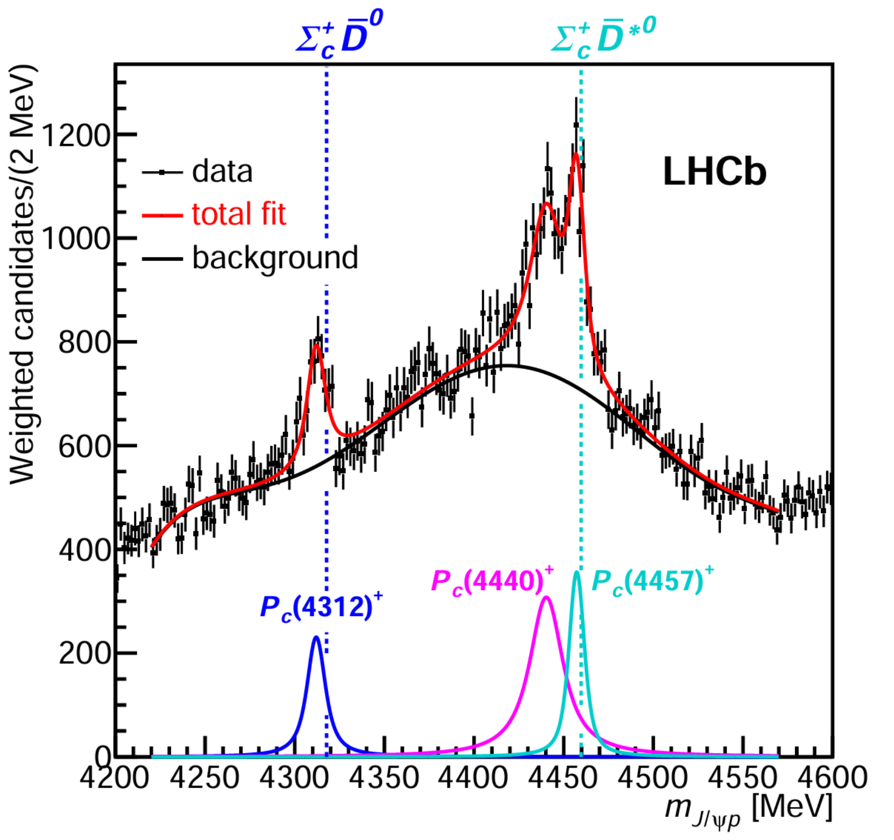


MC pdf ($100fb^{-1}$)



Compare with LHCb result ($\sqrt{s} = 6.5GeV$)

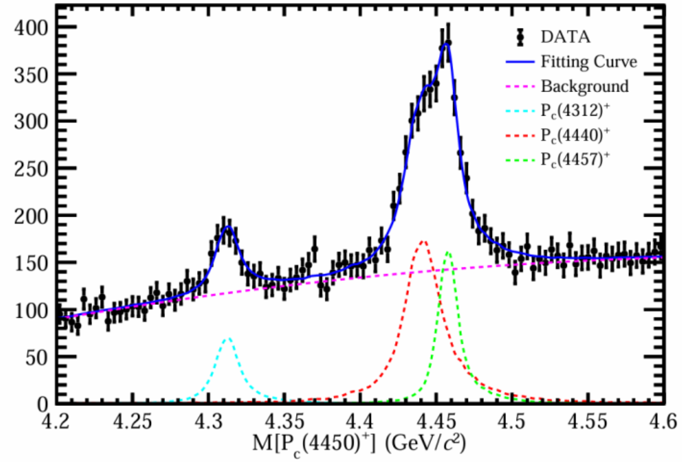
LHCb Fitting Result

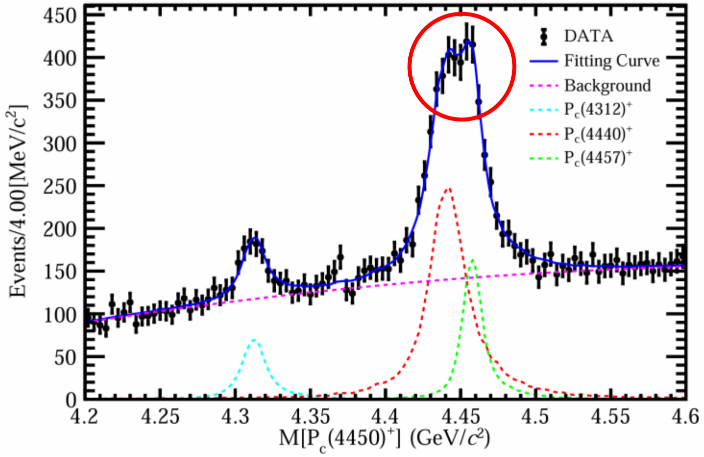


State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+3.7}_{-4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+5.7}_{-1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

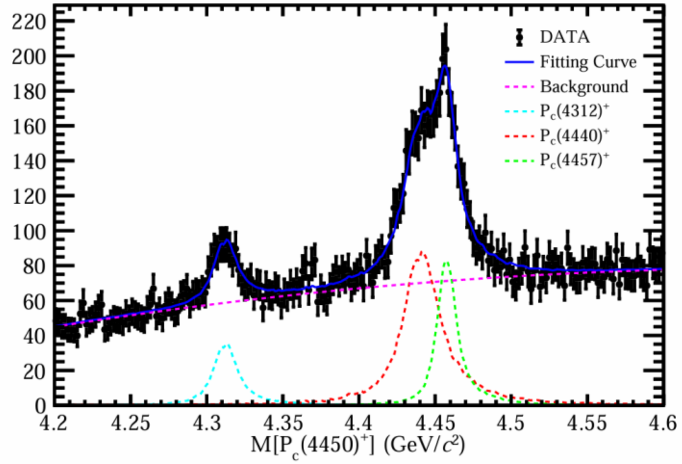
Bins = 100

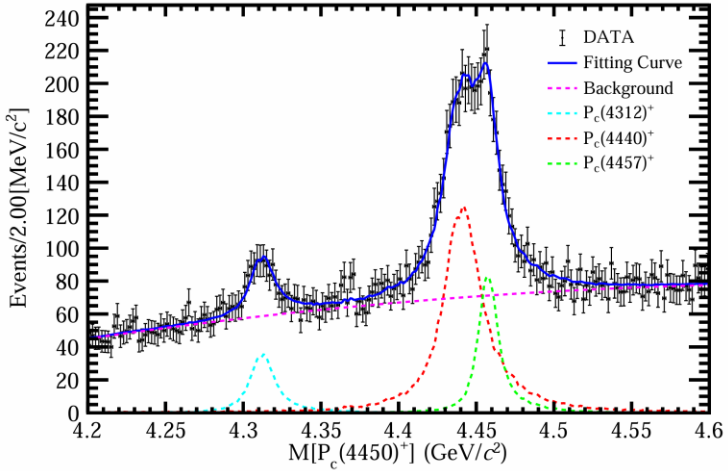
增大了$P_c(4440)^+$的比例





Bins = 200



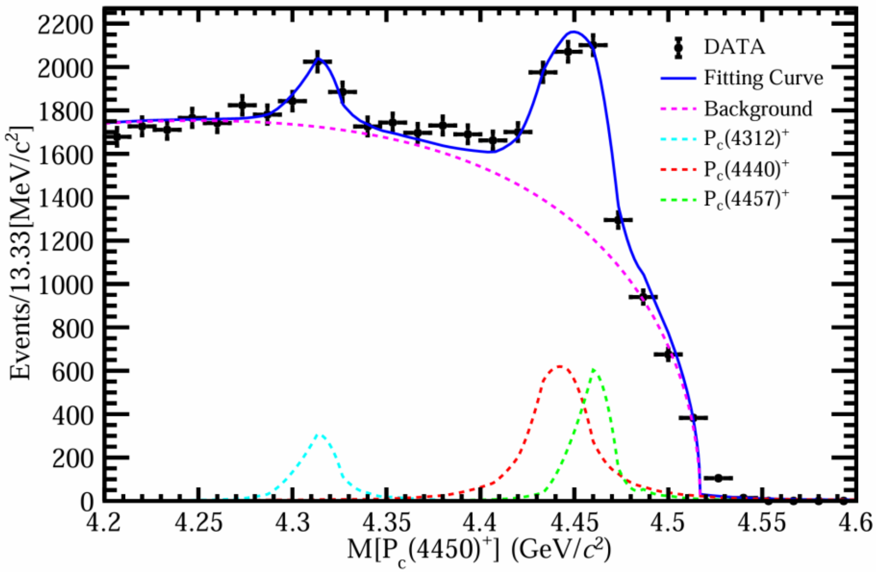


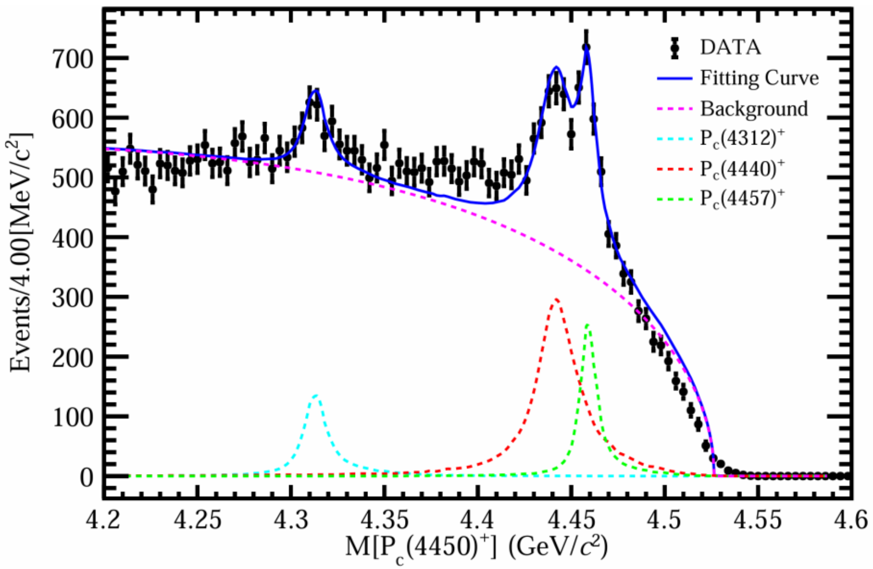
截面假设 $\sqrt{s} = 5.5GeV$

假设$e^+e^- \to J/\psi p\bar{p} = 1pb$, 考虑到探测效率为$\epsilon = 48.4\%$

	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$
截面	0.1pb	0.37pb	0.176pb
事例数	484.0	1790.8	851.8

假设亮度为$100fb^{-1}$，则本底事例数为1w(在[4.2,4.6]上为75127)， 观察到的本底事例数为：36361



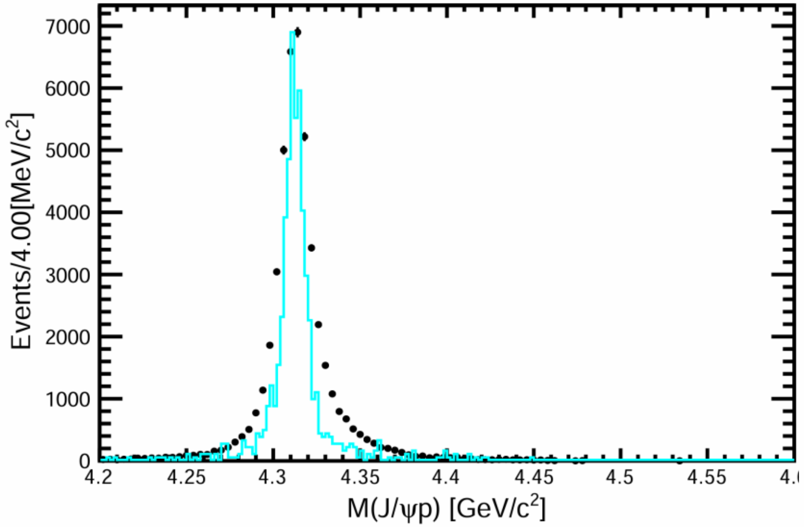


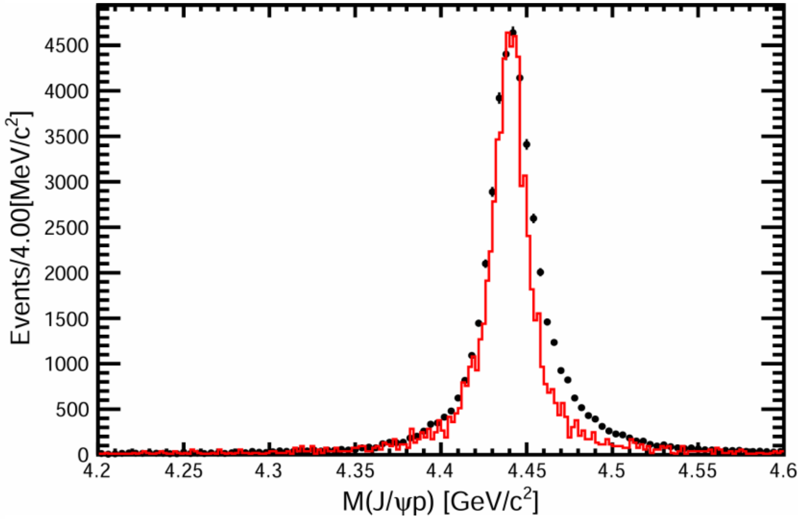
Cut Flow for different P_c states

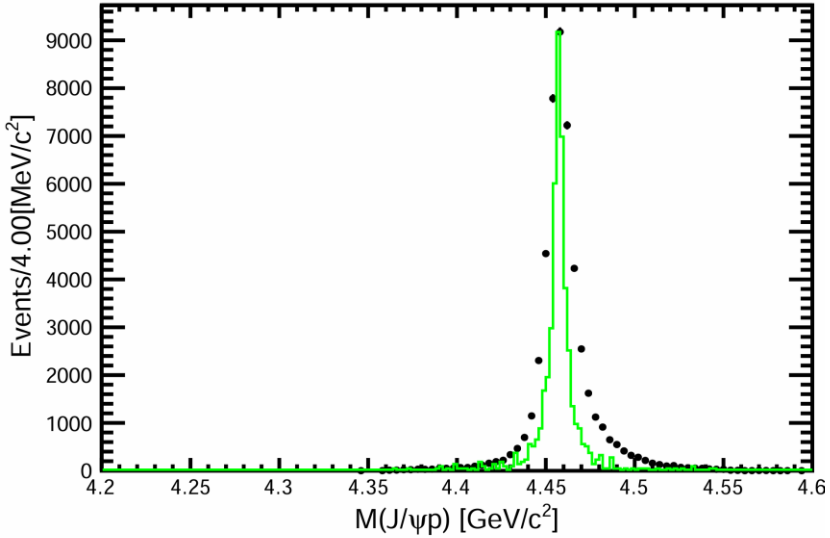
	Energy [GeV]	5.5			6.5		
	Resonance	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$
	Total number	100000	100000	100000	100000	100000	100000
$J/\psi \to e^+e^-$	Match Tracks	76.12%	73.16%	72.85%	76.01%	76.52%	76.16%
	nGoodp = nGoodm = 2	72.96%	67.45%	66.40%	73.80%	74.85%	74.36%
	$p = 1 \,\&\&\, \bar{p} = 1$	71.80%	63.76%	61.56%	66.59%	68.11%	67.56%
	$e^+ = 1 \,\&\&\, e^- = 1$ (PID)	71.54%	63.50%	61.32%	66.33%	67.82%	67.29%
	After Vertex Fit	70.75%	62.75%	60.60%	65.58%	67.09%	66.55%
	After Kmfit Fit	55.78%	52.92%	51.75%	46.27%	47.56%	47.28%
	$J/\psi \in [3.05, 3.15]\ GeV$	54.98%	52.50%	51.56%	45.22%	46.46%	46.25%
$J/\psi \to \mu^+\mu^-$	Match Tracks	76.43%	73.45%	73.10%	75.97%	76.63%	76.19%
	nGoodp = nGoodm = 2	73.88%	68.56%	67.54%	74.64%	75.55%	75.07%
	$p = 1 \,\&\&\, \bar{p} = 1$	72.77%	64.61%	62.48%	67.51%	68.87%	68.43%
	$\mu^+ = 1 \,\&\&\, \mu^- = 1$ (PID)	68.44%	60.54%	58.64%	62.92%	64.11%	63.79%
	After Vertex Fit	67.95%	60.15%	58.27%	62.42%	63.66%	63.35%
	After Kmfit Fit	62.43%	58.97%	57.59%	50.67%	52.07%	52.04%
	$J/\psi \in [3.05, 3.15]\ GeV$	61.52%	58.53%	57.39%	49.71%	51.12%	51.05%

Truth Compare

The comparison of truth and rec level for each P_c^+ resonance is shown in the figure below.

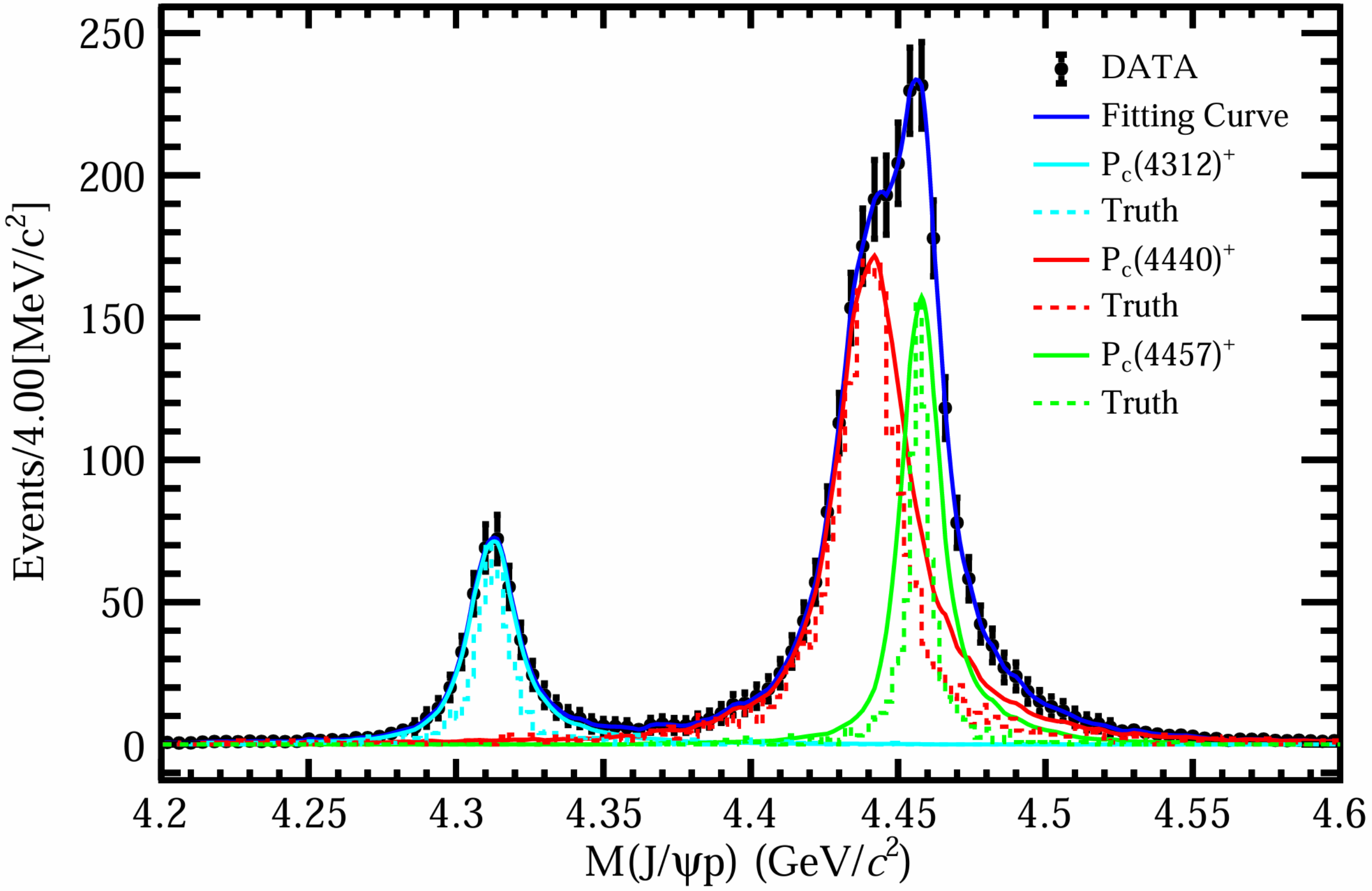




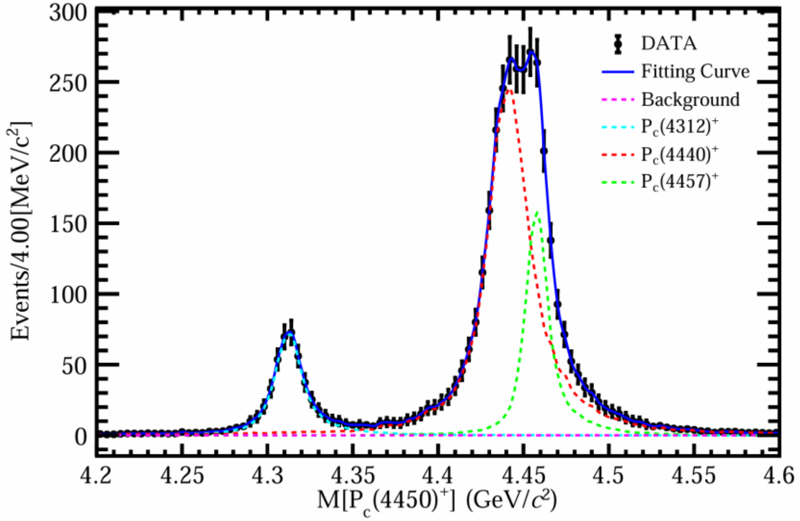


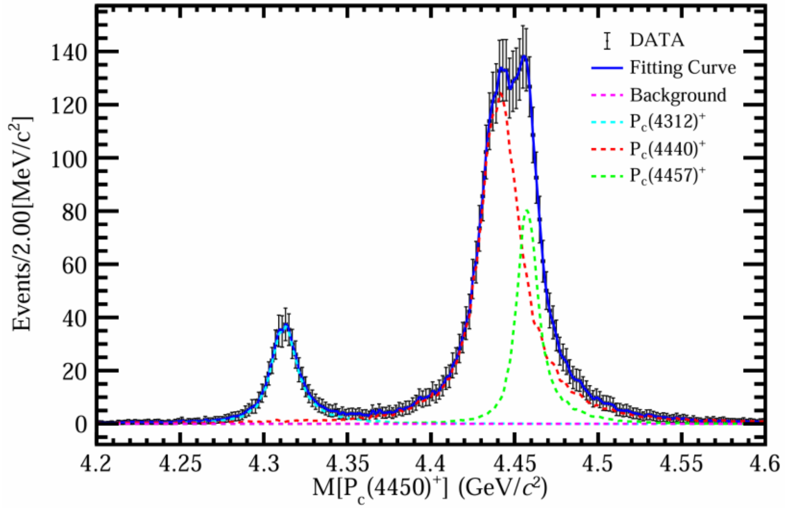
No Background

Original Ratio (Rec and Truth)



Raise $P_c(4440)^+$ Ratio





Backup

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- Yin J H, Li Y B, Won E, et al. Search for the double-charmonium state with ηcJ/ψ at Belle[J]. Journal of High Energy Physics, 2023, 2023(8): 1-21.

1. Chen Z Z, Chen X L, Yang P F, et al. P-wave fully charm and fully bottom tetraquark states[J]. Physical Review D, 2024, 109(9): 094011.
2. Faustov R N, Galkin V O, Savchenko E M. Fully heavy tetraquark spectroscopy in the relativistic quark model[J]. Symmetry, 2022, 14(12): 2504.
3. Dong W C, Wang Z G. Going in quest of potential tetraquark interpretations for the newly observed T ψ ψ states in light of the diquark-antidiquark scenarios[J]. Physical Review D, 2023, 107(7): 074010.
4. Debastiani V R, Navarra F S. A non-relativistic model for the tetraquark[J]. Chinese Physics C, 2019, 43(1): 013105.
5. Liu M S, Liu F X, Zhong X H, et al. Fully heavy tetraquark states and their evidences in LHC observations[J]. Physical Review D, 2024, 109(7): 076017.
6. Wang G J, Meng L, Oka M, et al. Higher fully charmed tetraquarks: Radial excitations and P-wave states[J]. Physical Review D, 2021, 104(3): 036016.

单标η_c

Exclusive MC production under OSCAR

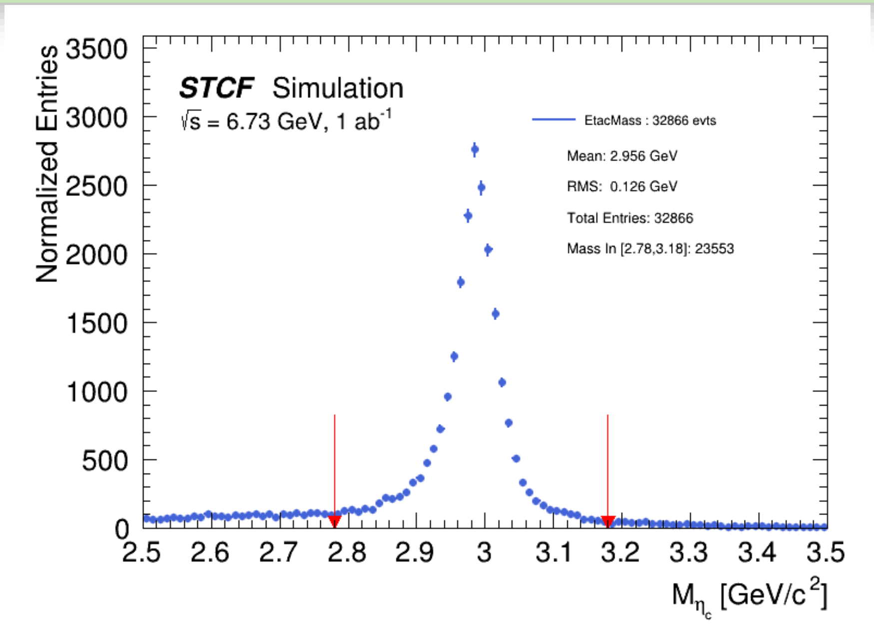
Generator：ConExc

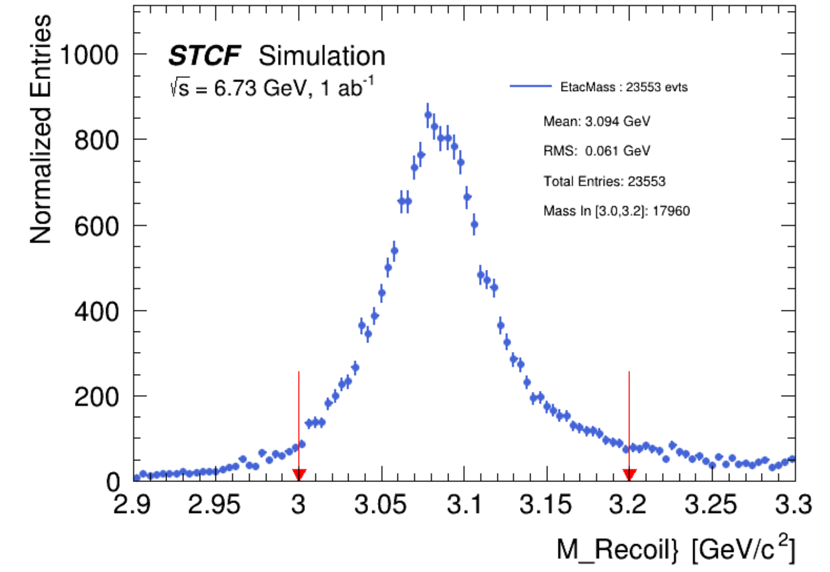
$\sqrt{S}$：6.73GeV   Number of event: 100000

Signal Channel：$e^+e^- \to T_{4c} \to \eta_c J/\psi$，

- $\eta_c \to K^+K^-\pi^0, J/\psi \to anything$

Cut Flow	N_{obs}	Relative Efficiency
$otal\ number$:	50000	100.00%
$nGood \geq 2$:	49015	98.05%
$nGood\gamma \geq 2$:	48676	99.30%
$nK_p \geq 1$:	40225	82.64%
$nK_m \geq 1$:	32866	81.71%
$n\pi^0 \geq 1$:	31284	95.13%
$\eta_c$mass cut:	23553	75.29%
Recoil mass cut:	17960	76.25%
$total\ cut$:	35.92%	





缪子

能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	17363	17500	17367	17521	16870	17557	17421	17311	17005
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	34.73%	35.00%	34.73%	35.04%	34.43%	35.11%	34.84%	34.62%	34.70%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	0.1	0.2	0.3	0.8	1.5	0.8	0.3	0.2	0.1

电子

能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	14378	14282	14129	14416	14001	14026	14418	14315	14275
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	28.76%	28.56%	28.83%	28.83%	28.57%	28.62%	28.84%	28.63%	28.55%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	0.1	0.1	0.3	0.6	1.3	0.6	0.3	0.1	0.1

单标J/ψ信号数据

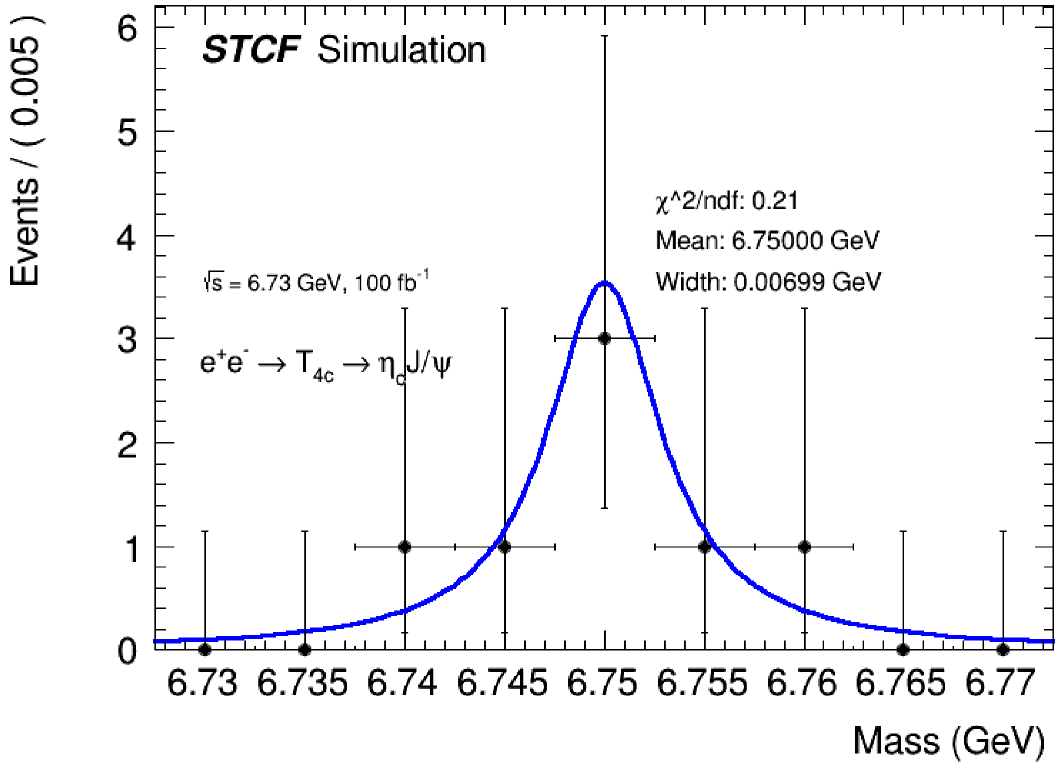
缪子

能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	39290	39121	39152	39252	39296	39230	39410	39242	39240
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	78.58%	78.24%	78.30%	78.50%	78.59%	78.46%	78.82%	78.48%	78.48%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	17.8	30.1	60.2	150.8	301.9	150.6	60.5	30.1	17.7

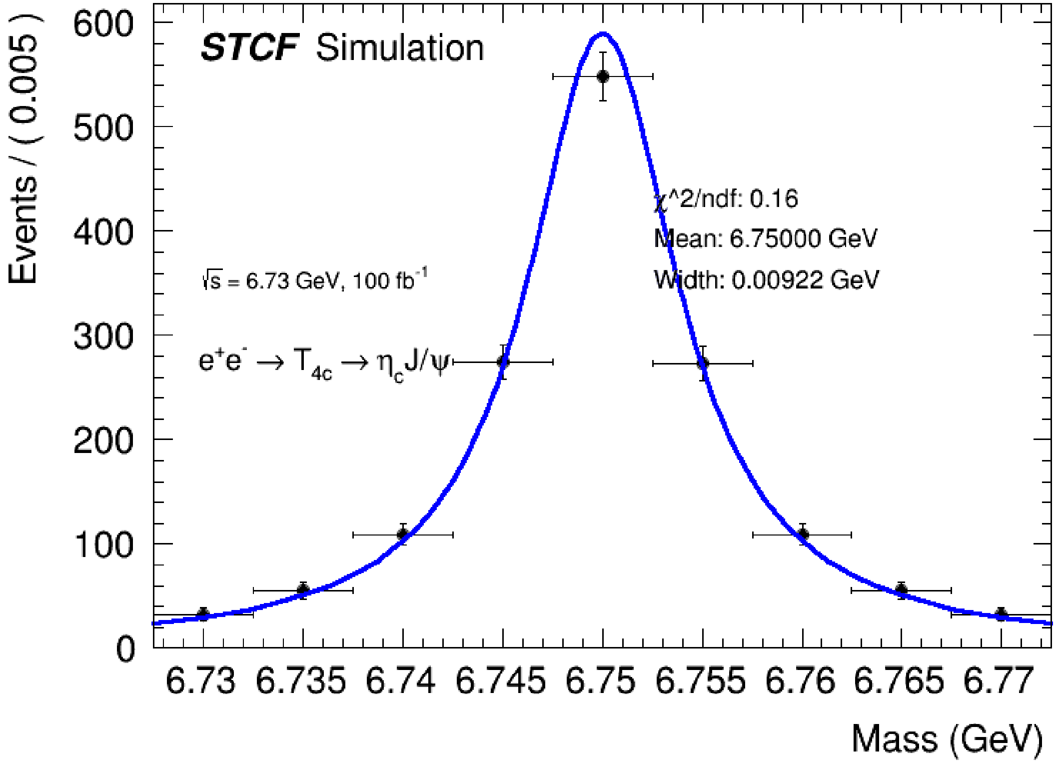
电子

能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	31287	29457	31308	31411	30698	30652	31886	30745	31238
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	63.85%	64.04%	63.89%	64.10%	63.95%	63.86%	63.77%	64.05%	63.75%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	14.5	24.6	49.1	123.2	245.7	122.6	48.9	24.6	14.4

➢ 只拟合信号

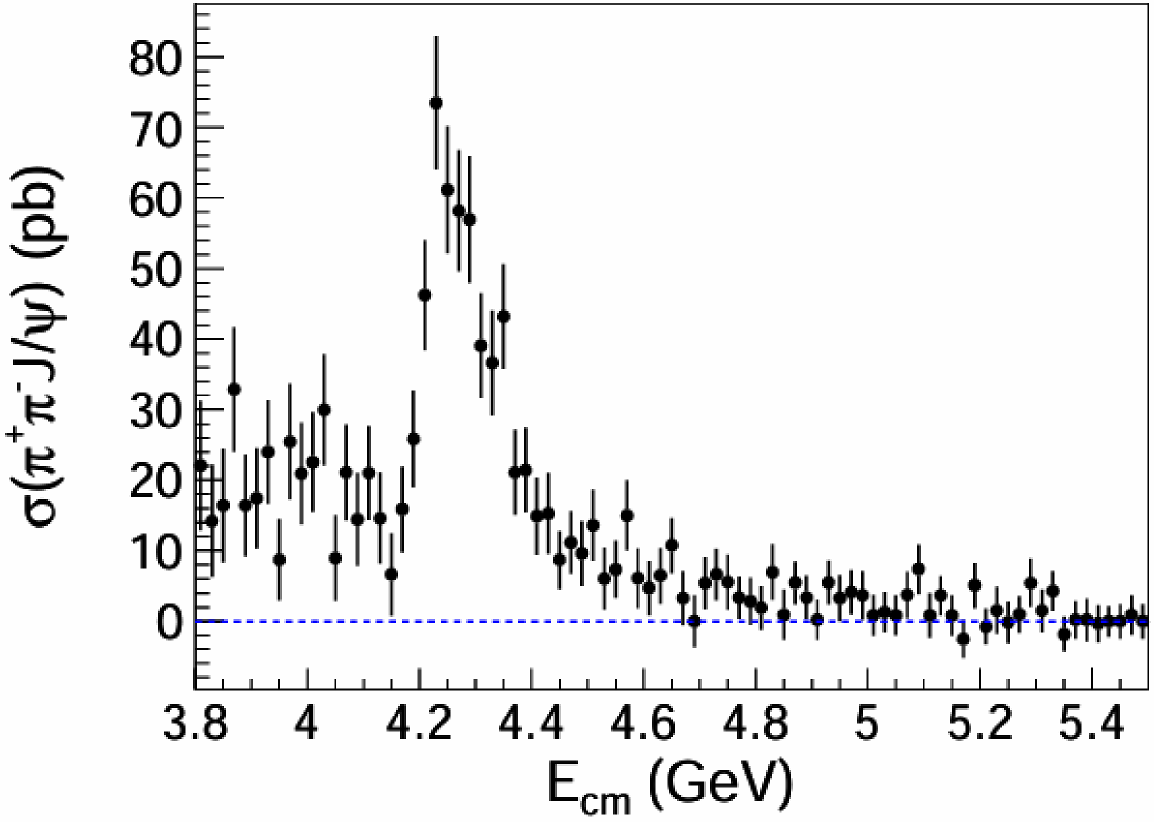


Events / (0.005)
STCF Simulation
χ^2/ndf: 0.21
Mean: 6.75000 GeV
Width: 0.00699 GeV
√s = 6.73 GeV, 100 fb-1
$e^+e^- \to T_{4c} \to \eta_c J/\psi$
Mass (GeV)



Events / (0.005)
STCF Simulation
χ^2/ndf: 0.16
Mean: 6.75000 GeV
Width: 0.00922 GeV
√s = 6.73 GeV, 100 fb-1
$e^+e^- \to T_{4c} \to \eta_c J/\psi$
Mass (GeV)

截面预估参考



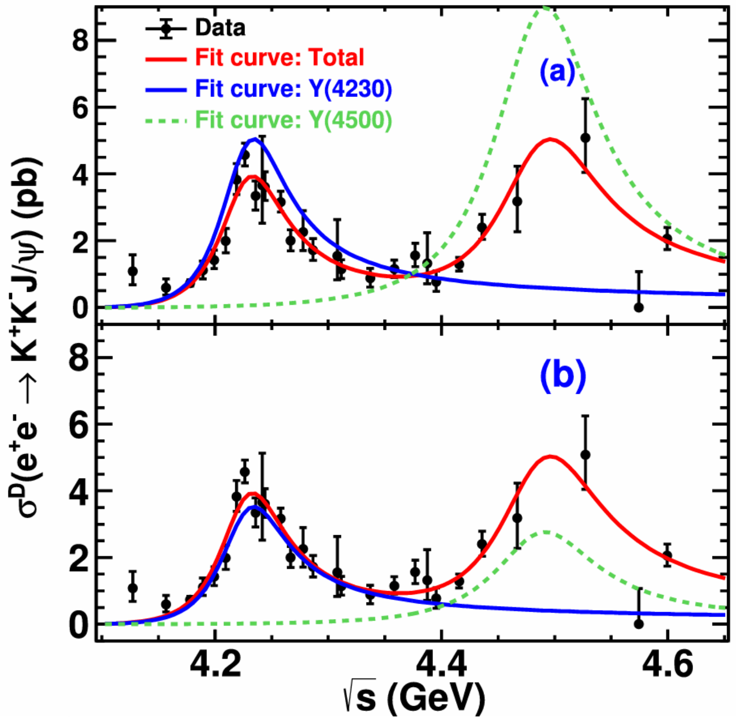


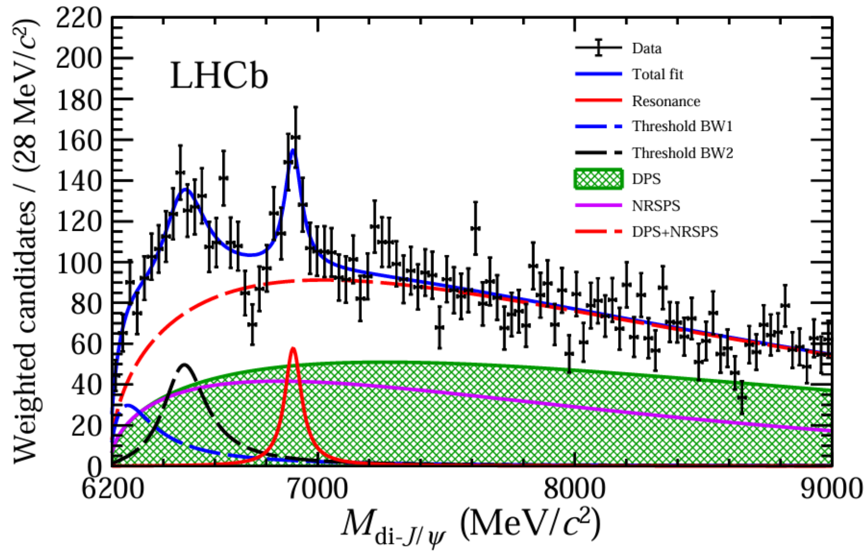
Figure 6: Cross sections of $e^+e^- \to K^+K^-J/\psi$, indicated by error bars with only statistical uncertainties. They are fitted by a coherent sum of two Breit-Wigner functions indicated by red solid curves. The Blue and green dashed curves are the amplitudes describing the resonances $Y(4230)$ and $Y(4500)$, respectively. (a) corresponds to solution I, (b) corresponds to solution II [22].

LHCB实验结果

➤ **Observation of structure in the J/ψ-pair mass spectrum**

- **States:** $T_{c\bar{c}c\bar{c}}(6550)^0$, $T_{c\bar{c}c\bar{c}}(6900)^0$, $T_{c\bar{c}c\bar{c}}(7290)^0$
- **Quantum numbers:** $I^G(J^{PC}) = 0^+(?^{?+})$
- **Minimal quark content:** $c\bar{c}c\bar{c}$
- **Experiments:** LHCb(first observed), ATLAS, CMS
- **Production:** prompt pp collisions
- **Decay modes:** $J/\psi J/\psi$
- **Nearby thresholds:** $J/\psi\psi(2S), \chi_{c0}\chi_{c0}, \dots$
- **Characteristic widths:** $80 - 191\ MeV$

- LHCb Collaboration. Observation of structure in the J/ψ-pair mass spectrum[J]. Science bulletin, 2020, 65(23): 1983-1993.



LHCb results:

Structure	Significance	
	$p_T^{\text{di-}J/\psi}$-threshold	$p_T^{\text{di-}J/\psi}$-binned
Any structure beyond NRSPS plus DPS	$3.4\,\sigma$	$6.0\,\sigma$
Threshold enhancement plus $X(6900)$	$6.4\,\sigma$	$6.9\,\sigma$
Threshold enhancement	$6.0\,\sigma$	$6.5\,\sigma$
$X(6900)$	$5.1\,\sigma$	$5.4\,\sigma$

Truth information

$\sqrt{s} = 6.73$ GeV

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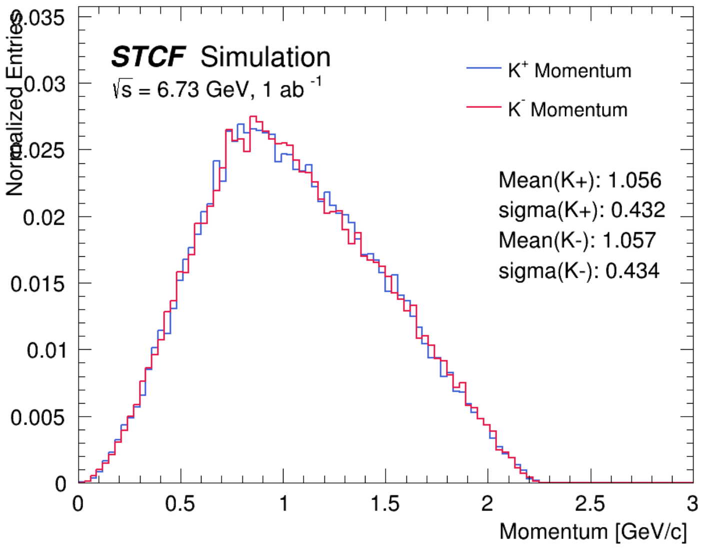
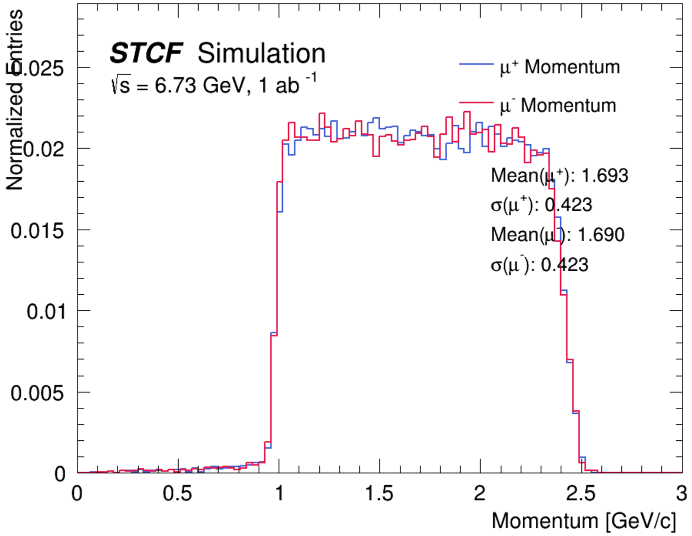
Kaon 动量分布--truth

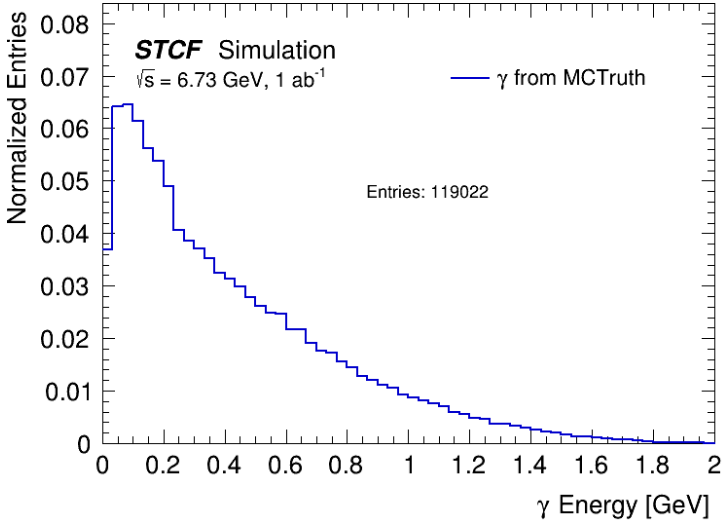


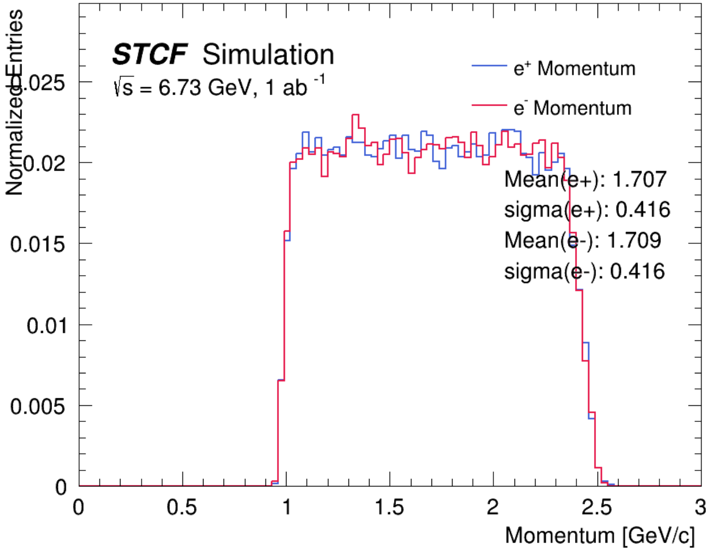
muon 动量分布--truth



动量大部分大于0.9GeV/c

光子能量分布--truth

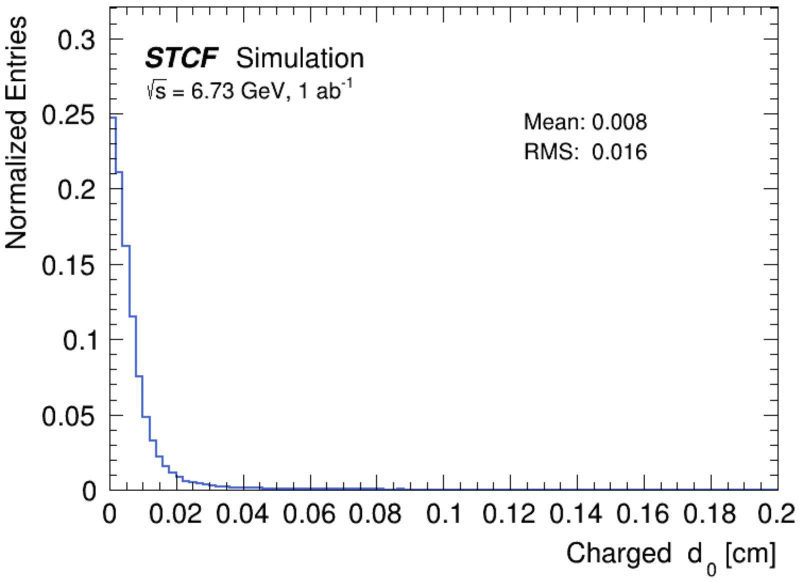




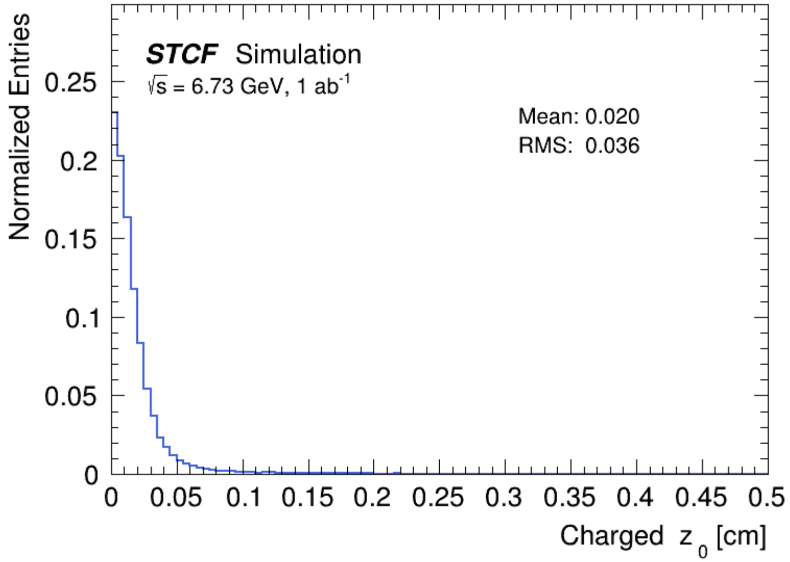
电子动量分布--truth

带电径迹 d_0、z_0、θ 分布

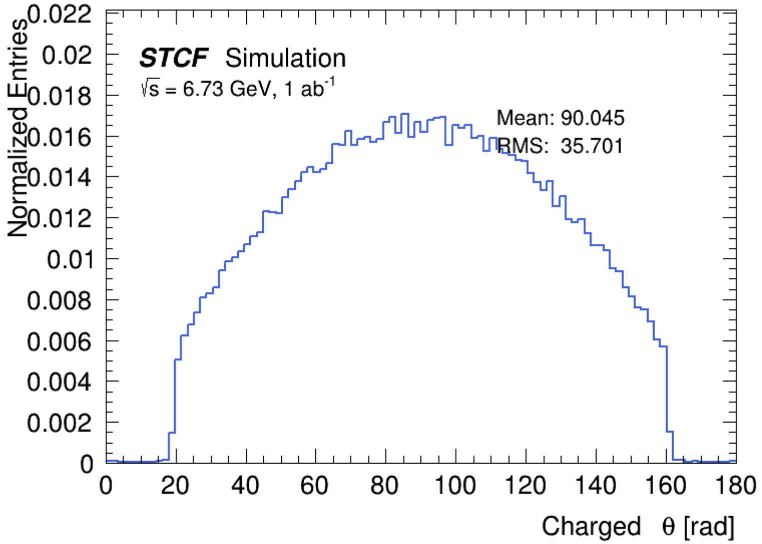
- 径迹参数从POCA点得到



d_0 分布



Z_0分布



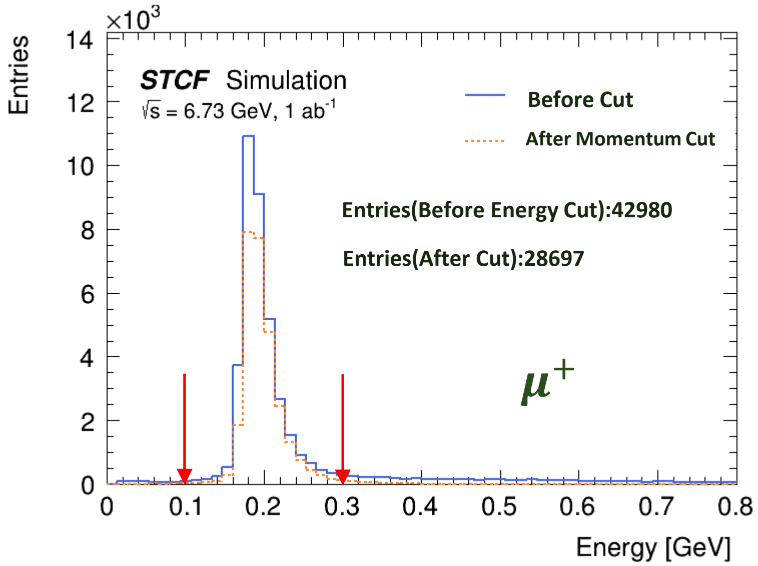
θ 分布

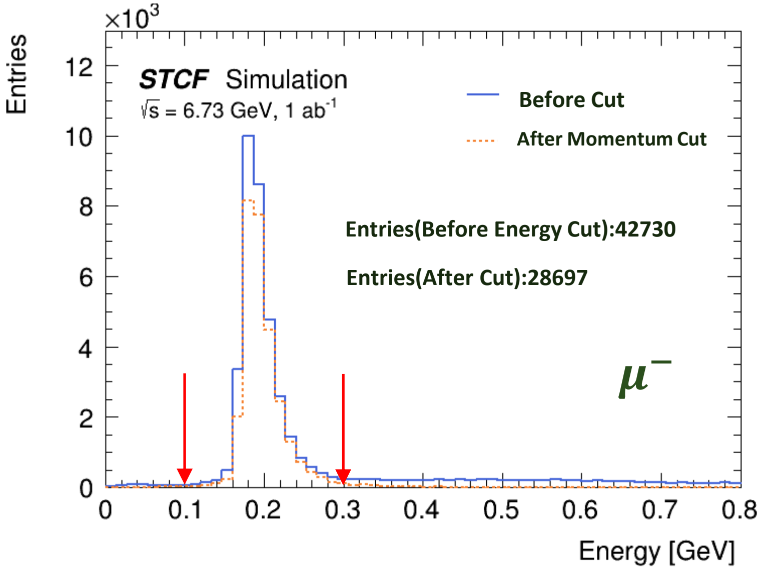
选择缪子

- **筛选条件：** $0.1 \le E_{emc} \le 0.3$ ， $|p_\mu| \ge 0.9\ GeV$

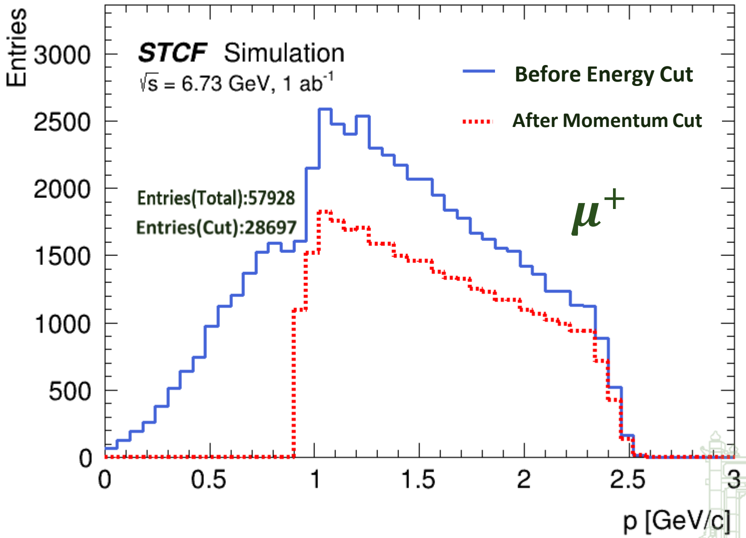
$\sqrt{s} = 6.73\ \mathrm{GeV}$

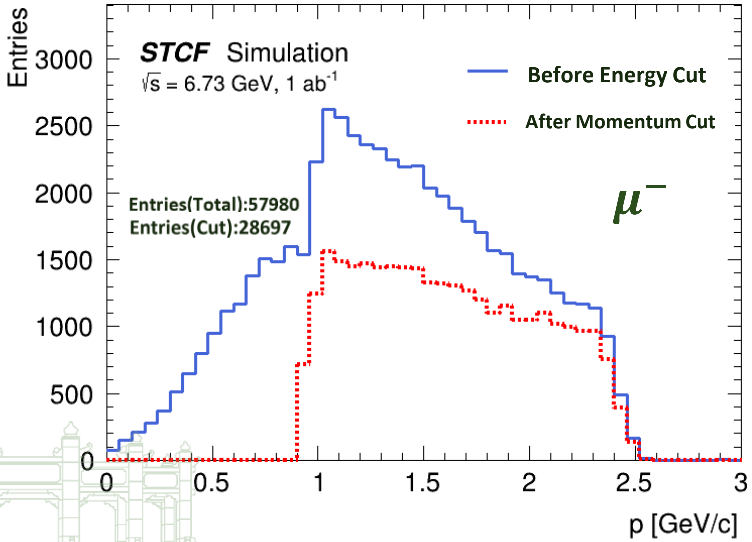
Emc里的能量沉积分布：





动量分布：



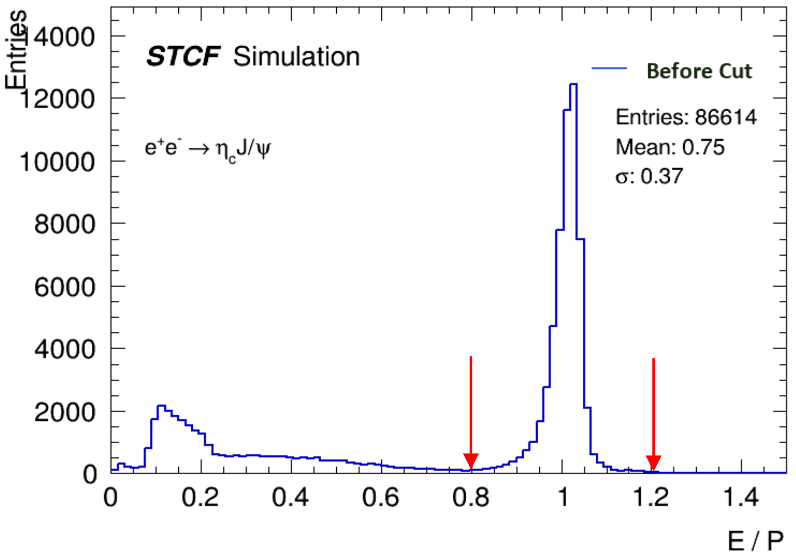


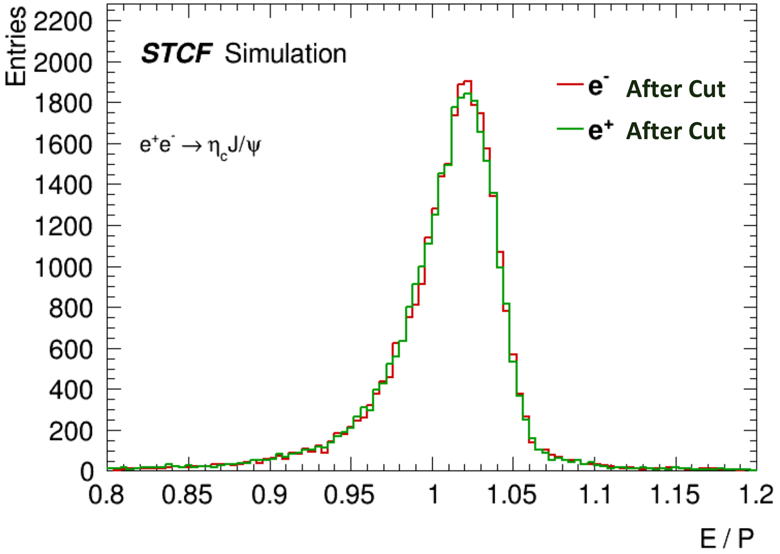
选择电子

- 筛选条件 $0.8 \le \frac{E_e}{p_e} \le 1.2$ ， $|p_e| \ge 0.9\ GeV$

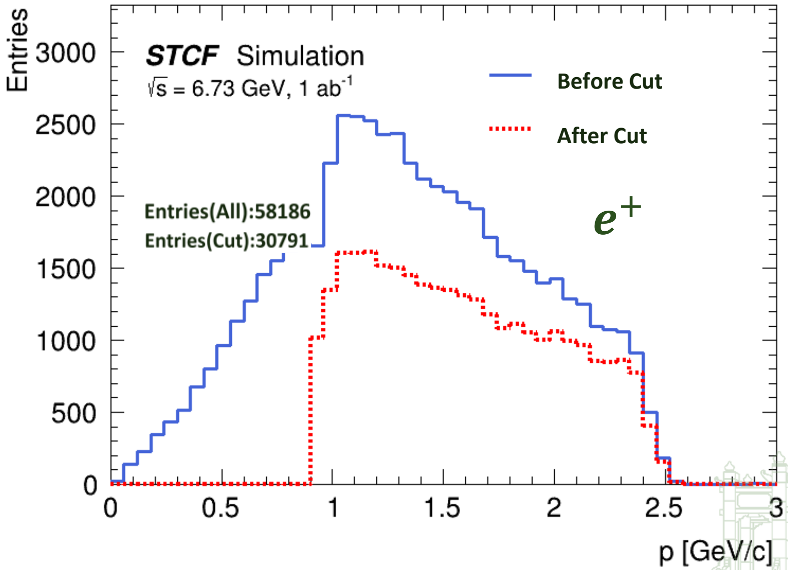
$\sqrt{S} = 6.73$ GeV

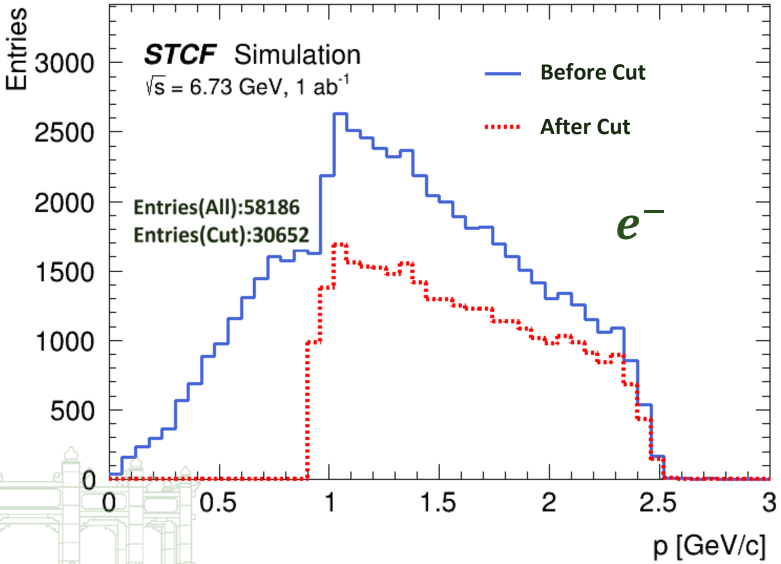
E/P分布：





动量分布：





重建η_c和J/ψ

- $\sqrt{S} = 6.73$ GeV

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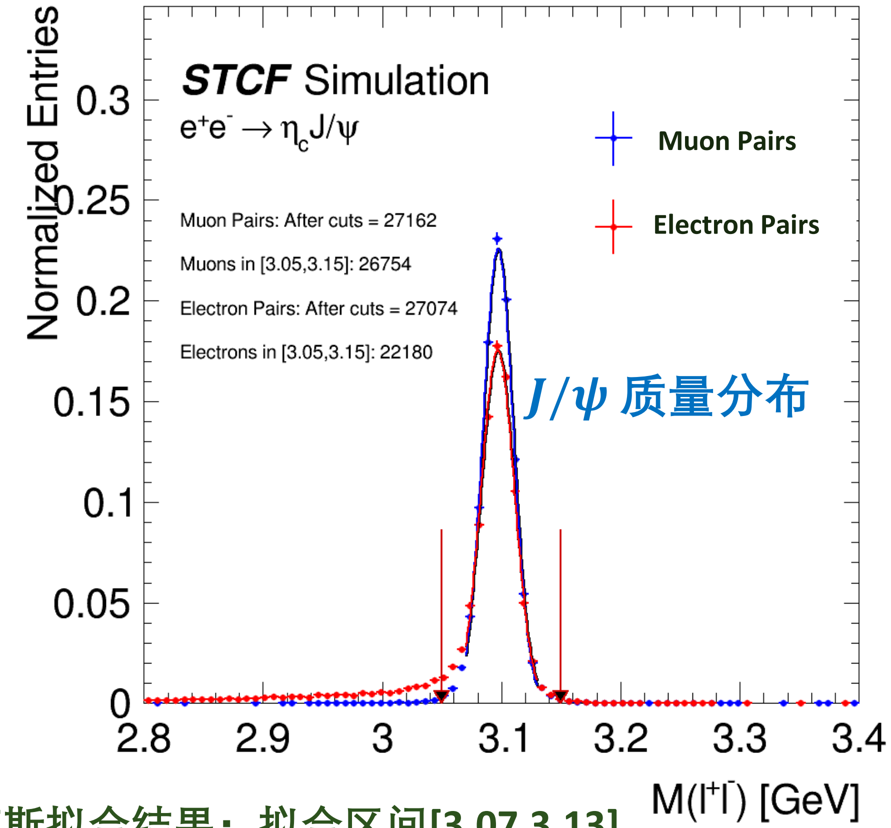
➢ $J/\psi \to \mu^+\mu^-$和$J/\psi \to e^+e^-$的质量分布对比

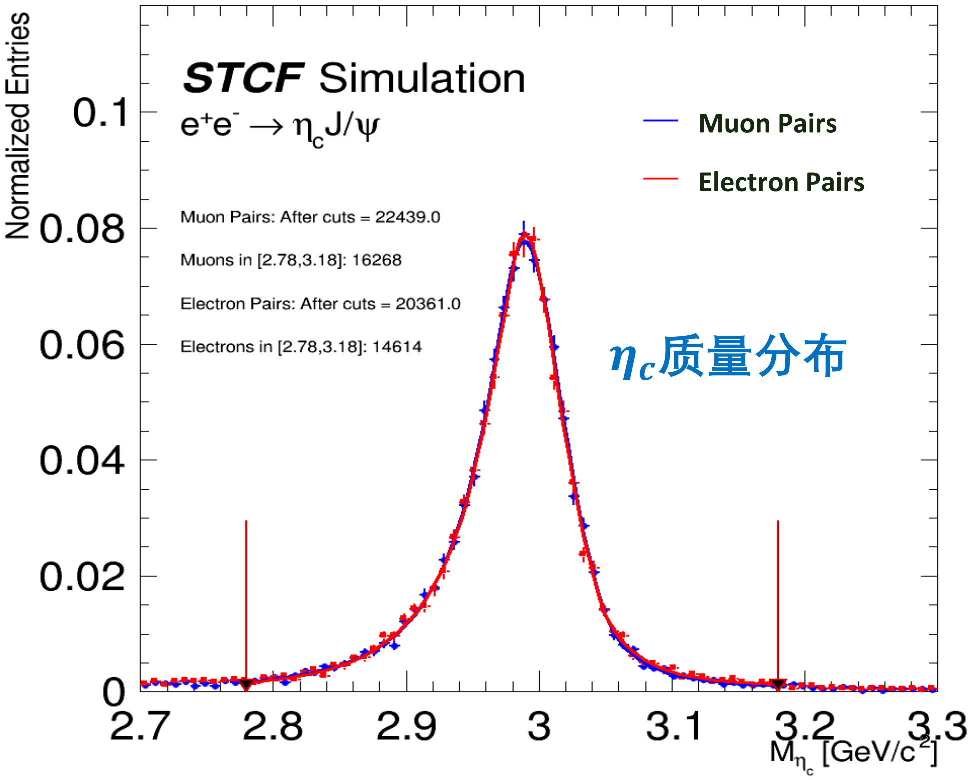
J/ψ $Mass\ cut$： $3.05GeV < M_{Le^+Le^-} < 3.15GeV$



单高斯拟合结果：拟合区间[3.07,3.13]

- $\mu: \sigma = 12.79 \pm 0.07MeV, mean = 3.097 \pm 0.001$
- $e: \sigma = 14.05 \pm 0.10MeV, mean = 3.096 \pm 0.001$

η_c $Mass\ cut$： $2.78GeV < M_{K^+K^-\pi^0} < 3.18GeV$



单高斯+双左右两个 Crystal Ball拟合结果：

- $\mu: \sigma = 49.99 \pm 5.02MeV, mean = 2.989 \pm 0.023$
- $e: \sigma = 49.99 \pm 5.21MeV, mean = 2.979 \pm 0.006$

$\sqrt{S} = 6.73$ GeV

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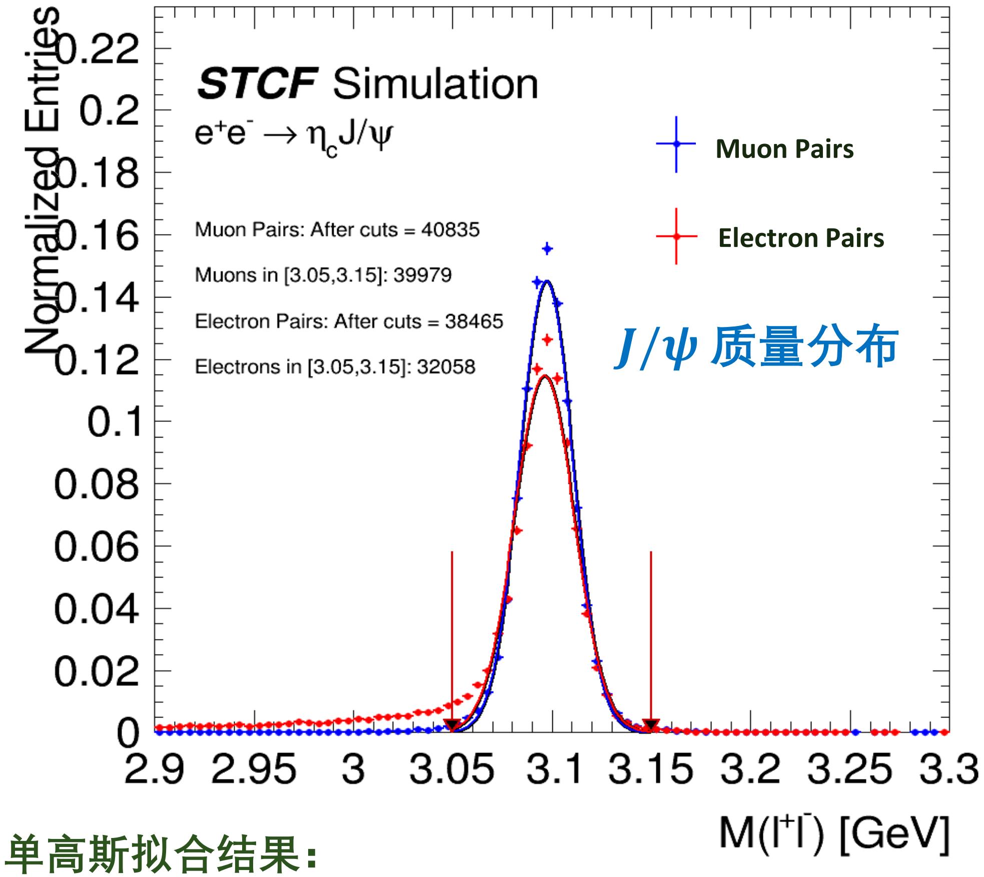
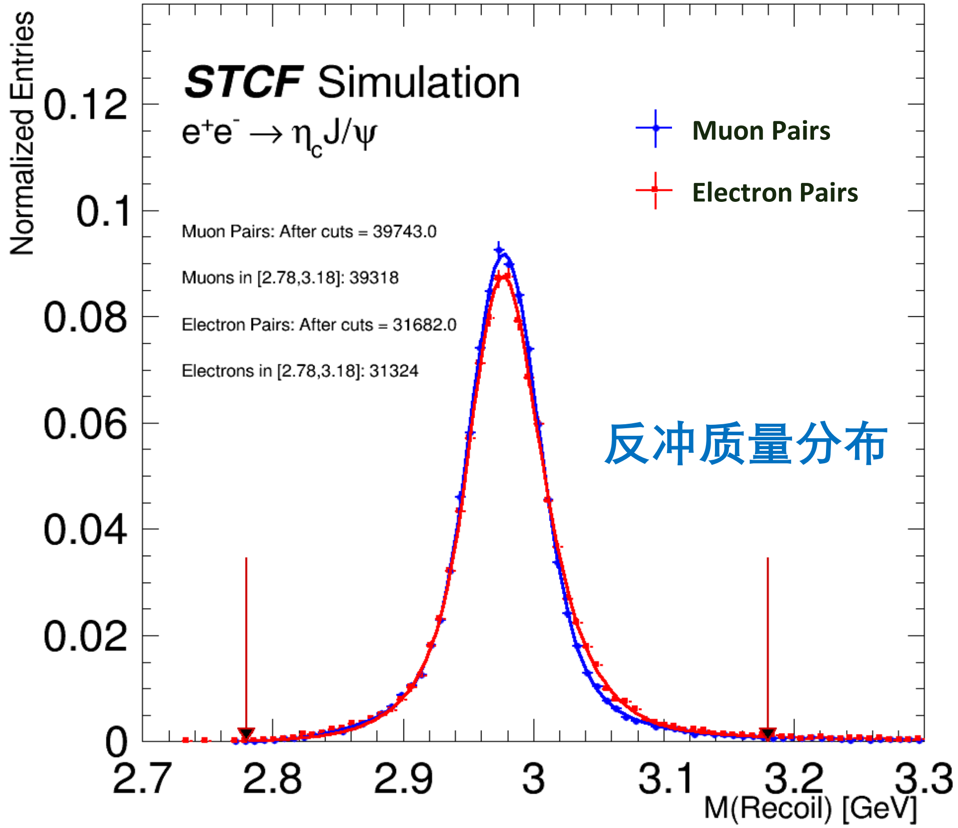
➢ $J/\psi \to \mu^+\mu^-$和$J/\psi \to e^+e^-$的质量分布对比

J/ψ $Mass\ cut$： $3.05GeV < M_{l e^+ l e^-} < 3.15GeV$

$Recoil$ $Mass\ cut$： $2.78GeV < M_{recoil} < 3.18GeV$





单高斯拟合结果：

- μ: $\sigma = 13.40 \pm 0.06MeV, mean = 3.097 \pm 0.007$
- e: $\sigma = 15.05 \pm 0.08MeV, mean = 3.096 \pm 0.009$

单高斯+双左右两个 Crystal Ball拟合结果：

- μ: $\sigma = 37.13 \pm 1.89MeV, mean = 2.881 \pm 0.003$
- e: $\sigma = 34.63 \pm 2.50MeV, mean = 3.019 \pm 0.003$

Truth information

$\sqrt{s} = 6.73$ GeV

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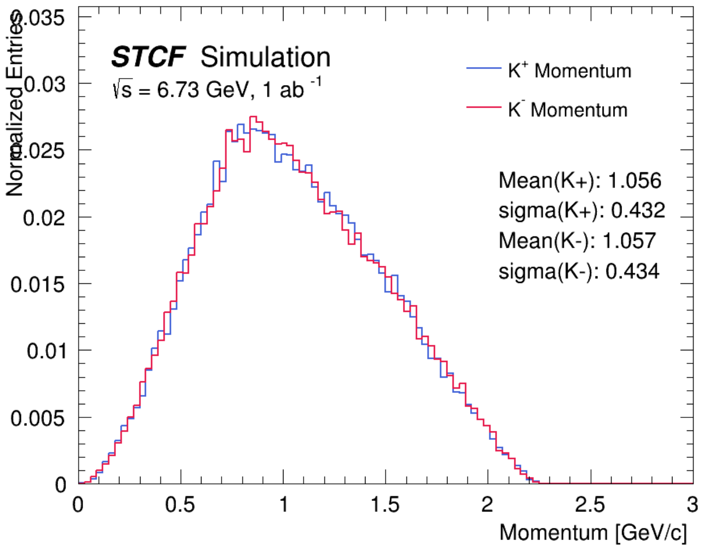
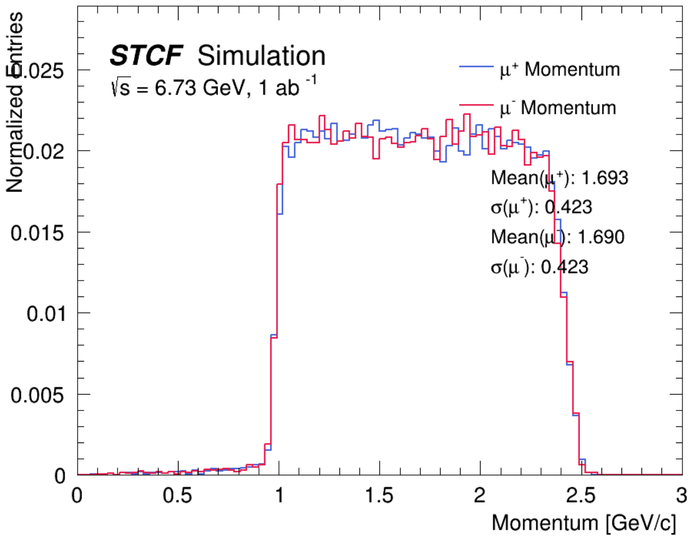
Kaon 动量分布--truth

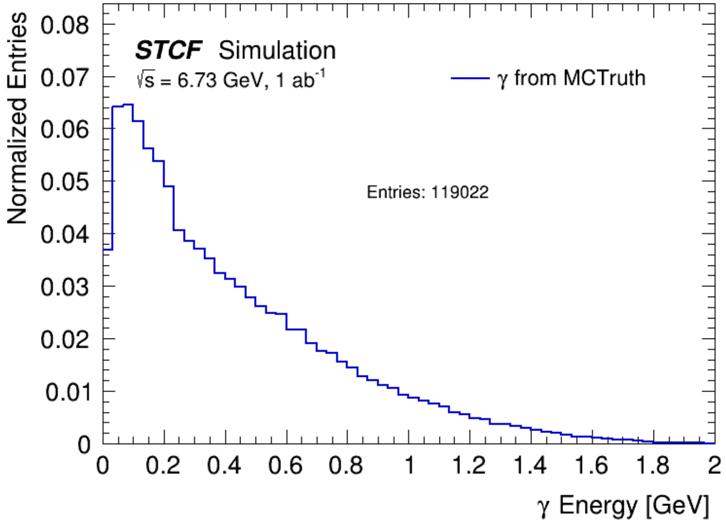


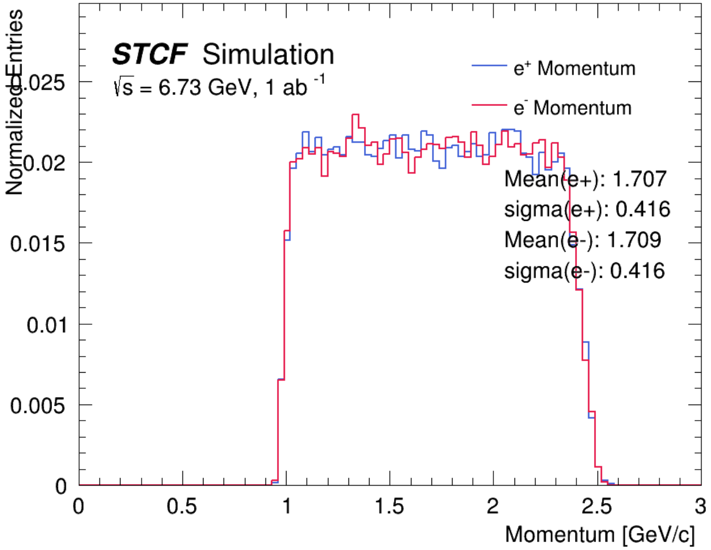
muon 动量分布--truth



动量大部分大于0.9GeV/c

光子能量分布--truth

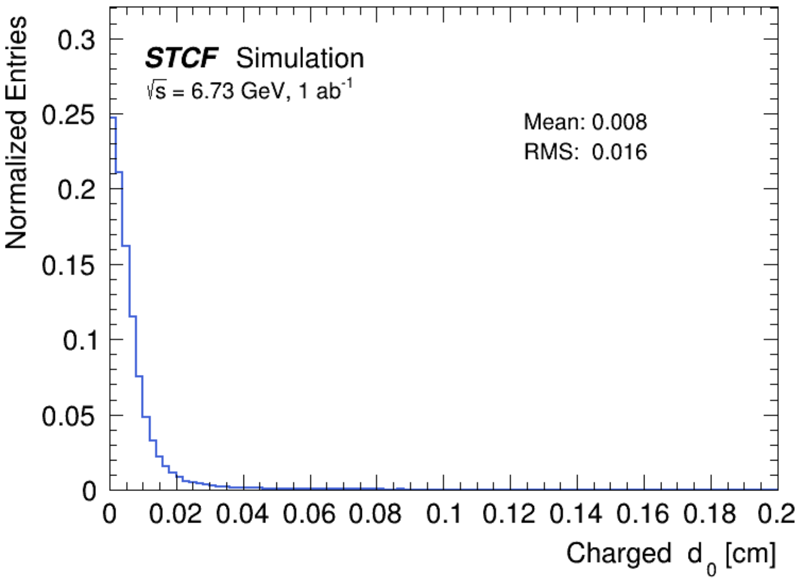




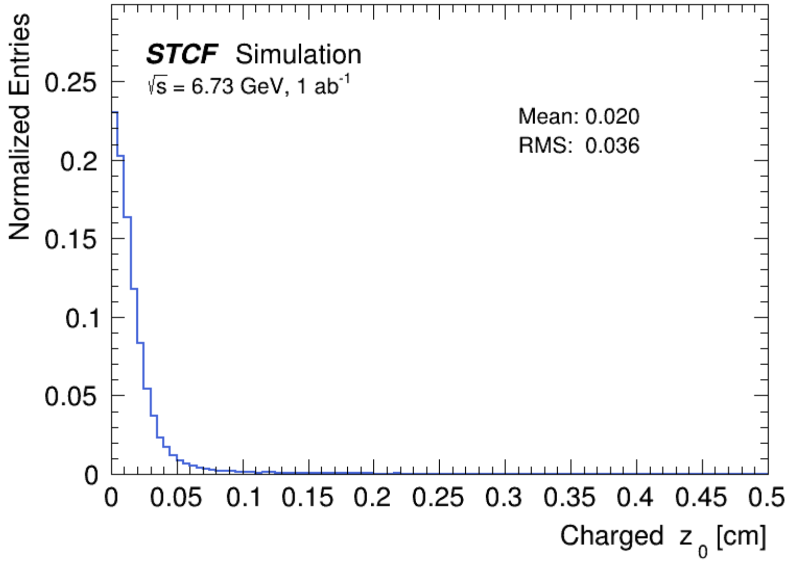
电子动量分布--truth

带电径迹 d_0、z_0、θ 分布

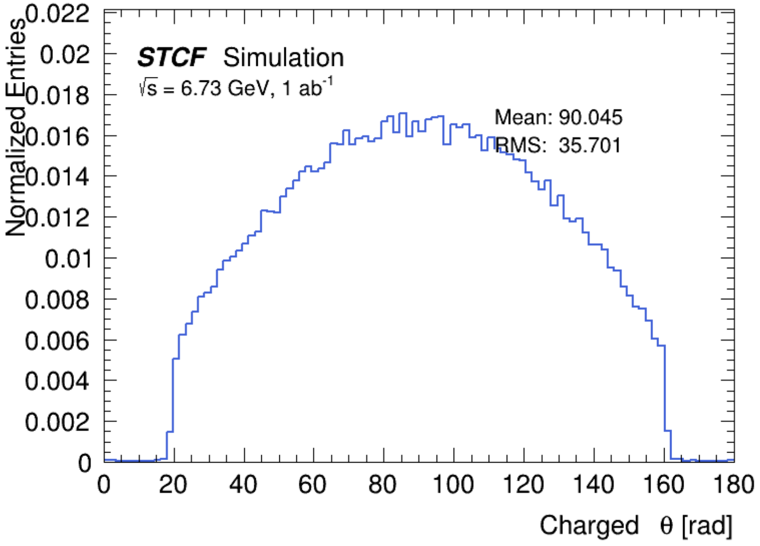
- ➢ 径迹参数从POCA点得到



d_0 分布



Z_0分布



θ 分布

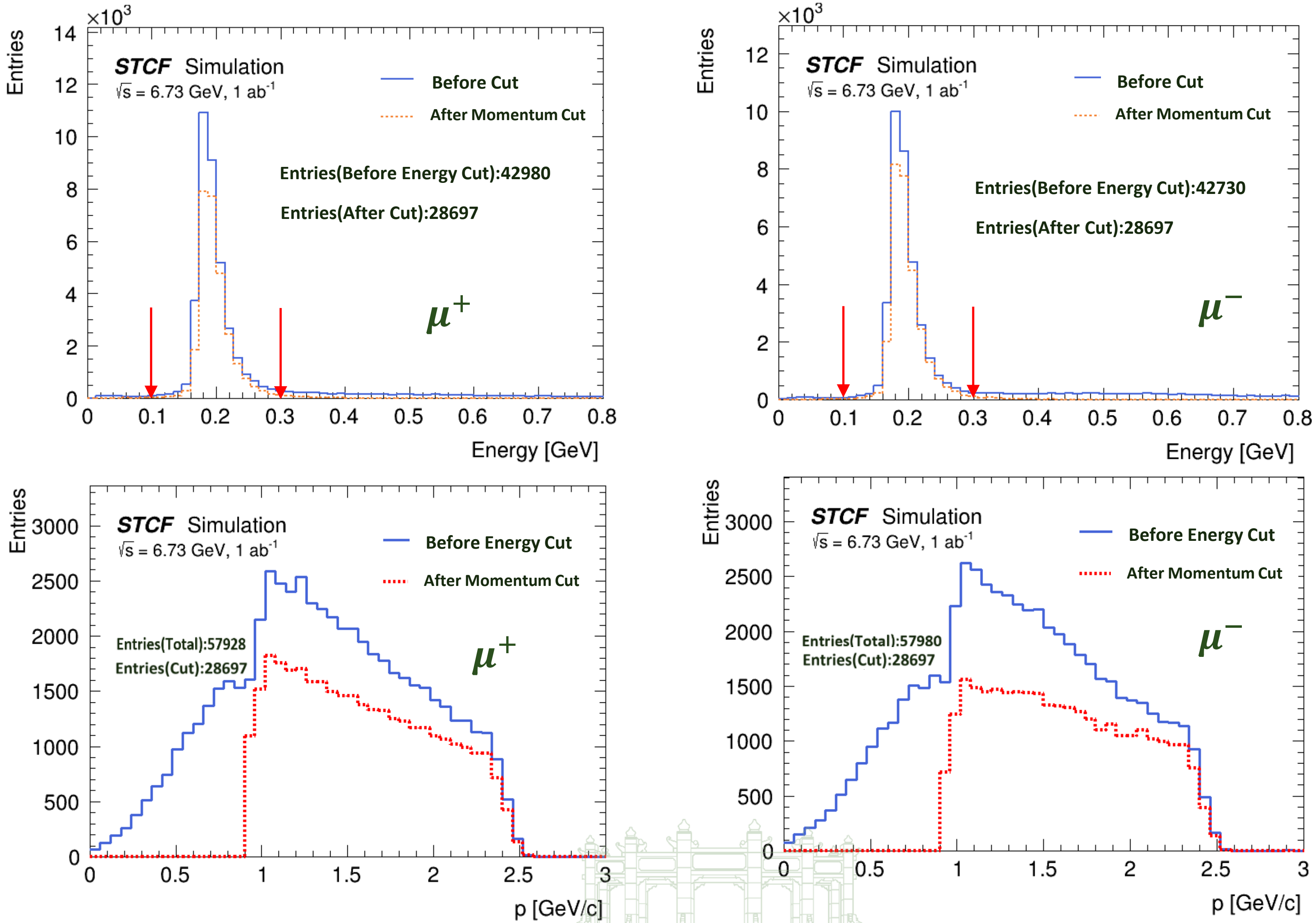
选择缪子

- **筛选条件：** $0.1 \le E_{emc} \le 0.3$ ，$|p_\mu| \ge 0.9\ GeV$

$\sqrt{s} = 6.73$ GeV

Emc里的能量沉积分布：

动量分布：

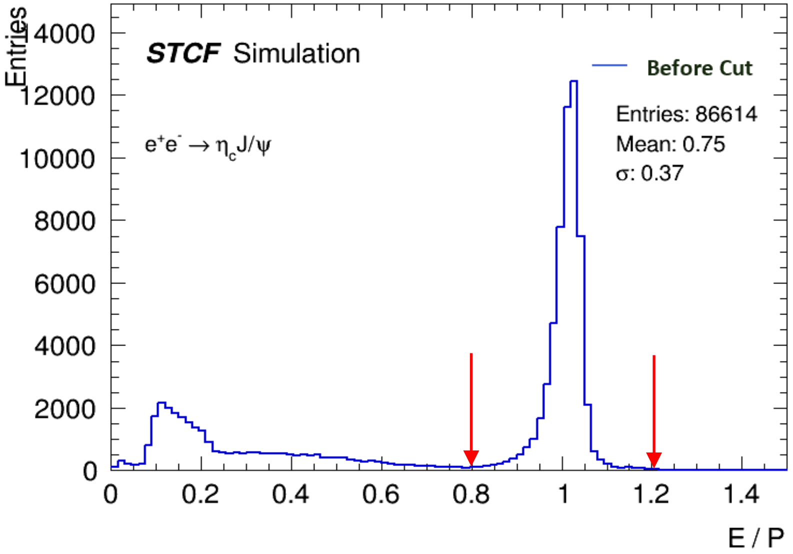


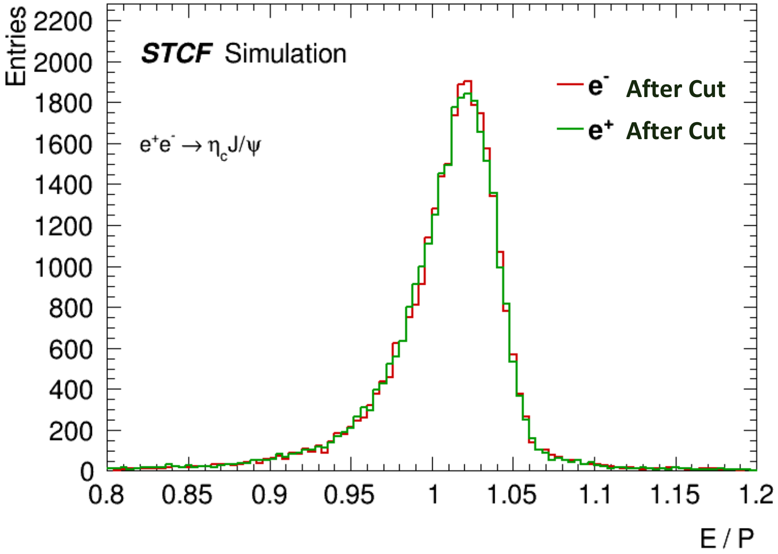
选择电子

- 筛选条件 $0.8 \le \frac{E_e}{p_e} \le 1.2$ ，$|p_e| \ge 0.9\ GeV$

$\sqrt{S} = 6.73$ GeV

E/P分布：





动量分布：